6-2-2015 12:00 AM

Effects of a Novel High Intensity Interval Training Protocol Versus Continuous Training in National and International Class Collegiate Rowers on Indices of Aerobic and Anaerobic Power

Sylvie D. Richer, *The University of Western Ontario*

Supervisor: Dr. Glen R. Belfry, *The University of Western Ontario*
A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Kinesiology

Effects of a novel high intensity interval training protocol versus continuous training in national and international class collegiate rowers on indices of aerobic and anaerobic power

(Thesis format: Integrated Article)

by

Sylvie Danielle Richer

Graduate Program in Integrative Physiology of Exercise

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

ABSTRACT

The purpose of this investigation was to compare 6 high intensity interval training (HIIT) sessions with predominately continuous training (CONT) over 11 days on highly trained rowers. Two groups (n=8) completed an incremental ramp test to determine Peak Aerobic Power (PAP), and a Critical Power test (CP). HIIT sessions consisted of 10 bouts of 10 s work (140% of PAP) with 5 s recovery, followed by 8 min of active recovery; repeated 6 times. 60 s power decreased in CONT (510±167–489±171W; $p=0.02$). CP increased in both groups (HIIT: 336±59-360±59W; CONT: 290±73-316±74W; $p\leq 0.05$). W' decreased in CONT only (14256±7022-11303±7360J; $p=0.01$). Mean Power Output Measure (MPOM) (10s, 60s, CP, and PAP) showed an improvement for HIIT (464±158-496±184W; $p=0.01$) vs. CONT (433±186-433±181W; $p\geq 0.05$). This study has demonstrated that 6 sessions of a novel HIIT protocol will increase MPOM, while maintaining anaerobic capacity compared to a predominantly CONT training protocol in elite rowers.

Keywords:

rowing; high intensity; interval training; training; supramaximal; power output; elite; well-trained

CO-AUTHORSHIP STATEMENT

This study was designed by G.R. Belfry and S.D. Richer with input from the advisory committee (V. Nolte and P.W.R. Lemon). The data were collected and analyzed by S.D. Richer with the assistance of G.R. Belfry. S.D. Richer wrote the original manuscript for the study. The co-authors provided financial support, lab support, and editorial feedback.

ACKNOWLEDGEMENTS

My father had always wanted to be a research scientist. He was never able to fulfill his dream. When I embarked on this two-year journey, I dedicated it to him. I share this degree with him. In his 90th year, his dream has come true.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF TERMS AND ABBREVIATIONS

[ATP] – adenosine triphosphate concentration

a-vO_2 difference – arterial-venous oxygen difference

bpm – beats per minute

Cat – Category

CONT – continuous steady state endurance training

CP – critical power

E – exercise

END - endurance

[H^+] – hydrogen ion

[HHb] – oxyhaemoglobin, measure of muscle deoxygenation

HIIT – high intensity interval training

HPO – high power output

HR – heart rate

INT – intermittent

IRT – incremental ramp test

J – Joules

km – kilometer

LPO – low power output

MPOM – mean power output measure

m – metre

MCT – monocarboxylate transporter

min – minute

NIRS – near infrared spectroscopy

O_2 – oxygen

P – pause

PAP – peak aerobic power

[PCr] – phosphocreatine

PO – power output

PP – peak power

PPO – peak power output

s – second

SD – standard deviation

TTF – time to fatigue

VO_2max – maximal oxygen uptake

W – watts

W' – anaerobic capacity

WR – work rate

$\Delta[HbO_2]$ – changes in total oxyhaemoglobin

$\Delta[HHb]$ – change in muscle deoxygenation

$\Delta50$ – work rate corresponding to 50% between VO_2 at lactate threshold and maximal VO_2

CHAPTER 1

1 REVIEW OF THE LITERATURE

1.1 INTRODUCTION

The goal of exercise physiologists and coaches is to develop conditioning programs whereby performance outcomes can be maximized. With athletes that are already highly trained and experienced, this objective becomes more complex. Considering that the difference between first and fourth place in the most recent international rowing events is 1% (Olympics, 2012; "World Rowing - The Official Site of World Rowing," 2014), the optimal training stimulus for performance enhancement could be minor adjustments to current training interventions. Moreover, training interventions performed by highly trained athletes within their training season are rare. The scarcity of these types of investigations has been attributed to the resistance by coaches and athletes to manipulate training regimens with previously untried protocols (Gibala, Little, Macdonald, & Hawley, 2012; Hawley, Myburgh, Noakes, & Dennis, 1997). Fortunately, the present authors have had excellent cooperation with international rowing coaches and their athletes to study this training intervention.

The purpose of this investigation was to compare the outcomes of a continuous training program (CONT) to a novel short work supramaximal intensity interval training (HIIT) program, during a real-time training schedule, performed by national and international level varsity rowers.

1.2 ENERGY SYSTEM DEMANDS OF A 2 km ROWING EVENT

The physiological demands of a 2 km rowing performance involve a complex interaction of oxidative and substrate phosphorylation energy systems. It has been determined that the overall energy system contributions of the 2 km rowing event is 80-85% aerobic and 15-20% anaerobic (Hagerman, 1984; Laursen, 2010; Nolte, 2005; Peronnet & Thibault, 1989; Secher, 1983), with suggestions by Hagerman (1984) that the anaerobic contribution may be as high as 25-30%. It has also been observed that rowers attain close to 100% of their VO_2max after the first minute of this approximately six minute event, and this VO_2 is sustained within this proximity until the completion of the race (Hagerman, 1984).

The traditional rowing pacing strategy has rowers start with a powerful sprint lasting approximately 30 to 40 seconds (Hagerman, 1984). This relies on approximately 71-78% anaerobic metabolism (Peronnet & Thibault, 1989) and utilizes both phosphocreatine [PCr] and glycolytic phosphorylation. A transition phase then occurs, lasting from 45 seconds to just under two minutes (Nolte, 2005), where VO_2 is near maximal (Hagerman, 1984), and the anaerobic contribution declines from approximately 68% to approximately 30% (Nolte, 2005; Peronnet & Thibault, 1989). This is followed by the middle 1000 m in which power output is reduced and the energy system contribution is 90-95% aerobic. This duration of reduced power output enables an increase in power output for the last 500 m to the finish, manifested by a replenishment of [PCr] stores and a reliance of 10-15% anaerobic metabolism (Nolte, 2005; Peronnet & Thibault, 1989). Based on the energy demands of such an event, training interventions that include both anaerobic and aerobic energy systems would be appropriate (Seiler, 2010).

Training categories (Cat) were developed by Fritsch and Nolte (1981) to address the energy system demands during a 2 km rowing event. They range from the highest intensity work (Cat 1) to the lowest intensity (Cat VI). Categories I to III include anaerobic energy system contributions as work intensity is above the anaerobic threshold. Category I is above the 2 km race pace and is generally only trained for approximately one minute intervals. Category II is close to race pace, with intervals of approximately five minutes. Whereas, Categories III and IV are in the vicinity of the anaerobic threshold, and sustainable for approximately 10 to 30 minute intervals respectively. Intensities below lactate threshold are Category V and VI. These consist of long steady-state sessions lasting from 40 minutes to over 90 minutes (Fritsch & Nolte, 1981; Nolte, 2005).

1.3 AEROBIC TRAINING

As such, rowing success is highly correlated with a superior aerobic capacity (Cosgrove, Wilson, Watt, & Grant, 1999; Hagerman, 1984; Kramer, Leger, Paterson, & Morrow, 1994; Secher, 1983). Moreover, 80% of the rowers' training volume is dedicated to long duration continuous steady state (CONT) intensities below the lactate threshold (Fiskerstrand & Seiler, 2004; Nolte, 2005; Steinacker, Lormes, Lehmann, & Altenburg, 1998). This high volume moderate intensity training is fundamental in order to improve cardiac functions such as increased cardiac output because of an increased stroke volume; and decreased peripheral resistance to blood flow, thereby increasing VO_2 max (Clausen, 1977; Wilmore, Costill, & Kenney, 2008). Other improvements from this intensity of training include an increase in number and size of muscle mitochondria, enhanced muscle myoglobin, a greater a-vO_2 difference, and an increase in enzymes associated with oxidative phosphorylation (Clausen, 1977; Holloszy & Booth, 1976; Scheuer & Tipton, 1977).

It appears that physiological improvements in VO_2max begin to plateau in well-trained experienced athletes (Laursen & Jenkins, 2002). This suggests that there is a maximal adaptation for improvement (Astrand & Rodahl, 1970). This was reflected in a study by Mikesell and Dudley (1984) who trained seven well-conditioned runners (mean VO_2max: 3.97 l/min; 61.0 ml/kg.min) for six weeks. For three days during the week, participants completed treadmill running for as hard as they could for 40 minutes. On three other days, the sessions consisted of five 5-minute cycle ergometer sessions at or near VO_2max, while maintaining an rpm of 85-90. The rest periods consisted of light jogging on a treadmill at 40-45% of VO_2max. There was a progressive overload of 11 watts per week on these cycling sessions. Aerobic capacity improved over the first five weeks. After this time, participants did not progress as exhibited by their inability to sustain further increases in intensity on the cycle ergometer. It was suggested that this was likely as a result of over training, and/or that they had reached their maximal genetic potential. Acevedo and Goldfarb (1989) concluded that over eight weeks of training, performance improvements could occur independently of VO_2max. Training consisted of one day per week of intervals at 90-95% of heart rate max (duration not given), followed by a rest period to a HR of 120 bpm. Two days per week consisted of Fartlek running near (above or below) 10 km pace, covering 6-10 miles. The other days consisted of regular running of 5-12 miles per day at moderate intensities. They observed no changes in VO_2max (mean VO_2max: 4.3 l/min; 65.3 ml/kg.min). However, running time to exhaustion improved (pre: 19:25 min; post: 23:18 min), as well as, 10 km race time (pre: 35:27 min; post: 34:24 min). Hawley et al. (1997) also observed that 90-120 second improvements in 40 km cycling time trials could occur without increasing VO_2max.

Twice per week over seven weeks, cyclists (mean VO_2max: 65 ml/kg.min) completed six to nine sets of five minutes at 80% of peak power output, followed by one minute rest. The authors linked the improvements to increased muscle buffering capacity and less reliance on carbohydrate as fuel.

1.4 INTERVAL TRAINING

Interval training has been defined by Gibala et al. (2012) as "physical exercise that is characterized by brief, intermittent bursts of vigorous activity, interspersed by periods of rest or low-intensity exercise". The acronym for interval training has been expressed by many different formats. For this thesis, we will refer to any high intensity interval training with the acronym of HIIT.

There are essentially infinite combinations of the exercise to pause ratios (E : P) that can be derived. Generally, shorter work phases (< 30 s) can elicit higher power outputs (HPO). Conversely, lower power outputs (LPO) manifest themselves by allowing longer work phases (> 120 s) (Fox, Bartels, Klinzing, & Ragg, 1977; Sloth, Sloth, Overgaard, & Dalgas, 2013). Fox et al. (1977) suggested that with low power output, participants generally reached 70% of VO_2max during the first minute of the interval, and then attained 96% of VO_2max from one to two minutes within that same interval. With the high power output group (E: < 30 seconds), the participants reached only 66% of their VO_2max. Christensen, Hedman, and Saltin (1960) concluded that a 10s work period with a five-second pause, allowed a participant to reach VO_2max (n = 2), as VO_2 did not drop during the short recovery period (Belfry, Raymer, et al., 2012). When rest was increased to 10 seconds (for the same 10s work phase), VO_2max was not reached with subsequent intervals (Christensen et al., 1960).

Many studies have observed physiological improvements with short duration work intervals and long recovery periods. However, many have utilized recreationally active populations who have not undergone systematic training. For example, Burgomaster, Hughes, Heigenhauser, Bradwell, and Gibala (2005) investigated a training protocol consisting of four to seven bouts of "all-out" 30s Wingate tests on a cycling ergometer, alternating with four minutes of recovery. These sets were completed six times over two weeks. The participants (mean VO_2max: 3.7 l/min; 44.6 ml/kg.min) improved their time to fatigue on the cycling ergometer by 100% (pre: 26 min; post: 51 min). They also increased their peak power output (PPO) during the last training session by approximately 25%. No changes in VO_2max occurred. Their proposed enhancements were confirmed by data that demonstrated an increase in both citrate synthase reflecting an increase in mitochondrial density, and an increase in muscle glycogen content.

Others, McKay, Paterson, and Kowalchuk (2009), examined a 60 s : 60 s interval protocol, which consisted of eight sessions over 19 days on recreationally active males (mean VO_2max: 3.78 l/min; 47 ml/kg.min). Each session comprised of 8-12 sets of 60 seconds on a cycle ergometer at 120% of pre-training maximal work rate from an incremental ramp test (IRT), followed by 60 seconds of loadless cycling. The Endurance Group (END) completed 90-120 minutes of cycling at 65% of pre-training VO_2max. Both groups did not increase their absolute VO_2max. However, time to fatigue (TTF) performance on a cycle test (work rate set at 100% of WR during max text), increased significantly by 55% for the HIIT group, and 43% for the endurance group. No changes were observed in a control group who continued only with their regular activity. The major finding of this study was faster VO_2 kinetics. Participants from both groups with initial faster O_2 kinetics at baseline testing showed less improvement. This may parallel previous statements that near-maximal training adaptions had already occurred and genetic limits imposed. In addition, data demonstrated that during each of the intervals, subjects either approached or reached VO_2max (McKay et al., 2009). It is difficult to extrapolate these training results performed on these cohorts to the elite athlete who has been exposed to years of systematic training (Londeree, 1997).

Moderately trained athletes have also been studied (mean VO_2max: 3.95 l/min; 57 ml/kg.min). Tabata et al. (1997) utilized a novel 20 s : 10 s protocol. They compared six to seven bouts of 20 seconds (at 170% of VO_2max) followed by 10 seconds rest (IE1), to four to five bouts of 30 seconds (at 200% of VO_2max) followed by a two-minute rest (IE2) on a cycle ergometer. Results showed that during the IE1 training session, participants did not attain their VO_2max until the last 10 seconds of the last interval. This was a result of the repeated drop in VO_2 over the 10s recovery period (Rossiter et al., 2002). In IE2, VO_2max was not attained at all during the 30s work intervals. Large fluctuations in VO_2 were observed in IE2, as a result of the much longer rest period. Oxygen deficit varied for both protocols. They observed that the oxygen deficit during IE1 was equal to the participants' anaerobic capacity, demonstrating maximal demands from the anaerobic energy system. This was not the case for IE2. The authors concluded that IE1 stressed both the aerobic and anaerobic energy systems concurrently.

Belfry, Raymer, et al. (2012) compared the synergy of energy system contributions during intervals of 10 s: 5 s (HIIT) and continuous work (CONT) by quantifying levels of [H^+] and [PCr] present in the muscle at specific times during isotonic plantar flexion exercises Measurements were taking at four seconds and nine seconds of the ten-second work interval phase, as well as, at four seconds of the rest period. All data for this discussion were collected after the 4th minute of exercise to allow for a steady state level to be reached. The authors observed that during the first four seconds of the HIIT work interval, there was a decrease in [PCr] indicating that ATP was being formed by the ATP/PCr alactic system, along with some contribution from oxidative phosphorylation. At nine seconds of the work period, PCr continued to be utilized, and simultaneously, there became a greater reliance on glycolysis, as reflected by an increase in [H^+]. During the five-second rest period, PCr resynthesis was occurring, thus contributing to higher [H^+] levels. This appears to be the result of phosphate from oxidative phosphorylation binding with creatine in order to regenerate [PCr]. This creatine kinase reaction results in the release of [H^+] thus contributing to the highest levels of [H^+] for the entire interval. For this to occur, oxidative phosphorylation was required in order to contribute to ATP regeneration. Moreover, the [H^+] during the rest period of the intervals were similar to the [H^+] during the entire continuous duration.

Pilot work in our lab has demonstrated that by performing a modified version of the Tabata and Belfry protocols (10 seconds high intensity work at 140% VO_2max followed by a shorter five-second recovery period performed at light intensity for 2.5 min), will elicit a VO_2 in the proximity of VO_2max by approximately 60 seconds which is sustained for the remainder of the 2.5 minute interval (Figure 3). In addition, this modified 10 s : 5 s protocol of supra maximal work required substantial anaerobic contribution. This combination fulfilled the energy system demands of a 2 km rowing event by training both the aerobic and anaerobic energy systems concurrently.

1.5 INTERVAL TRAINING AND THE WELL-TRAINED ATHLETE

HIIT has been utilized successfully to enhance the performance of elite endurance athletes. For instance, a meta-analysis by Londeree (1997) proposed that trained athletes require greater intensities at lactate threshold or higher to demonstrate improvements. In addition, Laursen and Jenkins (2002) suggested that higher intensity training is the only method by which improvements in performance can be attained within this population, because plateaus in aerobic capabilities occur with submaximal training. A three-week study by Stepto, Hawley, Dennis, and Hopkins (1999) on provincial-level cyclists (mean VO_2max: 4.78 l/min) that had no prior high intensity training (HIIT) investigated five different interval training protocols of varying times (30 seconds to eight minutes), intensities (80 to 175% of peak power) , and rest periods (one to 4.5 minutes). Six sessions of HIIT were completed over three weeks, in addition to regular aerobic conditioning. The authors concluded that the sessions consisting of eight bouts of four-minute work intervals followed by four minutes of rest, on a cycling ergometer at 85% of peak power, were most effective at increasing performances on 40 km cycling time trial. Similarly, Denadai, Ortiz, Greco, and de Mello (2006) investigated two different high intensity interval protocols on 17 well-trained runners (mean VO_2max: 3.73 l/min) that ran an average of 80 km per week. Their four-week study consisted of two high intensity interval (HIIT) sessions and four submaximal sessions per week on a treadmill. Both high intensity interval training protocols consisted of four to five bouts at intensities based on a percentage of velocity to time to exhaustion on a treadmill running test (100% velocity at VO_2max and 95% velocity at VO_2max). The submaximal sessions consisted of two bouts of 20 minutes at onset of blood lactate velocity with five minutes of active recovery, and three sessions of 45-60 min at 60-70% velocity of VO_2max. Their results showed that despite no changes in VO_2max in either training regimes, the group training at 100% of velocity at VO_2max (the higher intensity group) improved their 1500 m running time (pre: 271 s; post: 266 s). The group training at 95% velocity at VO_2max group did not statistically improve (pre: 271 s; post: 269 s) their running time. The authors proposed that the improvements might have been a result from enhanced motor unit recruitment and contractile properties, as a consequence of the higher training intensity.

Interval training sessions, especially those of very high intensities with shorter durations accompanied with long recovery periods stress the anaerobic glycolytic system. The rapid production of ATP generated by anaerobic glycolysis results in the increase of blood and muscle lactate (Astrand & Rodahl, 1970), which eventually impedes performance (Klausen, Knuttgen, & Forster, 1972). Although lactate and $[H^+]$ accumulation appear to be independent processes, both accrue at the same rate with increases in exercise intensity resulting in a negative effect on the working muscle (Juel, 2008). Intensities that produce increased muscle lactate also provide stimulus for muscle adaptations (A. R. Weston et al., 1997), specifically to pH regulation (Juel, 2008). Pilegaard et al. (1999) investigated the muscle adaptations to high intensity exercise. Participants performed one-legged knee extensor training to fatigue. Three to five sets of 2 x 30 seconds, followed by 3 x 1 minute, each followed by a two-minute rest were completed over eight weeks. Mean and peak power during the maximal knee extensor exercise test increased 15-16% in the trained leg. Results also demonstrated that although lactate formation after exercise was the same in both legs, the trained leg had an increase in lactate monocarboxylate transporters (MCT), specifically the MCT1 (70%) and MCT4 (10%) proteins, which resulted in a greater rate of sarcolemmal lactate/H^+ transport in muscle. It is suggested that the MCTI are more predominant in oxidative (Type I) muscles fibres (Pilegaard et al., 1999). Interestingly, elite male rowers have a high proportion (70%) of slow twitch muscle fibres (Hagerman, 1984; Secher, 1983; Steinacker, 1993), therefore, this training would be of benefit to these rowers A. R. Weston et al. (1997) conducted a HIIT study on well-trained cyclists (mean VO_2max: 5.2 l/min) that had not completed any interval training in the previous three months, to assess muscle buffering capabilities and performance. Six HIIT sessions, in addition to regular endurance training, were completed over 28 days. The sessions consisted of six to eight repetitions of five minutes at 80% of peak power output, followed by one minute of rest. Muscle buffering capacity improved 16% over baseline. Furthermore, this increased muscle buffering capacity was correlated with an increase in time to fatigue at 150% peak power output on a cycling ergometer (pre: 59.3 s; post 72.5 s) and the 40 km time trial (pre: 57.1 min; post: 55.9 min). Parkhouse, McKenzie, Hochachka, and Ovalle (1985) examined elite varsity rowers (n=5; mean VO_2max: 4.3 l/min) that had incorporated both endurance and high intensity interval training into their regular training regime (specific intensities and durations were not identified). On a running test (running as fast as possible) to exhaustion, the oarsmen accumulated 13.9 $mMol.l^{-1}$ blood lactate compared to 10 $mMol.l^{-1}$ in the marathon runners (mean VO_2max: 4.2 l/min; training > 40 miles/week over previous six months) that did very little sprint training. In addition, the rowers were able to run 35 % longer than the marathoners (76 s vs. 53 s). It was suggested that the high buffering capacity of the rowers facilitate “enhanced capacity for a muscle to function under conditions requiring high rates of anaerobic glycolytic energy" (Parkhouse et al., 1985).

Others, such as Hawley and Hopkins (1995) and Buchheit and Laursen (2013) also suggested that enhancing muscle buffering capacity with intervals with a high anaerobic component contribute to improvements in performance outcomes.

1.6 INTERVAL TRAINING AND ROWERS

Few training studies have been conducted on highly-conditioned rowers. Driller, Fell, Gregory, Shing, and Williams (2009), Akca and Aras (2015), Ingham, Carter, Whyte, and Doust (2008), Stevens, Olver, and Lemon (2015) examined different high intensity interval training protocols. In a four-week cross-over design, Driller et al. (2009), demonstrated that seven sessions of 8 x 2.5 minutes at 90% of velocity at VO_2max, alternating with a rest period to a target heart rate, elicited improvements in the 2 km time (CONT: pre: 7:14 min, post: 7:12 min; HIIT: pre: 7:17 min, post: 7:09 min), 2 km power, and relative VO_2max. The study by Akca (2014) was modeled from Driller et al. (2009) in that it included a similar protocol (8 session of 8 x 2.5 min at 90% peak power output) and compared it with 10 x 30 seconds at 150% peak power output. Eight sessions over four weeks improved the 2 km times significantly from pre- to post for both groups, but no differences were detected between groups (mean pre 2 km time: 6:49 min; post: 6:46 min). They also recorded improvements in VO_2max and peak power output, but with no differences between groups. There were no control participants in this study. This present study blends the Akca and Aras (2015); Driller et al. (2009); Tabata et al. (1997) protocols by utilizing intervals totaling 2.5 minutes at a supra maximal intensities of 140%. Ingham et al. (2008) compared a low intensity (LOW) protocol (all training below lactate threshold) with a protocol consisting of 70% below lactate threshold along with 30% at $\Delta 50$ (MIX) which is training at a work rate corresponding to 50% between VO_2 at lactate threshold and maximal VO_2. Total training volume (in km) was the same for both interventions (1148 km). Both groups improved their 2 km times (LOW: pre: 6:41 min; post: 6:34 min; MIX: pre: 6:45 min, post: 6:36 min), as well as, their VO_2max (LOW: pre: 4.68 l/min, post: 5.18 l/min; MIX: pre: 4.59 l/min, post: 5.04 l/min). However, this 12-week study was performed at the onset of their conditioning season, immediately after 25 days of an off-season period. Recent work by Stevens et al. (2015) compared a combined sprint interval (SIT) and endurance training protocol with an endurance-only protocol on trained rowers. Over four weeks, the participants completed 10 sprint interval training sessions of four to six sets of 60 seconds “all-out” rowing ergometer sprints. This was alternated with a 2.5-4 minute rest period. Results demonstrated improvements in the 2 km ergometer performance (CONT: pre: 6:53 min, post: 6:51 min; SIT: pre: 6:55 min, post: 6:50 min) and peak power output (average, in watts, of first three strokes). None of these training studies were performed on highly trained rowers during their training season.

A study of a high intensity training program that concurrently elicits VO_2max and supra-maximal work rates has not been studied on highly-trained rowers.

1.7 SUPRAMAXIMAL TRAINING

Participants in the present study were instructed to perform the 2.5 min (10 bouts of 10 s : 5 s) protocol at 140% of their peak aerobic power that was attained during the Incremental Ramp Test (IRT). This facilitated a maximal VO_2, as well as, a strong anaerobic stimulus during the training bouts (Fig. 3). This was repeated six times.

As described earlier, Tabata et al. (1997) utilized a work intensity of 170% of VO_2max (6-7 bouts of 20 seconds work : 10 seconds recovery) in varsity athletes (mean VO_2max: 3.95 l/min; 57 ml/kg.min). Their work to rest durations were not as effective in eliciting a VO_2 in the proximity of VO_2max during each training bout as the 10 s : 5 s protocol utilized here.

1.8 MAXIMAL AEROBIC POWER

Oxygen uptake as defined by Astrand and Rodahl (1970) is the "volume of oxygen extracted from the inspired air". Maximum oxygen uptake can be affected by age, health, fitness level, and other parameters (Astrand & Rodahl, 1970). In endurance-trained individuals, maximal oxygen uptake can be twice that of the average sedentary individual (approx. 3 l/min vs. 6 l/min). During laboratory testing, VO_2max is said to be attained when there is no further increase in O_2 uptake even though the work load has increased, and when lactic acid values reach eight to nine $mMol.l^{-1}$ (Astrand & Rodahl, 1970). As mentioned previously, there is a high correlation between high aerobic power and successful rowing performance. According to Kramer et al. (1994) and Secher (1983), VO_2max is the most consistent variable to success in rowing. Considering that the rowing event utilizes 80-85% aerobiosis, it would be advantageous to train this physiological component maximally.

1.9 CRITICAL POWER AND W'

Critical Power (CP) is defined as the highest "constant-load work rate that can be sustained for prolonged durations and presumably represents an inherent characteristic of the aerobic energy supply system" (Gaesser & Wilson, 1988). A 3-minute critical power test was proposed by Vanhatalo, Doust, and Burnley (2007) in order to accommodate laboratory testing. The participant is instructed to go “all out” for three minutes, on a cycle ergometer. The high power output at the beginning of the test is intended to deplete the anaerobic capacity. A steady state work output is maintained over the last min of the set in which aerobic metabolism is predominant. The work rate (W) is averaged over the last 30 seconds of the CP test. This work rate is considered to be in the heavy to severe intensity domain. This is approximately halfway between the lactate threshold and peak work rate attained in the Incremental Ramp Test (Vanhatalo et al., 2007).

W’ refers to the total work above Critical Power. It consists of finite energy stores limited to phosphocreatine [PCr], glycolysis, and myoglobin oxygen stores (Gaesser & Wilson, 1988). It is measured in Joules with the following equation:

Equation 1: W’ (in Joules) = watts x seconds

There appears to be varying responses of CP and W’ depending on the mode of training. Jenkins and Quigley (1993) investigated a high intensity protocol consisting of five bouts of 60s cycling at a load based on a percentage of body mass on untrained males (mean VO_2max: 3.96 l/min) followed by five minutes of passive recovery. Their results demonstrated an increase in VO_2max, and a 49% increase in “non-aerobic work” (W’) but no change in CP. Conversely, Jenkins and Quigley (1992) performed an eight-week endurance training study. Their participants (Mean VO_2max: 3.69 l/min) training consisted of 30-40 minute cycling intervals at an intensity based on the mean intensity during a 40-minute cycling test at CP, three times per week. Their results demonstrated that VO_2max and CP both increased statistically, whereas W’ did not.

Critical Power however, has been correlated to performance. Black, Durant, Jones, and Vanhatalo (2014) investigated this hypothesis by comparing the 16.1 km time trial road cycling race to a 3-minute Critical Power test. The participants (mean VO_2max: 4.41 l/min) completed the race in an average time of 27.1 minutes. The authors postulated that since this type of event requires a high sustainable aerobic contribution, (critical power), as well as contribution from anaerobic metabolism (W'), that there would be a strong correlation between this type of event and CP. Their results produced a correlation co-efficient of r = -0.83. It would seem plausible to associate this theory to a six to seven-minute rowing event, which is also considered high intensity endurance, and relies on both aerobic and anaerobic contributions.

1.10 LACTATES

As exercise intensity increases, oxygen demand eventually becomes greater than oxygen delivery. This result is an increased reliance on glycolysis to produce ATP. As glucose and/or glycogen are broken down to pyruvate, lactic acid is produced in the muscle. Hydrogen ions $[H^+]$ dissociate immediately from lactic acid forming lactate. As work intensity progresses more lactate is produced than can be eliminated. Some lactate can be utilized as substrate for oxidative phosphorylation in both slow and fast twitch fibers, as well as a precursor to gluconeogenesis (Gollnick, Bayly, & Hodgson, 1986). The associated $[H^+]$ contributes to decreased muscle pH. This alters the contractile properties of muscle, and eventually muscle fatigue ensues (Gollnick et al., 1986).

There is a delay from the onset of muscle lactate to when it accumulates in the blood (Gollnick et al., 1986). Consequently, blood lactate measurements are usually done two to five minutes post-exercise, in order to get a maximal value (Astrand & Rodahl, 1970; Farrell, Joyner, Caiozzo, & Medicine, 2012; Gollnick et al., 1986).

Resting blood lactate values are generally one to two $mMol.l^{-1}$. At the end of intense exercise, they can exceed 20 $mMol.l^{-1}$ (Gollnick et al., 1986). Lactates of four $mMol.l^{-1}$ have been suggested to be the average concentration at which further increases in work rate lead to a non-linear increase in blood lactate concentration (Nolte, 2005). In untrained individuals this will begin at work rates of approximately 50% of VO_2max. Conversely, trained individuals may reach work intensities of 75% of VO_2max before lactate threshold is reached (Gaesser & Wilson, 1988). Well-trained individuals also can tolerate higher blood lactate concentrations during exercise compared to untrained (Astrand & Rodahl, 1970). Cosgrove et al. (1999), have suggested that there is a correlation between the VO_2 at lactate threshold and rowing performance. The authors suggest that rowers that attain a higher velocity at four $mMol.l^{-1}$ of lactate are able to work at higher work rates before lactate accumulation becomes a limiting factor to performance (Gaesser & Wilson, 1988).

Although lactate levels will increase with high intensity intermittent work, it appears that with rest periods as short as five seconds, PCr will be resynthesized aerobically, thus decreasing reliance on glycolysis and its eventual accumulation of lactate (Belfry, Raymer, et al., 2012).

CHAPTER 2

EFFECTS OF NOVEL HIGH INTENSITY INTERVAL TRAINING PROTOCOL VERSUS CONTINUOUS TRAINING ON NATIONAL AND INTERNATIONAL CLASS COLLEGIATE ROWERS ON INDICES OF AEROBIC AND ANAEROBIC POWER

2.1 INTRODUCTION

The energy system contributions of a 2 km rowing race are 80-85% aerobic and 15-20% anaerobic (Hagerman, 1984; Laursen, 2010; Nolte, 2005; Peronnet & Thibault, 1989; Secher, 1983). Moreover, VO_2 is at or near maximal from the first minute to the completion of the race (Hagerman, 1984). Concomitantly, rowing success is highly correlated with a high aerobic capacity (Hagerman, 1984; Kramer et al., 1994; Secher, 1983). To this end, 80% of the elite rower's training is of long duration and below lactate threshold (Fiskerstrand & Seiler, 2004; Nolte, 2005; Steinacker et al., 1998). This low intensity high volume training increases cardiac output, by increasing stroke volume, and decreases peripheral resistance to blood flow (Clausen, 1977; Wilmore et al., 2008). Additionally, increases in muscle mitochondria, muscle myoglobin, oxidative metabolic enzymes, and a wider a-vO_2 difference have been observed (Clausen, 1977; Holloszy & Booth, 1976; Jones & Carter, 2000; Scheuer & Tipton, 1977). It has also been suggested that optimal performance enhancements in predominantly aerobic events require training protocols that elicit sustained VO_2 in the proximity of VO_2max (L. V. Billat, 2001; Gaesser & Wilson, 1988; Hickson, Hagberg, Ehsani, & Holloszy, 1981; Laursen & Jenkins, 2002; Smith, Coombes, & Geraghty, 2003; Stepto et al., 1999).

Shorter work: recovery intervals have also been studied. Tabata et al. (1997) compared multiple cycles of a 20 s (170% VO_2max): 10 s protocol to continuous training performed at 70% of VO_2max in trained individuals. The 20 s: 10 s group did not reach the proximity of VO_2max until the last 10 seconds of the last cycle. The authors concluded that the 20 s: 10 s training bouts stressed both the aerobic and anaerobic systems concurrently. This lab has developed a modified version (10 s : 5 s) of the Tabata et al. (1996) intermittent exercise protocol (20 s : 10 s) that provokes both the suggested high and sustained VO_2 while maintaining a strong anaerobic stimulus. This novel 10 s: 5 s protocol reduces the fluctuations in VO_2, as a consequence of the much shorter recovery period (Belfry, Paterson, Murias, & Thomas, 2012). Furthermore it has been shown that the anaerobic energy system contributions during the work period of these 10 s: 5 s intervals (HIT) is higher than the same work rate performed continuously (Belfry, Raymer, et al. (2012). Pilot work in this lab has demonstrated that performing a supramaximal VO_2 work rate (140% VO_2max) during this 10 second work followed by five seconds of light recovery, repeated for 2.5 min, elicits a non-oscillating VO_2 in the proximity of VO_2max (Fig 2.). This training bout configuration elicits a strong stimulus for both the anaerobic and aerobic energy systems.

Training studies that have been conducted on well conditioned rowers include Driller et al. (2009) which demonstrated that seven sessions of 8 x 2.5 min at 90% of velocity at VO_2max with a rest period to a pre-determined target heart rate (HIT), elicited greater improvements in 2 km performance compared to Continuous (CT) (CT: pre: 7:14 min, post: 7:12 min; HIT: pre: 7:17 min, post: 7:09 min, $p = 0.02$). Recent work by Stevens et al. (2015) compared a combined sprint interval (60 s work : ~3 min recovery) and endurance training (SIT) to an endurance-only training (EBT) program. They observed improvements in 2 km rowing ergometer performance times in both groups (EBT: pre: 6:53 min, post: 6:51 min, $p = 0.06$; SIT: pre: 6:55 min, post: 6:50 min, p =

0.001). A 12-week study by Ingham et al. (2008) compared a low intensity training regimen (below lactate threshold) to a combination of 70% below lactate threshold, with 30% above lactate threshold intensity. Although both groups improved their VO_2max and 2 km times (mean pre: 6:44 min; mean post: 6:35 min), there were no statistical differences between groups. The added value of the protocol of the present study compared to these aforementioned studies on rowers, is that a strong anaerobic stimulus is accompanied by a sustained and maximal stimulus of oxidative phosphorylation within the same training bout.

It has been suggested that studying training interventions after the initial training phase of the season has been completed is optimal, as the initial period of accelerated physiological adaptation and performance adaptations is removed, and a more accurate reflection of the efficacy of a particular training protocol is possible (Godfrey, Ingham, Pedlar, & Whyte, 2005). Actively manipulating the athlete's training regimen has, understandably, been resisted by coaches (Gibala et al., 2012; Hawley et al., 1997). Subsequently, training studies performed on more elite rowers has not been undertaken. Fortunately, our lab group has had excellent cooperation with international level rowing coaches and the athletes under their tutelage. The Canadian rowers in the present study ranged from collegiate, to national, to international competitors (Table 1).

The number of HIIT sessions was set at six. This was due a limited window available to perform this study on these rowers and that previous research has demonstrated positive results with other high intensity training interventions (Burgomaster et al., 2005; Hawley et al., 1997; Stepto et al., 1999; A. R. Weston et al., 1997).

The purpose of this investigation was to compare the outcomes of a novel high intensity interval training (HIIT) protocol to the predominantly continuous training (CONT) program during the real-time training schedule of highly trained rowers. We hypothesized that six HIIT sessions integrated into the rowers training schedule would elicit superior adaptations in anaerobic power output measures while sustaining the aerobic improvements compared to a CONT training program.

2.2 METHOD

2.2.1 Participants

Sixteen members of Western University's Rowing team gave written informed consent to participate in this study. All participants were healthy and presented with no musculoskeletal issues. All procedures were approved by The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects and conformed to the Declaration of Helsinki. See Table 1 for participant characteristics.

2.2.2 Experimental Protocol

The HIIT and CONT training sessions were performed over 11 days. Two days of testing were performed before and after this training period. The study began in mid-February, eight weeks after the onset of the 2014 training season. This delay was to enable the participants to perform an extended period of aerobic base training (five days per week, 90-100 min) and one session of longer higher intensity intervals (4-10 min) above lactate threshold (Table 2a). The subjects were randomized into two groups: a Continuous Group (CONT) (n = 8) and a High Intensity Interval Training Group (HIIT) (n = 8). Participants were advised to refrain from caffeine use 4 hours prior to testing. Two baseline tests were completed by all participants. Each test began with three minutes at 30 W to determine a baseline value. An incremental ramp test (IRT) to volitional fatigue was completed (Women: 25 W/min; Men: 30 W/min). The peak work rate achieved (W) on this IRT was defined as their Peak Aerobic Power (PAP). The following day, a Critical Power (CP) (Vanhatalo et al., 2007) test was performed. The participants were instructed to row in an "all-out" effort for three minutes. During the CP test, the mean power outputs during the first ten seconds, the first 60 seconds, and the final 30 seconds were represented as Peak Power (PP), 60 seconds (60 s), and Critical Power (CP) (Vanhatalo et al., 2007) respectively. W' (in Joules) was calculated as the total workload available above CP, also referred to as Anaerobic Capacity. It was calculated with the following equation:

Equation 1: W' (in Joules) = watts x seconds.

All testing was completed on the Dynamic Concept II Rowing ergometer, whereas, the training was done on a Standard Concept II Rowing ergometer (Concept II, Morrisville, VT, USA).

Following baseline testing, the CONT group remained with the nationally prescribed predominately moderate intensity, continuous training program. The HIIT consisted of 10 seconds of rowing at 140% of Peak Aerobic Power (PAP), followed by five seconds of easy rowing. The 10 s: 5 s intervals were repeated ten times for a total of 2.5 minutes. This was followed by eight minutes of active recovery rowing. The entire sequence was then repeated six times. In addition, the HIIT group also did high volume moderate intensity continuous training (Fig. 1). After two recovery days, post-tests were completed with the same incremental ramp test and CP test, respectively, on separate days. Warm up and cool down were similar between groups. Strength training, prescribed by the athletic trainer, was identical between groups as well. It focused on core strength conditioning. Total training minutes were similar for both groups (Table 2b).

2.2.3 Data Collection

All power out data (in watts) were collected manually every 2.5 seconds.

Breath-by-breath gas-exchange measurements similar to those described by Pandit and Robbins (1992) were made continuously during each testing protocol. During each trial, subjects breathed through a mouthpiece and while wearing a noseclip. Inspired and expired volumes and flow rates were measured using a low dead space (90 ml) bidirectional turbine (Alpha Technologies, VMM 110) and pneumotach (Hans Rudolph, Model 4813) positioned in series from the mouthpiece; respired air was continuously sampled at the mouth by mass spectrometry (Innovision, AMIS 2000, Lindvedvej, Denmark) and analyzed for concentrations of O_2 and CO_2. The volume turbine was calibrated before each test using a syringe of known volume (3 litres) and the pneumotach was adjusted for zero flow. Gas concentrations were calibrated with precision-analyzed gas mixtures. The time delay between an instantaneous, square-wave change in fractional gas concentration at the sampling inlet and its detection by the mass spectrometer was measured electronically by computer. Respiratory volumes, flow, and gas concentrations were recorded in real-time at a sampling frequency of 100 Hz and transferred to a computer, which aligned concentrations with respiratory flow as measured by the pneumotach, using the measured delay of the mass spectrometer. Flow from the pneumotach was used to resolve inspiratory-expiratory phase transitions and the turbine was used for volume measurement. The computer executed a peak-detection program to determine end-tidal PO_2, end-tidal PCO_2 and inspired and expired volumes and durations to build a profile of each breath. Breath-by-breath gas exchange at the pulmonary capillary was calculated using algorithms of Swanson (1980).

Blood lactates were taken 2 minutes prior to the start of the test and again 3 minutes post-test. Rubbing alcohol was swabbed on a left finger and blood was drawn using the ACCU-CHEK Safe-T-Pro Plus sterile, single-use lancing device. The first draw was wiped and the new droplet was measured with the SensLab GmbH Lactate SCOUT blood lactate analyzer.

2.2.4 Statistical Analysis

Data are presented as means ± SD. Paired t-tests were completed on all the pre- and post- testing means. All statistical analyses were calculated using SigmaPlot Version 12.3, (Systat Software Inc., San Jose, CA). Statistical significance was accepted at an alpha level less than or equal to 0.05.

2.3 RESULTS

All mean pre- and post-training power output (PO) measures in watts (W), are presented in Figure 2. Peak Aerobic Power and Peak Power showed no differences pre- to post- for both groups. However, the HIIT group demonstrated a noticeable increase approaching significance (PAP: $p = 0.09$; PP: $p = 0.08$). The 60-second (60 s) measure showed a statistically significant decrease in the CONT group ($p = 0.03$), whereas, it remained the same in the HIIT group. CP increased in both groups (CONT: $p = 0.03$; HIIT: $p = 0.05$). Mean Power Output Measure (MPOM) is described as the mean of all PO measures, in watts, for both the incremental and CP tests (excluding W'). MPOM demonstrated that the CONT group remained essentially unchanged ($p = 0.97$), whereas the HIIT group had a statistically significant increase ($p=0.02$). W' (in Joules) is also referred to as the work available above CP. It showed a decrease of 26% in the CONT group ($p=0.008$). W' was preserved in the HIIT group ($p=0.45$).

Blood lactates were taken two minutes prior to the start of the tests and again three minutes post-test. There was a significant decline in lactate levels with the CONT group with pre- to post- training for the IRT ($p = 0.02$). All other pre-training and post-training differences were not significant (IRT: HIIT $p = 0.23$; CP: HIIT $p = 0.70$, CONT $p = 0.57$) (Table 3).

The participants completed a 2 km time trial on the rowing ergometer three weeks prior to the beginning of the study, and again three weeks post study. Results are illustrated in Table 4. Pre- to post- times did show statistical significance for both groups ($p \leq 0.05$), however; overall decreases in time favoured the HIIT group.

Table 1
Participant characteristics (n = 16) including gender, age, height, weight, competitive category, peak aerobic power (pre-training and post-training, and highest level of rowing competition achieved.

Participant	Age	Height	Weight	Competitive Category	Peak Aerobic Power (Watts)		Highest Competitive Level
	(years)	(cm)	(kg)		Pre	Post	
CONT							
1. ♀	20	166	64	HW	255	267	University Team
2. ♀	24	173	67.4	HW	305	330	Canadian National Team
3. ♀	21	168	62	LW	300	289	Ontario Provincial Team
4. ♀	19	168	63	LW	260	258	University Team
5. ♂	24	179	75	LM	442	450	Canadian Sr. National Team
6. ♂	20	193	83	HM	427	435	Canadian Jr. National Team
7. ♂	24	195.5	102.6	HM	462	472	Ontario Provincial Team
8. ♂	20	182	78.2	HM	352	337	University Team
Mean(SD)	*21.5(2)*	*178.1(11.4)*	*74.4(13.8)*		*350.4(83.3)*	*354.8(85.8)*	
HIIT							
1. ♀	27	185.5	73.6	HW	335	324	Canadian National Team
2. ♀	27	171	61.2	LW	305	311	World Championship
3. ♂	21	184	82.6	HM	420	442	World Championship
4. ♂	19	185.7	88.4	HM	450	457	Ontario Provincial Team
5. ♂	18	186	85	HM	405	427	Canadian Jr. National Team
6. ♂	25	193	96.8	HM	480	517	World Championship
7. ♂	19	183	73.2	LM	367	390	University Team
8. ♂	19	180	74	LM	390	367	Canadian National Team
Mean(SD)	*21.9(3.8)*	*183.5(6.2)*	*79.3(11.1)*		*394(57.9)*	*404.4(69.9)*	

Competitive Category: HW: Heavy Women (>59kg), LW: Light Women (<59kg), HM: Heavy Men (>72.5kg), LM: Light Men (<72.5kg). Actual weight may vary from competitive category since this study was completed prior to their competitive season. ♀: female. ♂ male.

Table 2a

Total Training Time (min) prior to beginning the study for both CONT and HIIT groups.

	Cat I	Cat II	Cat III	Cat IV	Cat V	Cat VI
Week 1		35			60	325
Week 2			40		70	350
Week 3		35			80	370
Week 4		105	40			205
Week 5	1	35	60		79	230
Week 6			40		80	390
Week 7		35			60	270
Total	1	245	180	0	429	2140

Total minutes of cardiovascular training prior to the beginning of the study. Rowing categories defined as: Cat I: Anaerobic capacity; Cat II: Race Endurance; Cat III: Development of Aerobic Capacity; Cat IV: Anaerobic Threshold; Cat V: Utilization of Aerobic Capacity; Cat VI: Basic Endurance.

Table 2b

Total Training Time (min) during the study for CONT and HIIT groups.

	Cat I	Cat II	Cat III	Cat IV	Cat V	Cat VI	Total
CONT		35	120	130	80	610	975
HIIT	90				75	888	1053

Total minutes of cardiovascular training during the 11-day training portion of the study for each training category. Rowing categories defined as: Cat I: Anaerobic capacity; Cat II: Race Endurance; Cat III: Development of Aerobic Capacity; Cat IV: Anaerobic Threshold; Cat V: Utilization of Aerobic Capacity; Cat VI: Basic Endurance.

Table 3

Lactates (mMol.l $^{-1}$)

	Pre-training				Post-training			
	IRT		CP		IRT		CP	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
CONT								
Mean	2.39	11.59	1.76	16.6	2.23	16.18*	2.95	17.38
SD	*1.13*	*2.75*	*0.39*	*3.84*	*0.50*	*4.24*	*1.80*	*3.19*
HIIT								
Mean	4.29	15.99	2.09	15.95	2.13	16.65	2.18	17.64
SD	*3.90*	*4.55*	*0.44*	*3.14*	*0.55*	*3.90*	*0.24*	*3.21*

Lactate levels were taken 2 minutes prior to the beginning of the incremental VO_2max test and 3-minute Critical Power test, and again 3 minutes post-testing (pre- and post-training). IRT: Incremental Ramp Test. CP: Critical Power Test. *Statistically significant increase in lactates post-training on IRT for the CONT group.

Table 4

2 km rowing ergometer race times (in minutes and seconds), 3 weeks pre- and 3 weeks post-research training intervention

Participant	Pre-training	Post-training	% Change
CONT			
1. ♀ HW	7:57	7:48	(1.9)
2. ♀ HW	7:12	7:05	(1.6)
3. ♀ LW	7:25	7:19	(1.4)
4. ♀ LW	7:51	7:46	(1.1)
5. ♂ LM	6:19	6:15	(0.6)
6. ♂ HM	6:20	6:13	(1.8)
7. ♂ HM	6:17	6:09	(2.1)
8. ♂ HM	6:47	6:43	(1.0)
HIIT			
1. ♀ HW	7:15	7:00	(3.4)
2. ♀ LW	7:35	7:16	(4.2)
3. ♂ HM	6:24	6:19	(1.2)
4. ♂ HM	6:20	6:17	(0.7)
5. ♂ HM	6:24	6:21	(0.1)
6. ♂ HM	6:06	6:00	(1.5)
7. ♂ LM	6:37	6:33	(1.1)
8. ♂ LM	6:39	injured	n/a

Both groups improved their times ($p<0.05$). ♀: female. ♂: male. Competitive Category: HW: Heavy Women (>59kg), LW: Light Women (<59kg), HM: Heavy Men (>72.5kg), LM: Light Men (<72.5kg). Actual weight may vary from competitive category since this study was completed prior to their competitive season.

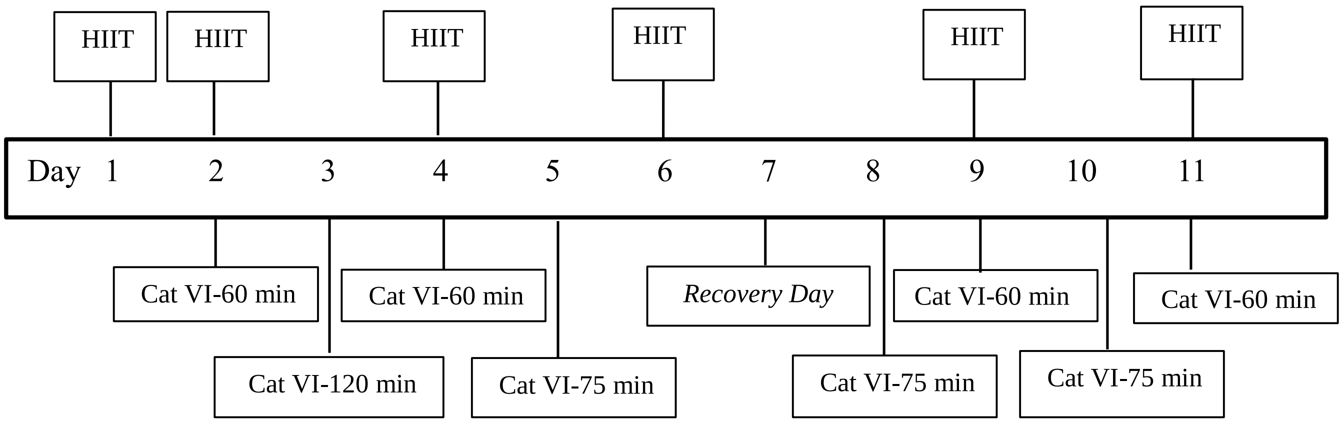

Figure 1. Study Design - HIIT Group
Daily training activity during entire study for the HIIT group. Cat I: Anaerobic capacity; Cat II: Race Endurance; Cat III: Development of Aerobic Capacity; Cat IV: Anaerobic Threshold; Cat V: Utilization of Aerobic Capacity; Cat VI: Basic Endurance.

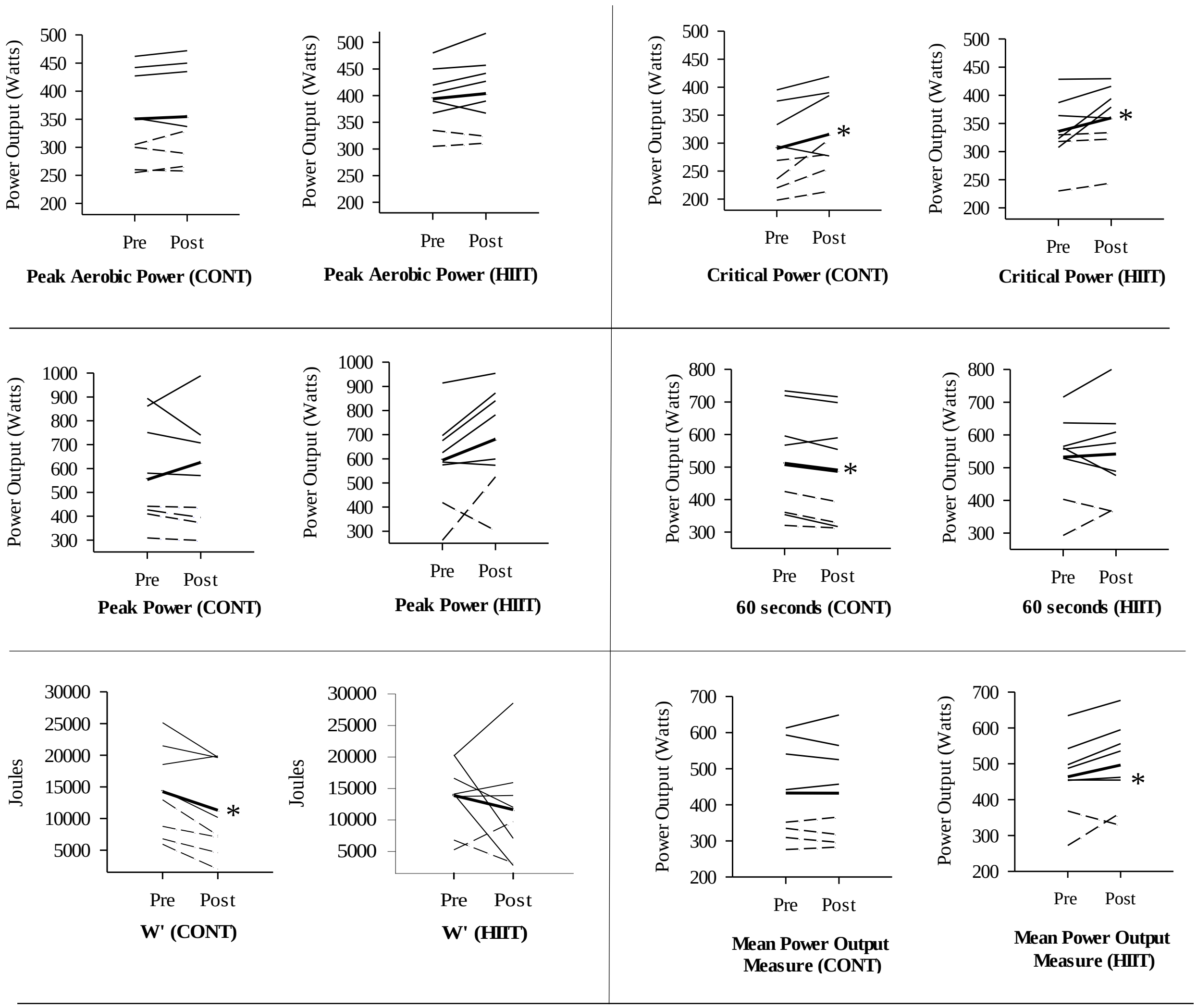

Figure 2. Power Output Summary
Peak Aerobic Power: maximum watts achieved at end of incremental ramp test. Critical Power: highest sustainable aerobic work rate. Calculated by averaging watts from the last 30 seconds of Critical Power test. Peak Power: Average watts achieved within first 10 seconds of the Critical Power test. 60 seconds: Average work rate of first 60 seconds of Critical Power Test. Indicator of glycolysis capacity. W' (W prime): total work above Critical Power indicating total anaerobic capacity. Mean Power Output Measure: Average of all aerobic variables (not including W') for each participant pre-training and post-training. Solid lines: Men. Dashed lines: Women. Bold lines: Mean. * Statistically significant difference.

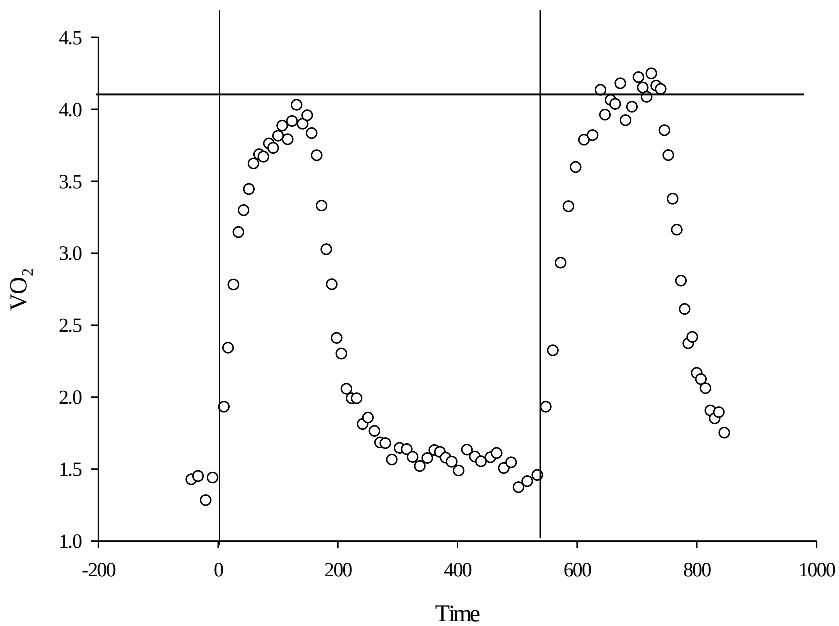

Figure 3. High sustainable VO_2 with 10 s : 5 s work to rest intervals.
Pilot work demonstrating sustained high VO_2 during repeated bouts of 10 s : 5 s work, beginning at approximately 60 second into the intervals and sustained for the remainder of the 2.5 minute total work bout. Top horizontal line: indicates participant's VO_2max (3.9 l/min). Vertical lines: beginning of 2.5 min work intervals.

2.4 DISCUSSION

The purpose of this study was to compare an original supramaximal high intensity training protocol to a predominately continuous training program in highly-trained collegiate rowers within their training season. It was hypothesized that six HIIT sessions over 11 days would elicit greater performance improvements over their predominantly continuously trained team-mates. Performance measures included peak power (PP), 60-second power (60 s), peak aerobic power (PAP), critical power (CP), and energy available above critical power (W'). The major findings included: 1) a maintenance of 60 s performance and W' post-HIIT training, whereas continuous training resulted in a decrease in both these measures; and 2) an improvement in the mean power output from all metrics (MPOM), pre- to post-training in the HIIT group. In summary, HIIT preserved anaerobic and aerobic capacity, in addition to eliciting similar improvements in CP compared to predominantly continuously trained, elite rowers.

To our knowledge, this is the first training study performed on highly trained rowers after an initial, predominantly aerobic preparation phase (Nolte, 2005) within a competitive season. Studies by Ingham et al. (2008) and Stevens et al. (2015) were completed some one to three months after the conclusion of their competitive season. This present study began after seven weeks of preparatory training for the next competitive season. This prior conditioning for both groups was comprised primarily of steady state continuous training of various intensities, interspersed with one higher intensity interval training session per week. Total weekly time progressively increased over the first three weeks, and was comprised of approximately 77% Category VI and 14% Category V work intensities. Weeks four and five incorporated approximately 25%

of higher intensities (Category II and Category III) with reduced total hours. Week six and seven were of lower intensity (Table 2).

Despite this extended reconditioning period prior to the study, notable improvements from the HIIT intervention were observed. Sixty-second (60 s) performance was maintained in the HIIT group, whereas it decreased in the CONT group. This parameter reflects approximately 60% anaerobic and 40% aerobic contributions (Medbø & Tabata, 1989; Peronnet & Thibault, 1989). Others, utilizing very different predominantly anaerobic protocols have seen comparable results. A four-week study by Paton, Hopkins, and Cook (2009) compared two groups (mean VO_2max: 4.5 l/min) that completed three sets of 5 x 30 s cycling at max effort, with 30 seconds of recovery, followed by a two-minute rest period. This training session was performed twice per week. They observed an approximately 9% increase in power output for a 60 s performance test. The preserved 60 s PO in the HIIT group suggests that the anaerobic stimulus from the HIIT was responsible for preserving the anaerobic component of this variable.

Furthermore, W' was also preserved in the HIIT group in the present study, yet decreased in the CONT group. It has been suggested that a decrease in W' will impact performance in endurance events (Laursen, Shing, Peake, Coombes, & Jenkins, 2005). In their four-week study comparing three different interval training protocols on well-trained cyclists (mean VO_2max: 66.0 ml/kg.min) during their off-season, they observed greater improvements in 40 km time trials and VO_2 peak compared to the control group. The time trial improvement was attributed, in part, to the increased W' from the supramaximal intensity training. Laursen et al. (2005) has suggested that this supramaximal intensity's reliance on glycolysis for ATP production provides the stimulus for adaptation of this energy system.

Previous research has also compared a similar short rest : shorter recovery interval training regime (20 s: 10 s) to an endurance protocol (Tabata et al., 1996). Their results demonstrated that the interval training group increased their anaerobic capacity by 28%, whereas, no change was observed in the endurance group. The key difference between the Tabata et al. (1996) protocol and the present study is the duration at which VO_2max is attained during the training bouts. The importance of training at VO_2max for maximal adaptations of aerobic power in well-trained athletes has been suggested previously (V. L. Billat et al., 2000; Spencer & Gastin, 2001). In the current study, VO_2max was reached by 60 s of the 2.5 min training bout and maintained for the duration (Fig. 3). This high and sustained VO_2 during training in the present study compared to the Tabata protocol is a function of coupling the shorter recovery period (5 s vs. 20 s) with a moderate intensity recovery (Belfry, Paterson, et al., 2012). Furthermore, the glycolytic contribution required for this supramaximal intensity during the 10s work period is maintained into the 5s recovery (Belfry, Raymer, et al., 2012). This combination of a high anaerobic contribution, and maximal VO_2 within the training bouts of the current HIIT protocol, underpins the preservation of W'.

The athletes in both training groups of the present study increased their CP ($p < 0.05$). Poole, Ward, and Whipp (1990) observed an increase in CP utilizing similar duration interval sessions as the current study (2 min vs 2.5 min) but were performed on recreational athletes. Their training consisted of 10 bouts of 2 min: 2 min at 105% of maximal watts achieved during an incremental ramp test. This intensity would elicit similar high VO_2 as the present study. Jenkins and Quigley (1992) also observed an increase in CP; however, their participants were only active individuals. Their eight-week study had untrained participants (mean VO_2: 3.6 l/min) cycle for 30-40 minutes, three times per week, at the mean intensity calculated from a 40-minute CP ride.

Over the 11-day training period, peak aerobic power during the incremental ramp test did not improve significantly for both groups. It did however, approach significance for the HIIT group ($p = 0.09$). Studies have suggested that performance improvements can occur independently of increases in VO_2max. Daniels, Yarbrough, and Foster (1978) compared physical education (PE) students (mean VO_2max: 3.9 l/min) with well-trained runners (mean VO_2max 4.3 l/min) over eight weeks. Although training intensities were different for both groups, both had substantial increases in intensity and volume pre- to post- two months of training. The runners improved 4% on 805 metre and 3218 metre races, yet there was no increase in VO_2max. Whereas, a 9% increase in VO_2max by the 3rd week was observed in the PE students. No increases occurred thereafter despite further improvements in performance. Moreover, Barbeau, Serresse, and Boulay (1993) monitored and tested elite male cyclists (mean VO_2max: 5.53 L/min) over a training and competitive season. No significant changes in VO_2max occurred during this period, however, measures of heart rate and mechanical efficiency improved during a 16-minute cycling cadence-step test. Again providing evidence that performance may increase independent of VO_2max. Others (Bunc, Heller, Moravec, & Sprynarova, 1989) followed endurance runners (mean VO_2max: 4.6 l/min) over a training and competitive season. Their training consisted of six to 12 high volume sessions per week along with approximately 18-27% of training at, or above ventilatory threshold. They observed only modest changes (5%) over this 12-month training period.

The MPOM increased in the HIIT group only ($p < 0.05$). This improvement reflects adaptations in power from both anaerobic and oxidative phosphorylation. These adaptations match the energy system requirements for improvement in 2 km rowing performances. It is therefore recommended that this HIIT protocol be implemented at regular intervals to maintain peak performance.

The combination of aerobic and anaerobic contribution while eliciting such high power outputs during this type of training may also result in more efficient muscle buffering potentials, and thus the ability to sustain higher power outputs without compromising endurance performance. M. Weston, Taylor, Batterham, and Hopkins (2014) were successful at improving muscle buffering capacity by 16% with six to eight sets of five minutes at 80% peak power output, followed by one minute rest, in well-trained cyclists (mean VO_2: 5.1 l/min), six times over four weeks. This protocol also increased time to fatigue at 150% of peak power output, which is similar to the power output in our study (pre: 59.3 sec; post: 72.5 sec). A study by Edge, Bishop, Hill-Haas, Dawson, and Goodman (2006), compared muscle buffering capacity in female athletes engaged in different types of sport. One group participated in Team Sports such as soccer, hockey, netball and basketball with sprint type training two to four times per week, along with endurance type training one to two times per week (mean VO_2max: 2.86 l/min). The Endurance Training group (mean VO_2max: 3.03 l/min) consisted of cyclists, rowers, and tri-athletes that trained at or below lactate threshold two to three times per week. There was also a control group of physically active participants (mean

VO_2max: 2.27 l/min) that did walking, aerobics and dancing. Their testing protocol, on a cycling ergometer, consisted of five bouts of six seconds all-out, followed by 24 seconds rest. Measurements taken immediately after the testing confirmed that even though the Endurance Training group had a higher VO_2max, the Team Sports group had significantly higher muscle buffering capacity.

The recruitment of fast twitch muscle fibres, as a function of working at 140% of PAP will also improve performance. This is manifested by enhanced neural recruitment (Laursen, 2010), increased oxidative potential, and greater muscle buffering capabilities of fast twitch fibres (Burgomaster et al., 2005).

The highly trained status of the rowers in this study is exemplified by their 2 km performance times (mean: 6:25 min). Moreover, nine of the male and female's current best 2 km times would have ranked them in the top 10 at the recent 2015 Indoor World Rowing Championships (IRC) ("World IRC Results 2015," 2015). In contrast, Driller et al. (2009), Ingham et al. (2008), Stevens et al. (2015), and Akca and Aras (2015) who have described their male participants as "experienced", "well-trained", "trained" or "national level" had mean male 2 km performance times ranging from 6 min 43 s to 7 min 35 s.

The two top athletes in the HIIT group (Tables 1 and 3, participants 2 and 6) who would have ranked second at the 2015 IRC, realized increases on all performance metrics. According to Eynon et al. (2011) elite endurance athletes have a higher number of a specific endurance-related allele compared to well-trained athletes. They suggest that this supports their elite performances. The top athletes in the HIIT group in this study validate this supposition. Notably, the top male in the CONT group, who would have ranked number 1 at the 2015 IRC, did not improve on any of the anaerobic measures. This illustrates the positive effects of this HIIT protocol on preserving anaerobic power and capacity while improving the aerobic measures of these elite athletes.

In conclusion, six sessions of a novel HIIT training protocol was superior in promoting adaptations in power output metrics compared to predominantly moderate intensity training in elite, well-trained athletes. Rowing coaches should be advised to intersperse this novel training protocol within their predominantly aerobic training program to maintain anaerobic fitness and peak performances.

2.5 SUMMARY: LIMITATIONS AND FUTURE DIRECTION

Due to the nature of the breathing behavior of these athletes during maximal rowing, breath-by-breath gas-exchange measurement data were difficult to assess and as such these data were not included in this study. Power output data were collected and analyzed. Interestingly, the athlete’s familiarity with power output measures facilitated the interpretation of their own results.

Anecdotally, the participants in the HIIT group reported feeling more power on the “pulling” stroke on the rowing ergometer from this type of intensity. Initially, their prescribed watts were difficult to attain, however, with successive trials, they were able to reach their target. This reinforcement provided motivation since they were able to quantify their progress. The participants also reported enjoying the variety from traditional continuous rowing, which according to Bartlett et al. (2011), HIIT may increase enjoyment and thus contribute to adherence to an exercise training program. Survey research by Kilpatrick, Greeley, and Collins (2015) agreed that intermittent training is more enjoyable than continuous training in the heavy intensity domain.

The participants that did not demonstrate an improvement with Peak Aerobic Power during post-tests reported heightened fatigue from this intense training stimulus. The onset of fatigue in these athletes may have precipitated a decline in power output. Rodas, Ventura, Cadefau, Cusso, and Parra (2000) reported that despite improvements in physiological measures such as higher [PCr] and lower lactate concentrations, the inability to improve performance outcomes may be due to neuromuscular fatigue. Their study demonstrated that one day of rest following a HIIT intervention demonstrated no improvements in post-tests, however, improvements were noted when the post-tests were completed five days post intervention. This present study had two days of recovery, albeit continuous steady state training. The ideal recovery time may not have transpired which would have enabled them to perform at their peak. For example, HIIT participant #1 did not demonstrate an improvement in PAP (Table 1), however a 2 km ergometer race time improved by 3.45% (Table 4). This may have implications for the timing of training and/or tapering prior to competition and needs to be investigated further in order to determine the optimal rest period in order to prevent the detrimental effects of overtraining.

Performance enhancement studies at the elite level must be done on the same population since subtle improvements may represent meaningful gains in competition (Londeree, 1997). Within this present study, although some improvements were not statistically significant, they may be considered substantial at this caliber of competition, specifically with those participants that demonstrated higher adaptations to the training stimulus. A larger sample size with a more homogenized group of the athletes may be advantageous.

The long term effects of this stimulus has yet to be elucidated. The dynamic nature of the preparation and competition phases limits consecutive studies on the same population. However, our study gained meaningful insight into the benefits of supra-maximal intensity interval training for coaches and for future rowing training studies.

CHAPTER 3

3 REFERENCES

Acevedo, E. O., & Goldfarb, A. H. (1989). Increased training intensity effects on plasma lactate, ventilatory threshold, and endurance. *Med Sci Sports Exerc, 21*(5), 563-568.

Akca, F. (2014). Prediction of rowing ergometer performance from functional anaerobic power, strength and anthropometric components. *J Hum Kinet*, *41*, 133-142.

Akca, F., & Aras, D. (2015). Comparison of rowing performance improvements following various high intensity interval trainings. *J Strength Cond Res*.

Astrand, P.-O., & Rodahl, K. (1970). Textbook of work physiology. United States of America: McGraw-Hill Book Company.

Barbeau, P., Serresse, O., & Boulay, M. R. (1993). Using maximal and submaximal aerobic variables to monitor elite cyclists during a season. *Med Sci Sports Exerc, 25*(9), 1062-1069.

Bartlett, J. D., Close, G. L., MacLaren, D. P., Gregson, W., Drust, B., & Morton, J. P. (2011). High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: implications for exercise adherence. *J Sports Sci*, *29*(6), 547-553.

Belfry, G. R., Paterson, D. H., Murias, J. M., & Thomas, S. G. (2012). The effects of short recovery duration on VO2 and muscle deoxygenation during intermittent exercise. *Eur J Appl Physiol, 112*(5), 1907-1915.

Belfry, G. R., Raymer, G. H., Marsh, G. D., Paterson, D. H., Thompson, R. T., & Thomas, S. G. (2012). Muscle metabolic status and acid-base balance during 10-s work:5-s recovery intermittent and continuous exercise. *J Appl Physiol (1985), 113*(3), 410-417.

Billat, L. V. (2001). Interval training for performance: a scientific and empirical practice. Special recommendations for middle- and long-distance running. Part II: anaerobic interval training. *Sports Med, 31*(2), 75-90.

Billat, V. L., Slawinski, J., Bocquet, V., Demarle, A., Lafitte, L., Chassaing, P., & Koralsztein, J.-P. (2000). Intermittent runs at the velocity associated with maximal oxygen uptake enables subjects to remain at maximal oxygen uptake for a longer time than intense but submaximal runs. *Eur J Appl Physiol, 81*(3), 188-196.

Black, M. I., Durant, J., Jones, A. M., & Vanhatalo, A. (2014). Critical power derived from a 3-min all-out test predicts 16.1-km road time-trial performance. *Eur J Sport Sci, 14*(3), 217-223.

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle. Part II: anaerobic energy, neuromuscular load and practical applications. *Sports Med, 43*(10), 927-954.

Bunc, V., Heller, J., Moravec, P., & Sprynarova, S. (1989). Ventilatory threshold and mechanical efficiency in endurance runners. *Eur J Appl Physiol Occup Physiol, 58*(7), 693-698.

Burgomaster, K. A., Hughes, S. C., Heigenhauser, G. J., Bradwell, S. N., & Gibala, M. J. (2005). Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *J Appl Physiol (1985), 98*(6), 1985-1990.

Christensen, E. H., Hedman, R., & Saltin, B. (1960). Intermittent and continuous running. (A further contribution to the physiology of intermittent work.). *Acta Physiol Scand, 50*, 269-286.

Clausen, J. P. (1977). Effect of physical training on cardiovascular adjustments to exercise in man. *Physiol Rev, 57*(4), 779-815.

Cosgrove, M. J., Wilson, J., Watt, D., & Grant, S. F. (1999). The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. *J Sports Sci, 17*(11), 845-852.

Daniels, J. T., Yarbrough, R. A., & Foster, C. (1978). Changes in VO2 max and running performance with training. *Eur J Appl Physiol Occup Physiol, 39*(4), 249-254.

Denadai, B. S., Ortiz, M. J., Greco, C. C., & de Mello, M. T. (2006). Interval training at 95% and 100% of the velocity at VO2 max: effects on aerobic physiological indexes and running performance. *Appl Physiol Nutr Metab, 31*(6), 737-743.

Driller, M. W., Fell, J. W., Gregory, J. R., Shing, C. M., & Williams, A. D. (2009). The effects of high-intensity interval training in well-trained rowers. *Int J Sports Physiol Perform, 4*(1), 110-121.

Edge, J., Bishop, D., Hill-Haas, S., Dawson, B., & Goodman, C. (2006). Comparison of muscle buffer capacity and repeated-sprint ability of untrained, endurance-trained and team-sport athletes. *Eur J Appl Physiol, 96*(3), 225-234.

Eynon, N., Ruiz, J. R., Oliveira, J., Duarte, J. A., Birk, R., & Lucia, A. (2011). Genes and elite athletes: a roadmap for future research. *J Physiol, 589*(13), 3063-3070.

Farrell, P. A., Joyner, M. J., Caiozzo, V., & Medicine, A. C. o. S. (2012). *ACSM's advanced exercise physiology*: Wolters Kluwer Health/Lippincott Williams & Wilkins.

Fiskerstrand, A., & Seiler, K. S. (2004). Training and performance characteristics among Norwegian international rowers 1970-2001. *Scand J Med Sci Sports, 14*(5), 303-310.

Fox, E. L., Bartels, R. L., Klinzing, J., & Ragg, K. (1977). Metabolic responses to interval training programs of high and low power output. *Med Sci Sports, 9*(3), 191-196.

Fritsch, W., & Nolte, V. (1981). *Rudern: Trainingswissenschaftliche und biomechanische Beiträge* (Vol. 26): Berlin : Baratels & Wernitz.

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. *Int J Sports Med, 9*(6), 417-421.

Gibala, M. J., Little, J. P., Macdonald, M. J., & Hawley, J. A. (2012). Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol, 590*(Pt 5), 1077-1084.

Godfrey, R. J., Ingham, S. A., Pedlar, C. R., & Whyte, G. P. (2005). The detraining and retraining of an elite rower: a case study. *J Sci Med Sport, 8*(3), 314-320.

Gollnick, P. D., Bayly, W. M., & Hodgson, D. R. (1986). Exercise intensity, training, diet, and lactate concentration in muscle and blood. *Med Sci Sports Exerc, 18*(3), 334-340.

Hagerman, F. C. (1984). Applied physiology of rowing. *Sports Med, 1*(4), 303-326.

Hawley, J. A., & Hopkins, W. G. (1995). Aerobic glycolytic and aerobic lipolytic power systems. A new paradigm with implications for endurance and ultraendurance events. *Sports Med, 19*(4), 240-250.

Hawley, J. A., Myburgh, K. H., Noakes, T. D., & Dennis, S. C. (1997). Training techniques to improve fatigue resistance and enhance endurance performance. *J Sports Sci, 15*(3), 325-333. 5

Hickson, R. C., Hagberg, J. M., Ehsani, A. A., & Holloszy, J. O. (1981). Time course of the adaptive responses of aerobic power and heart rate to training. *Med Sci Sports Exerc, 13*(1), 17-20.

Holloszy, J. O., & Booth, F. W. (1976). Biochemical adaptations to endurance exercise in muscle. *Annu Rev Physiol, 38*, 273-291.

Ingham, S. A., Carter, H., Whyte, G. P., & Doust, J. H. (2008). Physiological and performance effects of low- versus mixed-intensity rowing training. *Med Sci Sports Exerc, 40*(3), 579-584.

Jenkins, D. G., & Quigley, B. M. (1992). Endurance training enhances critical power. *Med Sci Sports Exerc*, *24*(11), 1283-1289.

Jenkins, D. G., & Quigley, B. M. (1993). The influence of high-intensity exercise training on the Wlim-Tlim relationship. *Med Sci Sports Exerc*, *25*(2), 275-282.

Jones, A. M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Med, 29*(6), 373-386.

Juel, C. (2008). Regulation of pH in human skeletal muscle: adaptations to physical activity. *Acta physiologica, 193*(1), 17-24.

Kilpatrick, M. W., Greeley, S. J., & Collins, L. H. (2015). The Impact of Continuous and Interval Cycle Exercise on Affect and Enjoyment. *Research quarterly for exercise and sport* (ahead-of-print), 1-8.

Klausen, K., Knuttgen, H. G., & Forster, H. V. (1972). Effect of pre-existing high blood lactate concentration on maximal exercise performance. *Scand J Clin Lab Invest, 30*(4), 415-419.

Kramer, J. F., Leger, A., Paterson, D. H., & Morrow, A. (1994). Rowing performance and selected descriptive, field, and laboratory variables. *Can J Appl Physiol, 19*(2), 174-184.

Laursen, P. B. (2010). Training for intense exercise performance: high-intensity or high-volume training? *Scand J Med Sci Sports, 20 Suppl 2*, 1-10.

Laursen, P. B., & Jenkins, D. G. (2002). The scientific basis for high-intensity interval training: optimising training programmes and maximising performance in highly trained endurance athletes. *Sports Med, 32*(1), 53-73.

Laursen, P. B., Shing, C. M., Peake, J. M., Coombes, J. S., & Jenkins, D. G. (2005). Influence of high-intensity interval training on adaptations in well-trained cyclists. *J Strength Cond Res*, *19*(3), 527-533.

London 2012 Olympics. (2012). Eight with coxswain (8+) men results - Rowing. Retrieved from:http://www.olympic.org/olympic-results/london-2-12/rowing/eight-with-coxswain-8-m?event=31388.

Londeree, B. R. (1997). Effect of training on lactate/ventilatory thresholds: a meta-analysis. *Med Sci Sports Exerc*, *29*(6), 837-843.

McKay, B. R., Paterson, D. H., & Kowalchuk, J. M. (2009). Effect of short-term high-intensity interval training vs. continuous training on O2 uptake kinetics, muscle deoxygenation, and exercise performance. *J Appl Physiol (1985), 107*(1), 128-138.

Medbø, J., & Tabata, I. (1989). Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *J Appl Physiol, 67*(5), 1881-1886.

Mikesell, K. A., & Dudley, G. A. (1984). Influence of intense endurance training on aerobic power of competitive distance runners. *Med Sci Sports Exerc, 16*(4), 371-375.

Nolte, V. (2005). *Rowing faster*. Champaign, IL: Human Kinetics.

Pandit, J. J., & Robbins, P. A. (1992). Ventilation and gas exchange during sustained exercise at normal and raised CO2 in man. *Respir Physiol, 88*(1-2), 101-112.

Parkhouse, W. S., McKenzie, D. C., Hochachka, P. W., & Ovalle, W. K. (1985). Buffering capacity of deproteinized human vastus lateralis muscle. *J Appl Physiol (1985), 58*(1), 14-17.

Paton, C. D., Hopkins, W. G., & Cook, C. (2009). Effects of low-vs. high-cadence interval training on cycling performance. *The Journal of Strength & Conditioning Research, 23*(6), 1758-1763.

Peronnet, F., & Thibault, G. (1989). Mathematical analysis of running performance and world running records. *J Appl Physiol (1985), 67*(1), 453-465.

Pilegaard, H., Domino, K., Noland, T., Juel, C., Hellsten, Y., Halestrap, A. P., & Bangsbo, J. (1999). Effect of high-intensity exercise training on lactate/H+ transport capacity in human skeletal muscle. *Am J Physiol, 276*(2 Pt 1), E255-261.

Poole, D. C., Ward, S. A., & Whipp, B. J. (1990). The effects of training on the metabolic and respiratory profile of high-intensity cycle ergometer exercise. *Eur J Appl Physiol Occup Physiol, 59*(6), 421-429.

Rodas, G., Ventura, J. L., Cadefau, J. A., Cusso, R., & Parra, J. (2000). A short training programme for the rapid improvement of both aerobic and anaerobic metabolism. *Eur J Appl Physiol, 82*(5-6), 480-486.

Rossiter, H., Ward, S., Kowalchuk, J., Howe, F., Griffiths, J., & Whipp, B. (2002). Dynamic asymmetry of phosphocreatine concentration and O2 uptake between the on‐and off‐transients of moderate‐and high‐intensity exercise in humans. *J Physiol, 541*(3), 991-1002.

Scheuer, J., & Tipton, C. M. (1977). Cardiovascular adaptations to physical training. *Annu Rev Physiol, 39*, 221-251.

Secher, N. H. (1983). The physiology of rowing. *J Sports Sci, 1*(1), 23-53.

Seiler, S. (2010). What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sports Physiol Perform, 5*(3), 276-291.

Sloth, M., Sloth, D., Overgaard, K., & Dalgas, U. (2013). Effects of sprint interval training on VO2max and aerobic exercise performance: A systematic review and meta-analysis. *Scand J Med Sci Sports, 23*(6), 341-352.

Smith, T. P., Coombes, J. S., & Geraghty, D. P. (2003). Optimising high-intensity treadmill training using the running speed at maximal O(2) uptake and the time for which this can be maintained. *Eur J Appl Physiol, 89*(3-4), 337-343.

Spencer, M. R., & Gastin, P. B. (2001). Energy system contribution during 200- to 1500-m running in highly trained athletes. *Med Sci Sports Exerc, 33*(1), 157-162.

Steinacker, J. M. (1993). Physiological aspects of training in rowing. *Int J Sports Med, 14 Suppl 1*, S3-10.

Steinacker, J. M., Lormes, W., Lehmann, M., & Altenburg, D. (1998). Training of rowers before world championships. *Med Sci Sports Exerc, 30*(7), 1158-1163.

Stepto, N. K., Hawley, J. A., Dennis, S. C., & Hopkins, W. G. (1999). Effects of different interval-training programs on cycling time-trial performance. *Med Sci Sports Exerc, 31*(5), 736-741.

Stevens, A. W., Olver, T. T., & Lemon, P. W. (2015). Incorporating Sprint Training With Endurance Training Improves Anaerobic Capacity and 2,000-m Erg Performance in Trained Oarsmen. *J Strength Cond Res, 29*(1), 22-28.

Tabata, I., Irisawa, K., Kouzaki, M., Nishimura, K., Ogita, F., & Miyachi, M. (1997). Metabolic profile of high intensity intermittent exercises. *Med Sci Sports Exerc, 29*(3), 390-395.

Tabata, I., Nishimura, K., Kouzaki, M., Hirai, Y., Ogita, F., Miyachi, M., & Yamamoto, K. (1996). Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. *Med Sci Sports Exerc, 28*(10), 1327-1330.

Vanhatalo, A., Doust, J. H., & Burnley, M. (2007). Determination of critical power using a 3-min all-out cycling test. *Med Sci Sports Exerc, 39*(3), 548-555.

Weston, A. R., Myburgh, K. H., Lindsay, F. H., Dennis, S. C., Noakes, T. D., & Hawley, J. A. (1997). Skeletal muscle buffering capacity and endurance performance after high-intensity interval training by well-trained cyclists. *Eur J Appl Physiol Occup Physiol, 75*(1), 7-13.

Weston, M., Taylor, K. L., Batterham, A. M., & Hopkins, W. G. (2014). Effects of low-volume high-intensity interval training (HIT) on fitness in adults: a meta-analysis of controlled and non-controlled trials. *Sports Med, 44*(7), 1005-1017.

Wilmore, J. H., Costill, D. L., & Kenney, W. L. (2008). *Physiology of sport and exercise* (4th ed.). Champaign, IL: Human Kinetics.

World IRC Results 2015. (2015). Retrieved from: http://www.concept2.com/indoor-rowers/racing/world-irc/2015/results.

World Rowing - The Official Site of World Rowing. (2014). Retrieved from: http://www.worldrowing.com/events/2014-world-rowing-championships/mens-eight/.

APPENDIX A: ETHICS APPROVAL NOTICE

Western Research

Research Ethics

Use of Human Participants - Revision Ethics Approval Notice

Principal Investigator: Glen Belfry
File Number: 100674
Review Level: Delegated
Protocol Title: The effect of a short work/short rest interval or continuous training program on selected physiological variables and performance in varsity rowers - 17868E
Department & Institution: Health Sciences\Kinesiology, Western University
Sponsor:
Ethics Approval Date: February 04, 2014 **Expiry Date:** May 31, 2015
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Revised Study End Date		

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the University of Western Ontario Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]

Signature

Ethics Officer to Contact for Further Information

[redacted]

This is an official document. Please retain the original in your files.

Western University, Research, Support Services Bldg., Rm. 5150
London, ON, Canada N6A 3K7 t. 519.661.3036 f. 519.850.2466 www.uwo.ca/research/services/ethics

CURRICULUM VITAE

Name:	Sylvie D. Richer
Post secondary Education and Degrees:	The University of Western Ontario London, Ontario, Canada 2005-2013 B.A. Kinesiology
	The University of Western Ontario London, Ontario, Canada 2013-2015 M.Sc. Kinesiology
Related Work Experience:	Teaching Assistant The University of Western Ontario London, Ontario, Canada 2013-2015

Honours and Awards:

2013-2015	Western Graduate Research Scholarship
2013-2015	Graduate Teaching Assistant/Research Assistantship

Published Abstract:

Richer, S. D., Nolte, V., Belfry, G. R. (2014). Effects of supra maximal high intensity interval training vs. continuous training in well-trained rowers on peak power, aerobic power, critical power, and energy available above critical power. *Appl Physio Nutr and Metab.*