A 10 s: 5 s high-intensity interval training regime improves rowing performance in varsity and international class rowers

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

The purpose of this study was to investigate the effects of a high-intensity interval training regime with elite collegiate rowers on their rowing performance. A total of 10 interval training sessions were performed over a four-week period with four males and five females completing all pre-testing performance and training sessions. Participants completed a 2000 m performance test to determine initial training intensity. The interventional training sessions consisted of 30 min of 10 s work: 5 s recovery. The 10 s mean power output improved 17% from training session one to ten. The moderate-intensity increased by 44%; mean power output over 30 min increased by 22%. Three participants that performed a post-testing 2000 m row improved their power output by 3%. This study has demonstrated that 10 sessions of a 10 s: 5 s training regime improved training performances as well 2000 m in select elite rowers.

Keywords
rowing; interval training; 10 s work: 5 s recovery; 30 min; 2000 m performances
Summary for Lay Audience

High-intensity interval training is a type of training that requires intermittent high efforts followed by a recovery period. The novel training paradigm in this study reflects the short work periods (10 s) followed by a shorter recovery periods (5 s). A group of collegiate and international class rowers underwent bi-weekly training sessions of this program for four weeks. Performance markers were assessed before and after the intervention as well as during each prescribed workout to track changes for each individual participant. This training regime improved their performances over the course of the training period.
Co-Authorship Statement

This study was designed by G.R. Belfry and B.J. Reid with input from the advisory committee (P.W.R. Lemon). The data was collected and analyzed by B.J. Reid with the assistance of G.R. Belfry. B.J. Reid wrote the original manuscript for this study. The co-author provided financial support, lab support, and editorial feedback.
Acknowledgements

I would like to thank professor Dr. G.R. Belfry for his patience and guidance through the course of this investigation. I would also like to thank Rowing Canada’s Dane Lawson and Jordan Clarke in addition to Western’s rowing staff Dr. Dan Bechard and Dr. Matthew Waddell to allow this investigation to commence in season training and the support during the training sessions. Thank you to all friends, family, and other staff members for their support during the investigation and the challenges brought forward from the restrictions and lockdown period.
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List of Abbreviations

[ATP] – adenosine triphosphate concentration
a-vO2 difference – arterial-venous oxygen difference
bpm – beats per minute
Cat – Category
CONT – continuous steady state endurance training
CP – critical power
[H+] – hydrogen ion
[HHb] – oxyhaemoglobin, measure of muscle deoxygenation
HR – heart rate
INT – intermittent
IRT – incremental ramp test
km – kilometer
m – metre
MCT – monocarboxylate transporter
min – minute
O2 – oxygen
PAP – peak aerobic power
[PCr] – phosphocreatine
PO – power output
PP – peak power
PPO – peak power output
s – second
SD – standard deviation
VO2 max – maximal oxygen uptake
W – watts
Chapter 1

1 « Review of Literature »

1.1 Introduction

The goal of a conditioning program for rowing is to optimize evidence-based practices to enhance performance. Rowing athletes train about 1000 h or 5000-7000 km a year (Steinacker, 1993). In northern latitudes much of that training is performed on rowing ergometers with training programs prescribed by their professional sports organization.

However, coaches and other individuals involved in high-performance sports are sometimes hesitant when it comes to new or unfamiliar training interventions, despite their support from empirical evidence (Weston et al., 1996). This can make it a challenge to employ non-traditional approaches in training (Hawley et al., 1997). Moreover, the United States Olympic Committee’s physiologists state the difference between the gold-medal and fourth-place can be as little as 0.05%, making it more difficult for professional coaches to deviate from their own tried and true methods as a novel training intervention is associated with the risk of a detrimental performance (Saporito, 2012). The alternative argument is that if the “new” training is based on empirical evidence then the probability of a positive outcome from the training paradigm will be high.

In light of the above, the purpose of this present study was to investigate the effects of a novel high-intensity interval training intervention with a group of well-trained rowers from provincial to international class, at a time when they were preparing for national ranking testing. The following review of literature discusses the aerobic and
anaerobic energy systems within the context of the physiological adaptations to training. These include those metabolic pathways associated with the aerobic and anaerobic phosphorylation.

1.2 « Energy System Demands of an Elite Rowing Athlete »

1.2.1 Aerobic Training

Elite-level rowers require exceptional aerobic capacity if they are to achieve podium-level results as the aerobic energy systems (Figure 1) contribute roughly 70-80% of total energy requirements, whereas the anaerobic energy systems contributes the remaining 20% (Figure 2) over the course of a standard 2000 m race (Das et al., 2019).

![Figure 1. Aerobic Energy System: Aerobic metabolic pathway.](https://pdhpe.net/factors-affecting-performance/how-does-training-affect-performance/energy-systems/aerobic-energy-system/)  

This indicates why rowing is an endurance dominant sport and the importance of aerobic training for rowers. Aerobic training is continuous and typically endures from anywhere from approximately 2 to 240 minutes, at intensities ranging between 100% and 40% VO₂ max (Jones & Carter, 2000). VO₂ max, has long been associated with success in
endurance athletes, and reflects the maximal rate at which oxygen can be utilised by active muscle during exercise (Saltin & Strange, 1992). A key variable in determining VO\(_2\) max is one’s maximal cardiac output and its direct affect on oxygen delivery. Cardiac output itself is dependent on not only heart rate but stroke volume. Moreover, stroke volume has been shown to have the strongest correlation to VO\(_2\) max and as such is an important metric for elite level endurance performance (Jones & Carter, 2000). Literature also has shown that during maximal exercise a greater extraction of oxygen by active muscles results in a greater VO\(_2\) max (Jones & Carter, 2000). Further, endurance athlete performance is highly correlated with lactate threshold, the intensity at which blood lactate concentration begins to rise, a key component of exercise economy; i.e., oxygen uptake required at a given intensity (Pate & Branch, 1992). As such, VO\(_2\) shares a constant interactive relationship with exercise economy (Jones & Carter, 2000). The precise interaction between athletic performance improvement and optimal training strategies to improve the aerobic capacity to maximize performance is discussed below.

Most rowing training programs dedicate 80% of their training volume below anaerobic threshold (Steinacker, 1993). These longer periods of ‘steady-state’ training (< aerobic blood lactate threshold) are considered fundamental for improving endurance training and reducing recovery time between training sessions (Steinacker, 1993). It also reflects the boundary between sub-lactate threshold and supra-lactate threshold intensities (Whipp, 1996). To meet the oxygen demands of high-volume steady state training, the heart increases stroke volume in response to increased demand for oxygen to working muscle (Lima-Silva et al., 2010). Furthermore, the circulatory response from muscle activity elicits a local vasodilation, increasing blood flow, and over time, increases
capillary to muscle fibre density, as a part of the remodelling surrounding skeletal muscle circulation (Sarelius & Pohl, 2010). Moreover, adaptations to this moderate-intensity steady state training are associated with increased lactate clearance by slow twitch fibres that are dependent on lactate transporters monocarboxylate transporters 1 (MCT-1). These are responsible for transporting lactate from the cytosol to the mitochondria to be oxidized into pyruvate by lactate dehydrogenase (LDH) into substrate in the Krebs cycle located in slow twitch fibres (Sarelius & Pohl, 2010). Aerobic training elicits hypertrophy in slow twitch muscle fibres with an increase mitochondrial content and number, as well as an increased concentration of these MCT-1 transporters (Steinacker, 1993). These adaptations made at the cellular level result in increasing mitochondrial bioenergetics resulting in greater arterio-venous oxygen differences from increased oxygen extraction, and greater oxidative phosphorylation capacity (Korthuis, 2011, Ní Chéilleachair et al., 2017).

Training below the aerobic threshold elicits the resynthesis of ATP through the three major macronutrients: carbohydrates, proteins, and lipids. Another key metabolic adaptation to endurance training is the reciprocal shift from glycogen to fat oxidation (Fiskerstrand & Seiler, 2004; Whipp, 1996). The interaction between glycogen stores and free fatty acids does not occur in total isolation but simultaneously shifting from one to the other substrate as a function of a lower exercise intensity and increased duration (Hargreaves, 2006). Aerobic glycolytic phosphorylation facilitates high aerobic ATP resynthesis though glycogen stores are limited (Spriet, 2014). However, ATP resynthesis via beta oxidation preserves the muscle glycogen reservoirs (Fiskerstrand & Seiler, 2004). Research has demonstrated that free fatty acids contribute to ATP resynthesis via beta-
oxidation at intensities up to approximately 70% of VO₂ max (Achten & Jeukendrup, 2004).

Training at Greater Aerobic Intensities

As athletes train at greater intensities, the increased utilization of fat as a fuel source through training, will preserve glycogen stores and improve endurance (Friedlander et al., 2007). This ability to train closer to ‘race pace’ and continue to use fats before full transition to the use of glycogen stores only, will improve stamina both during training and performance (Billat et al., 2003; Boyd et al., 1974). Furthermore, this is a unique opportunity for athletes to delay rapid lactate accumulation and removal as the rate of fatty-acid oxidization increases though training (Ni Chéilleachair et al., 2017). Within endurance events, the anaerobic or lactate threshold has been shown to coincide with a blood lactate concentration of 4 mmol, observed between 50%-80% VO₂ max, on average and has been identified as the highest correlation of endurance running and rowing performance compared to any other standardized testing of performance prediction (Farrell et al., 1979; Kumagai et al., 1982; Steinacker, 1993). Increasing the power output at which this lactate threshold occurs is a key objective of endurance training.

1.2.2 Anaerobic Training

As mentioned, approximately 20% of the ATP demand during the Olympic 2000 m rowing event is met from anaerobic phosphorylation (Fiskerstrand & Seiler, 2004; Guellich et al., 2009; Seiler & Kjerland, 2006). The result of lactate accumulation in active muscle during physical activity originates from the pyruvate to lactate reaction (Brooks, 1985; De Feo et al., 2003). As the power output demand increases, the ATP
supplied by aerobic metabolism becomes insufficient and the muscle must work anaerobically to supplement aerobically derived ATP (Figure 2 & 3) (Wasserman, 1984). As pyruvate entering the mitochondria is rate limited, the excess pyruvate is converted to lactate by the enzyme lactate dehydrogenase (LDH) and is reduced by the coenzyme NAD+, which accepts the H⁺ and forms lactic acid, which then dissociates immediately to lactate and hydrogen (Wasserman, 1984). NAD⁺ is then recycled back into glycolysis for continuous anaerobic ATP resynthesis (Doi, 2018).

![Diagram of anaerobic pathway](https://www.hindawi.com/journals/jnme/2010/905612/fig11/)

**Figure 2.** Anaerobic Pathway; oxygen absence. [Link](https://www.hindawi.com/journals/jnme/2010/905612/fig11/)

This increase of hydrogen ions from lactic acid causes the build up of acid in active muscles and diffuses into the blood, creating the phenomena known as acidosis. The hydrogen ions interact with the pain receptors located in the myofibril of the muscle tissue, causing inflammation, discomfort and pain that is experienced during intense exercise (Doi, 2018).
The body releases lactate into the blood via MCT-1 transporters. Once the lactate and $\text{H}^+$ enters the blood stream, bicarbonate ($\text{HCO}_3^-$), the chemical compound released by the kidneys to regulate pH levels in the body, binds to hydrogen and results in the formation of water ($\text{H}_2\text{O}$) and carbon dioxide ($\text{CO}_2$). The body eliminates the $\text{CO}_2$ with increased pulmonary ventilation, termed ventilatory buffering. Some lactate is also reabsorbed by the liver by MCT-1 (Rodas et al., 2000), and in the presence of LDH, within the liver, forms pyruvate and then further undergoes gluconeogenesis (formation of glucose) to be transported back through the blood stream and may be recycled as glucose for glycolysis. This process is known as the Cori cycle. (Brooks et al., 1973). These reactions lead to recovery (phosphorylation of ADP) after intense exercise. Billat (2001), suggested that assessing the running speed at lactate threshold, rather than the VO$_2$ at lactate threshold is considered a better conductor for training improvement for endurance athletes (Billat,
Billat (2001) also notes the range of velocities used in a race must be taken into consideration, since long distances are not run at a constant pace throughout. It is important for endurance athletes to possess a high VO$_2$ max as well as a high lactate threshold. Billat et al. has also suggested that the duration endured at VO$_2$ max is a critical criteria for the adaptation of this maximal aerobic capacity (Billat et al., 2000).

**Figure 4.** ATP turnover time among the three energy systems during high-intensity exercise of various durations. [https://www.hindawi.com/journals/jnme/2010/905612/fig9/](https://www.hindawi.com/journals/jnme/2010/905612/fig9/)

The energy system contributions during maximal effort exercise can be seen in Figure 4. As an example, during a 30 second sprint, the energy provision of ATP resynthesis is 23% phosphagen system, 49% glycolysis, and 28% mitochondrial respiration while a 10-second maximal sprint it has been estimated that energy is provided by 53% phosphagen, 44% glycolysis, and 3% mitochondrial respiration (Figure 4) (Bangsbo, 2003). The
resynthesis of ATP through the phosphagen system is shared through three reactions: creatine kinase, adenylate kinase, and AMP deaminase (Julien S. Baker, 2010).

![Diagram of energy systems](https://www.hindawi.com/journals/jnme/2010/905612/fig5/)

**Figure 5.** ATP turnover in energy system contribution from 10 s of high-intensity exercise.

High power output sports that require quick movements or short bursts of intense activity are dependent on an efficient phosphagen system for performance as it is the most readily available from cell surface ATP to free energy use (Cooke & Wu, 2020). ATP is readily available and has the highest turnover rate in contrast to the other energy systems, but the total quantity of the ATP reservoir stored in the muscle cells is finite to 1 – 5 seconds before other anaerobic energy sources including creatine phosphate must phosphorylate the ATP to form ATP once again (Baker, 2010; Siegler et al., 2006; Walter et al., 1997).

1.3 Interval Training
Interval training is described as repeated short to longer bouts of high-intensity exercise combined with active or passive recovery periods (Billat, 2001). Interval training was first described by Reindell and Roskamm and was popularised in the 1950s by the Olympic champion, Emil Zatopek (Billat, 2001). Interval training can be sub-categorized by the combinations that make up a training program: the durations of the work and recovery periods, frequency, intensity, and volume (Morton et al., 2019). Work-to-rest ratios are important elements when an interval training regime is created (Weston et al., 2014). The specific ratio of work to rest has been utilised to enhance sports-specific performance improvement (Jones et al., 2019). Generally, shorter work periods with longer rest will result in greater power outputs and a greater anaerobic contribution compared to longer work periods with shorter rest which is designed to give a greater aerobic contribution. In the present study, short (10 s) work periods have been coupled with shorter (5 s) recovery periods to elicit both an aerobic and anaerobic stimulus.

*High-Intensity Training with Endurance Athletes*

Submaximal intensity is defined as the physical workload below an individual's VO₂ max (< VO₂ max) (Knuttgen & Saltin, 1972). These include elite endurance training programs that have about 80% of their training volume training that is completed at low intensities, resulting in blood lactate concentrations < 2 mmol (Seiler, 2010). It has been suggested by Billat et al. and others, that higher intensities of interval training would also be of benefit (Billat, 2001). Two examples include Weston et al. (1996) who investigated skeletal muscle buffering capacity in endurance cyclists that performed a submaximal, yet high-intensity interval training regime to complement their prescribed program of predominantly low-intensity exercise. A total of six interval training sessions were
performed and each session consisted of six to eight sets of five-minute work periods at 80% peak power output separated by one minute of recovery between each set over a four week period (Weston et al., 1996). All six athletes’ peak power output, time to fatigue cycling at 150% peak power output, and 40 km time trial improved ($P < 0.05$) (Weston et al., 1996). It is important to note that Weston et al. (1996) conducted the post-testing within 4-5 days after the last session to allow a brief recovery period for the participants (Weston et al., 1996). Others, Denadai et al. (2006), investigated the effects of two different high-intensity training interventions in 17 well-trained runners. Participants were assessed with an incremental treadmill test and sub-maximal constant intensity test to collect several initial physiological and performance markers. Participants’ VO$_2$ max, running velocity associated with VO$_2$ max (vVO$_2$ max), running economy, and lactate threshold as well as pre- and post-1500 and 5000 m performances were assessed (Denadai et al., 2006). The intervention consisted of a four-week training program with two high-intensity sessions at their respective 95% or 100% intensities and four lower-intensity sessions per week. Participants were re-tested immediately following the four-week intervention. Both groups exerted greater vVO$_2$ max and improved running economy, however the 100% group showed a faster post-training velocity at VO$_2$ max, as well as the time to exhaustion. The 100% group also elicited greater adaptations in the 1500 m time trial and running economy associated with the 1500 m time trial (Denadai et al., 2006). The authors noted participants’ VO$_2$ max values did not improve after the training period for both groups (Denadai et al., 2006). The benefit examined in this study suggests that well-trained individuals can improve their running economy in addition to corresponding blood lactate with high-intensity interval interventions.
Submaximal Interval Training Regimes Exploring Short Work, Shorter Rest Ratios

Several studies have conducted interventions with short work, shorter rest interval training regimes. This specific type of intervention regime, which is the one employed in this current study, replaces full rest with a 5 s light-intensity work period followed by a 10 s work period (Belfry, Raymer, et al., 2012). The inclusion of a light intensity recovery period in a cyclical high-intensity interval regime has been shown to improve blood flow and \( \text{O}_2 \) delivery to active muscles (Belfry, Raymer, et al., 2012; Dorado et al., 2004). A study that utilises this method of cyclical short 10 s work period followed by a short 5 s recovery on VO\( _2 \) and muscle deoxygenation (\( \Delta \text{HHb} \)) during intermittent exercise compared to a continuous load was undertaken by (Belfry, Paterson, et al., 2012b). Nine male participants performed three separate protocols: two intermittent interval and one continuous. The first intermittent protocol (INT 1) consisted of 10 s work 5 s active recovery at 20 watts (W). The second intermittent (INT 2) consisted of 10 s work periods and 5 s at moderate-intensity and the continuous group (CONT) that performed a constant workload. All protocols were performed for 10 minutes on separate days. Prior to the intervention, participants completed a series of ergometer tests on four separate days. An incremental ramp test to fatigue was used to determine VO\( _2 \) max and gas exchange threshold (\( V_{ET} = \text{Production of VCO}_2 > \text{VO}_2 \)). The second test required participants to complete 40 cycles (10 min) of the INT 1 10 s: 5 s high-intense protocol while the third test was the INT 2 10 s: 5 s protocol. The work rate during the 10 s period of both INT 1 and INT 2 was \( V_{ET} \) plus 50% of the difference between VO\( _2 \) at \( V_{ET} \) and VO\( _2 \) max (\( \Delta50\% \)) and the power output was below lactate threshold during the 5 s recovery period (moderate intensity) (Belfry, Paterson, et al., 2012b). The work rate during the 5 s
recovery period of INT 2 was set at 50% of the difference between the subject’s 20 W cycling VO2 and gas-exchange threshold VO2 (Δ50% VET) (Belfry, Paterson, et al., 2012b). The fourth test was a continuous constant load exercise at an identical power output of the 10 s work period of the INT protocols from testing day two and three (Belfry, Paterson, et al., 2012b). All three protocols had different mean power outputs despite having the same power output used for the 10 s work period (p < 0.05) (CONT, 270 ± 43 W; INT 1, 185 ± 28 W (cycles of 270 W with recovery 20 W); and INT 2, 209 ± 30 W (cycles of 270 W with recovery 92 W) (Belfry, Paterson, et al., 2012b). Mean VO2 were also different across all three protocols, the continuous group experienced the highest average (CONT) 3.77 ± 0.61 L min−1, followed by INT 2 3.04 ± 0.49 L min−1, and INT 1 2.81 ± 0.36 L min−1 (p < 0.05) (Belfry, Paterson, et al., 2012b). Interestingly, there were no observable difference between VO2 response during the work and recovery during INT 2 protocol (p > 0.05) and resulted in a VO2 approaching maximum.

A follow up study examined the same 10 s: 5 s protocol to investigate the muscle metabolic status and acid base balance compared to continuous exercise in seven recreationally active males (Belfry, Raymer, et al., 2012). Glycolytic phosphorylation contribution was greatest during the work periods of intervals due to the high concentration of H+ during the rest period eliciting rapid ATP recovery, compared to the continuous training that required the same work rate. The response of this intermittent exercise bout resulted in a greater glycolytic contribution as shown by the increase in H+ (Belfry, Raymer, et al., 2012; Casey et al., 1996).

This novel 10 s work: 5 s recovery training intervention was then performed on elite and collegiate rowers (Richer et al., 2016). The purpose was to compare between six
supramaximal intermitted sessions over 11 days versus continuous training and determine any selected power measures (Richer et al., 2016). Sixteen participants were randomized into two groups (10 open weight rowers and 6 lightweight rowers). The interval training session would consist of 6 sets of 10 cycles: 10 s at 140% peak aerobic power followed by 5 s recovery. After 10 cycles, participants would have 8 min of active recovery then repeat the next set. The continuous group performed regular training which consisted of predominantly moderate intensity, below blood lactate threshold. After the 11-day intermittent interval regime, critical power increased by 7% in the interval group and 9% in the continuous group; (336 ± 59W to 360 ± 59W; 290 ± 73W to 316 ± 74W; p ≤ 0.05) (Richer et al., 2016). The mean power output from all performance measures increased only in the interval group (7%) (464 ± 158W to 496 ± 184W; p ≤ 0.05), no change was statistically observed in the continuous group (p > 0.05). The continuous group also underperformed in the critical power and 60 s test, decreasing their W' average by 21% and 60-second power (4%) (p ≤ 0.05) respectively.

This current study utilised this same 10 s: 5 s interval training paradigm but increased the 2.5 min intervals performed six times of the Richer et al. (2016) study to one exercise bout 30 min in duration performed ten times. An extended period in the proximity of VO₂ max while also forcing a high anaerobic glycolytic contribution would elicit both high aerobic and anerobic contributions. Finally, the timing of the pre-training and post-training testing in this previous work was not optimal as they were performed three weeks before and three weeks after the training intervention. It has been shown that the validity of performance testing, from a training intervention, decreases with the
number of days before training and after training, therefore testing should occur within 48 hours before and 10 days after a training program (Stevens & Dascombe, 2015).

1.5 « References »


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Chapter 2

2 « Manuscript »

2.1 « Introduction »

Elite-level rowers require high aerobic and substantial anaerobic power to maximize their potential. Of the total energy required for their 2000 m rowing performances, the aerobic energy systems contribution is approximately 70-80%, whereas the anaerobic energy systems contribute the remaining 20-30% (Das, 2019). This indicates why rowing is a predominantly endurance sport, however optimising the capacity of both the aerobic and anaerobic systems is required for optimal performance improvements.

One such training regime has been composed of training bouts of repeated cycles of short work (10 s) and shorter recovery (5 s) for 30 min performed on alternate days over three weeks (Belfry, Paterson, et al., 2012a). This training improved VO\textsubscript{2} max, lactate threshold, and aerobic and anaerobic performances (Belfry, Paterson, et al., 2012a). This training paradigm’s aerobic and anaerobic contributions were investigated to determine the energy system contributions (Belfry, Paterson, et al., 2012a). They demonstrated that there was a 12% anaerobic contribution and the remainder of energy supplied by the aerobic system. Moreover, their findings indicated that if a moderate-intensity work rate was performed during the recovery period, the fluctuations of VO\textsubscript{2} were mitigated and overall greater compared to a 5 s light intensity work rate (Belfry, Paterson, et al., 2012a).

The participants in these studies were recreationally active individuals. However, the efficacy of this training paradigm has yet to be tested on a well-trained competitive
group whose performances require a high aerobic energy system contribution and a significant anaerobic energy system contribution such as the Olympic 2000 m rowing event.

Therefore, the purpose of this study was to investigate the effects of ten, 30 minute, high-intensity training sessions, performed on alternate days with a group of well-trained male and female rowers from varsity to international class, within their competitive season at a time when they were preparing for national ranking testing.

We hypothesized that increases in aerobic and anaerobic energy systems would improve 6000 m, 60 s, Peak Power, and 2000 m rowing ergometer performances after this training program.

2.2 « Methods »

2.2.1 Participants

Nine members of the Western University’s Rowing team were recruited for this study, four males and five females.

This study was approved by Western University’s Health Sciences Human Research Ethics Board. All participants gave verbal and written consent to participate after reading the Letter of Information of the study. All participants were considered healthy and trained individuals with no reported injury.

2.2.2 Experimental Protocol

Due to the competitive nature of this group and the concern that those rowers not participating in the intervention were being given a superior training paradigm and would be given an unfair advantage, all members of the varsity rowing team participated in this
intervention. Thus, there was no separate control group; they acted as their own controls. Those participants who participated in all sessions and completed all testing were included in this manuscript. Those that did not were excluded.

To our knowledge, this is the first high-intensity interval training program applied to the entire team (one experimental group) with pre-testing and post-testing performance measurements during standardized testing – testing which Rowing Canada has identified to be critical indicators of athlete performance and success; the results of these tests are used for national team identification and progression.

2.2.3 High-Intensity Training Sessions

Participants performed a standardized warm-up on the rowing ergometer for 20 minutes at a moderate-intensity (heart rate below 60% of the age-predicted heart rate maximum). Three 10 s higher intensity efforts were then completed. The high-intensity session was composed of 120 cycles of 10 seconds of high-intensity (7 strokes) followed by five seconds of moderate-intensity (two strokes) that endured for 30 minutes followed this warmup. Ten interventional sessions were performed following the testing period over the course of four-weeks with blood lactate measurement occurring on the seventh training session. Post-testing was set to follow the interventional training period (Figure 6). The 10 s high-intensity segment of the first training session was set at 80% of the athlete’s mean power output (PO) in watts (W) from the 2000 m ergometer test performed within three days of the onset of the high-intensity training intervention. Jensen’s Model ‘Power Profile’ estimates a 6000 m test to be roughly 85% of 2000 m mean power output (Hill et al., 2003). To ensure the 30 min duration of the first session could be completed, 80% power output was set for the 10 s high-intensity period. This 2000 m test was
completed as part of a battery of tests, including a Peak Power, 1-minute test, 2000 m, 6000 m, and 60-minute tests, that were used for National Canadian Rowing Ergometer Rankings. The warm-up and cool-down portions of the training session were the same for each intervention training session. All work durations and intensities performed during all practices by the rowers in the group were recorded (Table 4).

The 5 s moderate-intensity portion of the cycle was performed at an RPE of 4. This intensity is recognized as ‘Moderate’ pace on the RPE scale used for steady aerobic exercise and is defined as a Category V intensity or ‘Basic Endurance’ as identified by Rowing Canada. Participants increased their high-intensity 10 s target power by 10 watts when scoring an RPE of 7 – Really Hard from the previous session. If a participant reported an RPE ≤ 6 – Hard, they would increase their target power output for the next session by 20 W. If a score of ≥8 – Very Hard was given, the participant was asked to attempt to maintain their previous power output.

Figure 6. Study Design – Intervention training outline from pre-testing, ten training sessions including lactate testing on session seven, and post-testing.
2.2.4 Testing

The study consisted of 4 testing days performed on alternate days.

Testing Day 1. 60-minute test. Participants completed a rowing ergometer test that required the rowers to row as hard as possible for 1 hour after the standard warm up. Distance, time, and power output are recorded following the completion of the test. Following this incremental rowing ergometer test, participants were instructed to row at low intensity for 15 minutes to recover.

Testing Day 2. Peak Power and 60-second testing. Participants performed a warmup on the rowing ergometer for 20 minutes at a moderate intensity (a heart rate below 60% of the age-predicted heart rate maximum will be maintained. Bouts of higher
intensity for <10 seconds would simulate their predicted 1-minute pace within the 20 minutes warm-up period. For the Peak Power test, participants were instructed to take 10 strokes as fast and hard as possible. Strokes per minute and the highest power output were recorded. Following this Peak Power test, participants recovered for 15 minutes and then performed the 60-second test. Participants were given the commands "Ready, row" to begin the test. Participants maintained the highest possible power output for 60 seconds. Verbal encouragement was given to facilitate maximal individual power output during the tests.

Testing Day 3. 6000 m rowing ergometer test. Participants performed a warmup for 30 minutes at moderate-intensity with two to four bouts of higher power for 10 s. The participants performed their 6000 m test based on their previous perceived optimal pacing strategy. Once the participants were ready to row on the ergometer, the command "Ready, row" was given. Time, distance, and power output was recorded.

Testing Day 4. 2000 m rowing ergometer test. Participants performed a warmup for 30 minutes at moderate intensity with two to four bouts of higher intensity for 10 seconds. The participants performed their 2000 m test based on their optimal pacing strategy. Once the participants were ready to row on the ergometer, the command "Ready, row" was given. Time, distance, and power output was recorded.

Post-training Testing days 5, 6, 7, and 8 would have been the same as 1, 2, 3, and 4. Unfortunately Covid-19 lockdown precluded all but three of the rowers from completing testing. Only the 2000 m tests were performed by these three international level rowing participants. Figure 6 displays the intervention study design, including testing days and testing order.
2.2.5 Data Collection

All power output data was collected from each participant using ErgData software. ErgData provides additional performance statistics, stores, and displays your workout results, and uploads results to the Concept 2 Online Logbook with complete stroke data (Concept 2 log book).

The rate of Perceived Exertion (RPE) was recorded after each training session from a scale of 1 to 10. Participants were shown a visual RPE scale to compare training sessions previously completed and to set their RPE objective for the upcoming session (Figure 7).

Blood lactates were taken two minutes before the seventh intervention training session, following a standardized warm-up period and again 1-minute post-training session. 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.

2.2.6 Statistical Analysis

Data are presented as means ± SD. One Way Repeated Measures Analysis of Variance was completed across all intervention training sessions for both high-intensity and moderate-intensity intervals for all participants (Figure 10). Paired -T tests were used to analyse potential differences pre- and post-training across all participants and sexes. Statistical analyses were calculated using SigmaPlot Version 12.3 (Systat Software Inc., San Jose, CA). Statistical significance was accepted at an alpha level \( \leq 0.05 \).
2.3 « Results »

Participants’ characteristics and pre-testing results are presented in Table 1. This includes their most recent 2000 m score result that was used to determine their starting target watts for the high-intensity portion of the first session (Table 2). The collective group of participants \((n = 9)\) had a mean and SD of 316 W (94.6) from their pre-testing 2000 m ergometer test. Participants who completed both pre-testing and post-testing 2000 m had a pre-testing mean and SD of 310 W (68) and a post-testing mean and SD of 320 W (71), resulting in a 3% mean PO increase, a 4 s improvement in 2000 m time (Table 2). Table 3 reflects the volume and training intensities starting from their return from the off-season, up to the training intervention period. This initial five-week period was divided into the volume in minutes (min) and hours (h) at each intensity for the week. Table 4 reflects the total training volume during the training intervention for five weeks.

Mean blood lactate (mMol.1\(^{-1}\)) was measured during warm-up and 1-min post-training session seven to determine the intensity of the training from each participant (Table 5). The mean (SD) of all participants blood lactate during warm-up was 1.7 (±0.5) and post-training session measured 8.4(±1.4). Males measured 1.2 (±0.3) and females 2.1 (±0.4) during their warm-up and measured 8.7 (±1.7) and 8.2 (±1.2), 1-min post-training session respectively. The mean PO for both the high-intensity portion and moderate-intensity portion for each participant from session one and session ten can be found in Figure 8 and Figure 9 respectively. The mean PO across all participants for the high-intensity portion improved by 43 watts or 17% from session one (248 w) to session ten (291 w). Mean PO for moderate-intensity improved drastically by 55 watts, a 44% increase from session one at 125 watts to session ten at 180 watts. Total mean PO from
session one to session ten increased by 22%, from 208 W to 254 W respectively (Figure 10). Figure 11 and Figure 12 reflect the mean high-intensity performance improvements from training session one to ten in males (Figure 11) and females (Figure 12). Males (n = 4) increased their mean high-intensity PO by 19% (60 W) and females (n = 5) increased their mean high-intensity PO by 14% (27 W). Figures 13 and 14 reflect the mean moderate-intensity performance improvements from training session one to ten in males (Figure 13) and females (Figure 14). Males increased their mean moderate-intensity PO by 42% (69 W) and females increased their mean moderate-intensity PO by 46% (43 W). Total mean PO performance improvements increased by 23% (63 W) in male participants and 21% (32 W) by female participants.

RPE collected from all training sessions from all participants scored a mean and (SD) of 7.4 (0.8); males = 7 (0.7), females = 8 (1) respectively. There was no statistical significance in change from session one to session ten (One-way repeated measures, p = 0.930).
**Table 1.** Participant characteristics and pre-testing exercise.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
<th>Competitive Category</th>
<th>2000 m Pre- (W)</th>
<th>6000 m Pre- (W)</th>
<th>Peak Power Pre- (W)</th>
<th>60 s Pre- (m)</th>
<th>60 min Pre- (W)</th>
<th>Highest Competitive Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ♀</td>
<td>24</td>
<td>196</td>
<td>97</td>
<td>OM</td>
<td>398</td>
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<td>996</td>
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<td>260</td>
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</tr>
<tr>
<td>2 ♀</td>
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<td>202</td>
<td>101</td>
<td>OM</td>
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<td>390</td>
<td>1096</td>
<td>386</td>
<td>302</td>
<td>World Championship</td>
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<td>82</td>
<td>OM</td>
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<td>317</td>
<td>889</td>
<td>367</td>
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<td>4 ♀</td>
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<td>LM</td>
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<td>304</td>
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<td>OW</td>
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<td>173</td>
<td>66</td>
<td>OW</td>
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<td>LW</td>
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<td>20</td>
<td>166</td>
<td>59</td>
<td>LW</td>
<td>234</td>
<td>191</td>
<td>486</td>
<td>305</td>
<td>174</td>
<td>University Team</td>
</tr>
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<td>9 ♀</td>
<td>20</td>
<td>168</td>
<td>60</td>
<td>LW</td>
<td>220</td>
<td>183</td>
<td>481</td>
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<table>
<thead>
<tr>
<th>Mean (SD)</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
<th>Competitive Category</th>
<th>2000 m Pre- (W)</th>
<th>6000 m Pre- (W)</th>
<th>Peak Power Pre- (W)</th>
<th>60 s Pre- (m)</th>
<th>60 min Pre- (W)</th>
<th>Highest Competitive Level</th>
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<tbody>
<tr>
<td>22 (2)</td>
<td>181 (12)</td>
<td>74 (16)</td>
<td></td>
<td></td>
<td>316 (95)</td>
<td>259 (76)</td>
<td>698 (247)</td>
<td>331 (38)</td>
<td>215 (53)</td>
<td>University Team</td>
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<td><strong>310</strong> (68)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Competitive Category: OM: Open Men (>72.5kg), LM: Light Men (<72.5kg), OW: Open Women (>59kg), LW: Light Women (<59kg). Previous: pre, post: after. Bolded numbers are participants who completed pre- and post-testing*
Table 2. Participant 2000 m Performances and Target Power Output for Training Session One.

<table>
<thead>
<tr>
<th>Participant</th>
<th>2000 m Mean (W) Pre</th>
<th>2000 m Mean (W) Post</th>
<th>Target (W): Session One</th>
<th>2000 m (min) Pre</th>
<th>2000 m (min) Post</th>
<th>Highest Competitive Level</th>
</tr>
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<td></td>
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<td>483</td>
<td>390</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>361</td>
<td>290</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4 ♀</td>
<td>388</td>
<td>402</td>
<td>06:26.4  06:22.1</td>
<td>National Team</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ♀</td>
<td>279</td>
<td>283</td>
<td>07:11.3  07:09.4</td>
<td>National Team</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>264</td>
<td>274</td>
<td>07:19.5  07:14.2</td>
<td>National Team</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>University Team</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>234</td>
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<td></td>
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<tr>
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<td>220</td>
<td>175</td>
<td>07:47.1</td>
<td>University Team</td>
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</table>

Mean (SD)
- 316 (95)
- 310 (68)
- 320 (71)

Table 3. Total training volume before intervention training period. Total time in (min) and (h) was calculated.

<table>
<thead>
<tr>
<th></th>
<th>Cat I</th>
<th>Cat II</th>
<th>Cat III</th>
<th>Cat IV</th>
<th>Cat V</th>
<th>Cat VI</th>
<th>Total (min)</th>
<th>Total (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>200</td>
<td>110</td>
<td>75</td>
<td>550</td>
<td>650</td>
<td>750</td>
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<tr>
<td>Week 2</td>
<td>250</td>
<td>85</td>
<td>90</td>
<td>725</td>
<td>750</td>
<td>955</td>
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<tr>
<td>Week 3</td>
<td>90</td>
<td>30</td>
<td>20</td>
<td>80</td>
<td>775</td>
<td>970</td>
<td>14.8</td>
<td></td>
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<tr>
<td>Week 4</td>
<td>120</td>
<td>65</td>
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<td>350</td>
<td>3450</td>
<td>4575</td>
<td>15.9</td>
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<tr>
<td>Week 5</td>
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<td>30</td>
<td>30</td>
<td>30</td>
<td>350</td>
<td>3450</td>
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</tr>
<tr>
<td>Total (min)</td>
<td>20</td>
<td>725</td>
<td>30</td>
<td>350</td>
<td>3450</td>
<td>4575</td>
<td>76.3</td>
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</tr>
</tbody>
</table>

*Total training volume six days of the week from Monday to Saturday after the December holiday break for the five weeks preceding the first intervention training session. Cat I: Anaerobic capacity; Cat II: Race Endurance; Cat III: Development of Aerobic Capacity; Cat IV: Anaerobic Threshold; Cat V: Basic Endurance; Cat VI: Utilization of Aerobic Capacity & Regeneration*
Table 4. Total training volume during the intervention period. Total time in (min) and (h) in each intensity category was calculated.

<table>
<thead>
<tr>
<th></th>
<th>Cat I</th>
<th>Cat II</th>
<th>Cat III</th>
<th>Cat IV</th>
<th>Cat V</th>
<th>Cat VI</th>
<th>Total (min)</th>
<th>Total (h)</th>
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<td>Week 1</td>
<td>130</td>
<td>100</td>
<td>625</td>
<td>855</td>
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<tr>
<td>Week 2</td>
<td>225</td>
<td>100</td>
<td>130</td>
<td>775</td>
<td></td>
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<td>Week 3</td>
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<tr>
<td>Week 5</td>
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<tr>
<td>Total</td>
<td>60</td>
<td>730</td>
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<td>3710</td>
<td>4830</td>
<td>80.5</td>
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Total training volume: Six days a week, Monday to Saturday for the five weeks of the intervention training period.

Table 5. Lactate (mMol.1-1)

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<tr>
<th>Participant</th>
<th>Warm-up</th>
<th>Post-workout</th>
<th>Warm-up</th>
<th>Post-workout</th>
<th>Warm-up</th>
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<td>6.7</td>
</tr>
</tbody>
</table>

Mean (SD) 1.7 (0.5)   8.4 (1.4)   1.2 (0.3)   8.7 (1.7)   2.1 (0.4)   8.2 (1.2)

Blood lactates were taken 2 minutes before the seventh intervention training session, following a standardized warm-up period and again 1-minute post-training session.
Figure 8. Mean Power Output (PO) of high-intensity work for men (dashed) and women (dotted) for each participant. Total mean PO (solid line) for all participants from session one and ten. High-intensity work period increased across all participants from session one to session ten (Cohen’s d 0.53, medium effect).

Figure 9. Mean Power Output (PO) of moderate-intensity for men (dashed) and women (dotted) for each participant. Total mean PO (solid line) for all participants from session one and ten. Moderate-intensity work period increased across all participants from session one to session ten (Cohen’s d 1.01, large effect).
Figure 10. Mean Power output (PO)(n=9) at 10 second high-intensity work period (across all participants) and moderate-intensity work period from Session One and Session 10. Closed circles: Open circles Mean PO at 10 s Work Period, Mean PO at 5 s. Bolded line represents the total workload from 10 s and 5 s combined with respected workload of the total training session. Means under symbols are significant changes (p<0.05) (Cohen’s d 0.54, medium effect).

Figure 11. Male group (n=4) Mean PO (watts) for high-intensity work period across each training session for each male participant.
Figure 12. Female group (n=5). Mean PO (watts) for the high-intensity work period across each training session for each female participant.

Figure 13. Male group (n=4). Mean PO (watts) for moderate-intensity work period across each training session for each male participant.
2.4 « Discussion »

This present study aimed to investigate a short work, shorter rest high-intensity interval training regime and its effects on rowing ergometer performance in varsity and international class rowers. It was hypothesized that after ten interval training sessions over four weeks, athletes would elicit performance improvements. The main findings include an increase in mean power output in the high-intensity (10 s) and moderate-intensity (5 s) portions of the 15 s cycles and mean power output during the 30-minute training session from session one to ten (Figure 10). Post-testing results also showed that the three international class rowers that completed the post-training 2000 m rowing test, showed a mean improvement of 4 s.

When the rowers in the present study returned from their off-season, they performed a predominantly aerobic training block for a five-week period comprised primarily of low-intensity, high-volume steady state rowing, interspersed with a limited volume of high-intensity training (Table 3). This enabled a reconditioning period recommended for athletes
returning from their off-season (Neufer, 1989). This initial training period also diminishes validity bias of an intervention performed immediately upon returning to training as it has been shown that virtually all types of training will result in improved performances as training is being performed at their lowest fitness levels of the year and will result in improved fitness (Godfrey et al., 2005; Joo, 2018). Furthermore, during the intervention, total training volume was similar to the prior reconditioning training period (Table 3 and Table 4). This allowed minimal transition to an intervention regime without affecting the athletes’ regular aerobic training.

This 10 s: 5 s interval training regime has been investigated previously by Belfry, Raymer et al. (2012) to determine the anaerobic energy contributions via observing the high energy phosphagens (ATP and PCr) and acid-base balance (H⁺) of the working muscle (Belfry, Raymer, et al., 2012). Belfry, Raymer et al. concluded that this 10 s: 5 s protocol elicits a greater anaerobic contribution than a continuous training session of the same duration and power output as the 10 s work period. Subsequently, Belfry, Paterson et al. (2012) further investigated this 10 s: 5 s regime by observing oxygen uptake during these same work: recovery intervals. Their results showed that mean VO₂ was lower during repeated cycles of the 10 s high: 5 s light-intensity work (20 W), compared to a similar 30 min session performed at the same PO as the 10 s interval. This was expected as the previous work had shown that the anaerobic contribution would be greater, and there was significant ATP and PCr replenishment during the 5 s recovery period that would be supplied by anaerobic glycolysis. However, they demonstrated that when a ‘moderate’ intensity power output (80% of lactate threshold) was substituted for the light intensity power output (20 W) during the 5 s recovery period, they observed a VO₂ that was greater (88% of VO₂ max) and
non-oscillating (Belfry, Paterson, et al., 2012b). A high and non-oscillating VO$_2$ training stimulus has been shown to elicit accelerated adaptations to VO$_2$ max and endurance performance compared to less intense exercise (Billat et al., 1999). This modified 10 s: 5 s interval training regime allowed the participants in the previous work, as well as the rowers in the present study, to train at close to their VO$_2$ max while eliciting a significant anaerobic contribution as reflected by the high blood lactate concentrations immediately post training (Table 5). Olympic rowing events require aerobic energy system contributions of 70-80%, complimented with an anaerobic contribution of 20 - 30% during the 2000 m rowing race (Issurin, 2019), this 10 s: 5 s training bout facilitates the training of both energy systems that are critical to rowing success. Notably, the inclusion of an intervention such as was performed here, with high-level athletes, requires the trust of both the rowers and their coaches in the exercise physiologists administering the training (Bourgeois et al., 2019). Fortunately, this group of researchers has gained this trust over a number of years.

Over the ten sessions performed during the intervention training period, mean PO improved by 22% from session one to session ten. These results exceed that of a similar cycle ergometer training study completed by Belfry et al. (2020) eliciting a mean power output improvement of 13%, investigating a similar 30 min, 10 s: 5 s protocol with provincial level athletes from a variety of sports (swimming, baseball, hockey, soccer, and rugby) on a cycle ergometer (Belfry et al., 2020). No moderate-intensity training was performed in this previous research. It is suggested that when this high-intensity training was combined with the high-volume moderate-intensity training of the rowers in the present study, the adaptations to moderate-intensity training such as additional lactate clearance and
buffering would have contributed to the improved training power output in the present study (Fiskerstrand & Seiler, 2004).

By the tenth session, participants had also increased their 10 s high-intensity power output by 17% compared to the first session (Figure 10). It is suggested that the improvements made in this high-intensity period contributed to the 3% performance improvement in 2000 m post-testing. For the international-level participants that completed the post-2000 m test, their power output improved by 18% from session one to session ten. At the international level, the difference between first and second can be less than 1%, therefore the 3% improvement in 2000 m performance exhibited by the participants in this study shows the value of this intervention regime. Moreover, it has been demonstrated that athletes of this calibre elicit the smallest increments of improvements over an entire season as they are mature in their physiological fitness and performance (Mikulic, 2011).

Furthermore, over the course of the training sessions in the present study, athletes were also able to increase their power output during the 5 s recovery period (Figure 13 & 14). By session ten, mean power output from the 5 s portion of all participants had increased by 44% (Figure 10). It is suggested that this improvement is a function of an increase in the power output of the rowers’ lactate threshold. The participants’ ability to produce a greater work rate during the recovery period would be reflected by increased buffering of H⁺ during the constant cyclical change between the 10 s and 5 s period (Kubukeli et al., 2002). In turn, the ability to buffer the effects of the anaerobic glycolytic contribution during a 2000 m race would improve their performances during both the 10 s high and 5 s moderate-intensity intervals (de Campos Mello et al., 2009; Martin & Tomescu, 2017).
Richer et al. (2016) completed a variation of this 10 s: 5 s interval training regime (repeated cycles of 10 s at 140% peak aerobic power, 5 s easy rowing for 2.5 minutes) with elite level rowers of similar calibre to this study and the effects on their 2000 m performance compared to continuous training (Richer et al., 2016). This previous study observed only six interval sessions over 11 days. Unlike the 30 min bout of the present study, this previous group performed six of these 2.5 min intervals per exercise bout. The intervention group of the Richer study did elicit improved 2000 m performances compared to the continuous training group. However, the 2000 m performance tests completed in this earlier work were three weeks prior to the first 10 s: 5 s training session and three weeks after the last session due to constraints placed on the testing windows by their coaches’ seasonal plan. It has been shown that the validity of post-testing decreases with prolonged periods between testing and the intervention period (Stevens & Dascombe, 2015). This present study rectified the timing the testing of this limitation by scheduling only a brief five-to-seven-day period immediately after their last 10 s: 5 s training session with reduced training intensity to recover from this 10 s: 5 s high-intensity training prior to the post-testing. This reduction in the high-intensity training stimulus has been suggested to maximize recovery from the high-intensity training without losing the adaptations accrued during the four-week intervention training period (Le Meur et al., 2012). In the present study, select participants showed a 3% improvement in 2000 m performance over the four-week period without sacrificing the high-volume of moderate-intensity continuous training. These select rowers had all performed at the international level. It has been demonstrated that athletes in this international category are not as responsive to training stimuli as less seasoned athletes (Smith et al., 1994). This suggests that the improvements observed in the present study are that much more notable (Haff et al., 2008). Others have found improved 2000 m performance (Δ1.7 %) with their
intervention, while reducing moderate-intensity training by 20% (Ni Chéilleachair et al., 2017). However, the value of rowers maintaining their moderate-intensity volume at the international level is seen by coaches of elite rowers’ to be a necessary component of their training and it be would difficult to convince them to reduce this volume. Previous research has shown that maintaining this higher volume of moderate-intensity aerobic work is associated with enhanced fat oxidation, heart and lung function, as well as the increase in mitochondria size and number (Davies & Thompson, 1979; Andrew M Jones & Helen Carter, 2000). These aerobic contributions via beta oxidation and increased heart function are not elicited by higher aerobic or anerobic intensities and therefore reducing the volume of moderate-intensity training diminishes the achieved adaptations in as early as 14 days (A. Hawley et al., 1997; Houmard et al., 1989; Joyner & Coyle, 2008). In the present study, moderate-intensity training volume was not reduced, as these higher intensity sessions were added to their regular training volume. This addition accounted for an additional 60 min of training volume per week, a modest adjustment to their training regime (Table 4).

In conclusion, this four-week intervention training regime improved 2000 m performance without compromising training volume associated with moderate-intensity aerobic training. All participants elicited improvements in their high-intensity and moderate-intensity work periods. Our data clearly demonstrated performance improvements in all rowers over the course of the ten training sessions. This high-intensity interval training regime when interspersed with regular prescribed training could provide benefit to elite and international class rowers.

2.5 « Strengths and Limitations »
All training sessions were performed during regular training hours as a group, providing an encouraging testing atmosphere which positively effects training adherence and performance outcomes, compared to a laboratory setting which can be quite unmotivating (Balsom, 1994; Clemente-Suárez et al., 2021; Rattray & Roberts, 2012). Moreover, during training sessions, participants were situated immediately beside their crew members who were performing similar power outputs. This facilitated their motivation for training with maximal efforts. Evidence has suggested that when athletes are paired or share the same platform as others with similar performances, it creates motivation and positive reinforcement to increase perceived physical limits (Hollingshead, 1998).

The limitations include, total training volume increased by 25 min from the first week and second week during the intervention period from the initial five-week re-conditioning period which may have improved their fitness independently of the high-intensity interval training. Moreover, nutritional intake was not controlled during the study period and there were no acclimatization sessions of the 10 s: 5 s training bout before the ten-training sessions began. The main limitations of the present study were the impacts of COVID-19 and the restrictions that followed. As the rowers performed this study in February and March of 2020. The participants were within 48 hours of their post-training 2000 m test when the university rowing training facility was forced to close, entering a COVID-19 lockdown period. The adherence to this study was 100% across all participants presented in this study over the training period. However, only three of the nine participants were able to complete their post-2000 m test before the lockdown. Fortunately, all three of these athletes were considered international class rowers. In the sporting world, top athletes response to a
training regime is the key measure of the efficacy of a training intervention (Zentgraf et al., 2017).
2.6 « References »


Concept 2 log book. [https://log.concept2.com/](https://log.concept2.com/)


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Doi, Y. (2018). Lactic acid fermentation is the main aerobic metabolic pathway in Enterococcus faecalis metabolizing a high concentration of glycerol. *Applied Microbiology and Biotechnology, 102*(23), 10183-10192.


Saporito, B. (2012). Who is the Fittest Olympic Athlete of Them All?


Spriet, L. L. (2014). New Insights into the Interaction of Carbohydrate and Fat Metabolism During Exercise. *Sports Medicine, 44*(1), 87-96. [https://doi.org/10.1007/s40279-014-0154-1](https://doi.org/10.1007/s40279-014-0154-1)


Appendix

Western Research

Date: 27 October 2020
To: Dr. Glen Belfry
Project ID: 115306

Study Title: The physiological effects of high intensity interval training over a three week training intervention in collegiate rowers.
Application Type: HSReB Initial Application
Review Type: Full Board
Meeting Date: 06/Oct/2020 13:00
Date Approval Issued: 27/Oct/2020 07:35
REB Approval Expiry Date: 27/Oct/2021

Dear Dr. Glen Belfry,

The Western University Health Science Research Ethics Board (HSReB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSReB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

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No deviations from, or changes to, the protocol or WREM application should be initiated without prior written approval of an appropriate amendment from Western HSReB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSReB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH-GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSReB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000040.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Nicola Geoghegan-Morphet, MSc. Nicola Geoghegan-Morphet, Ethics Officer on behalf of Dr. Joseph Gilbert, HSReB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).
LETTER OF INFORMATION
The effect of a 30-minute High Intensity Interval training program on selected physiological variables and performance in varsity rowers.
Principal Investigator: Glen Belfry PhD
Co-investigator: Braden Reid MSc candidate

You are being invited to participate in a research study. This consent form will provide you with information on the research project, what you will need to do, and the associated risks and benefits of the research. Your participation is voluntary. Please read this form carefully. It is important that you ask questions and fully understand the research in order to make an informed decision. You will receive a copy of this document to take with you.

Purpose of Study:
You are being invited to participate in a study that will determine whether a specific High Intensity Interval training program will result in an improvement in your ability use oxygen as well as improve your performance.

Testing will take place at the Fanshawe Lake Boathouse. You will perform physiological testing on dry-land rowing machine (rowing ergometer). The training sessions will take-place on-water during regular practice hours.

A total of (20) healthy male or female members of the rowing team will be invited to participate in this study. In order to participate you must be between 18-35 years of age. You will not be able to participate in the study if you have been diagnosed previously with any respiratory, cardiovascular, metabolic, neurological or musculoskeletal disease; or you are currently on medication; or you are a smoker; or you respond to the exercise protocol in an irregular manner or cannot tolerate the exercise or exercise training protocol.

Prior to your first testing session and/or first Intervention session, you will be assigned to the appropriate boat/weight class that will be used for all training sessions until completion of the study. At this same time you will be randomly selected to either the control group or the high intensity training group.
Your first task, if you decide to participate, will be to complete the GET ACTIVE QUESTIONNAIRE designed for adults’ ages 15-69 years of age. This questionnaire “will tell you if you should check with your doctor before you start this study”.

**Research Testing Protocol:**
You will execute six different performance tests on the rowing ergometer before and after you have completed the ten training sessions. Verbal encouragement will be given to you during these tests.

**Testing Day 1. Incremental Test.** You will complete an Incremental rowing ergometer test that will require you to increase exercise intensity in two-minute intervals. You will be given a one-minute rest after each two-minute interval of rowing. A blood lactate sample will be taken by a finger-prick prior to testing, while you are sitting quietly on the rowing ergometer, after each two-minute work period. Prior to the finger prick, an alcohol swab will be used to sterilize your left index finger. Once your blood lactate concentration begins to increase no additional lactate samples will be taken during the test. You will be required to increase your rowing intensity as instructed by the attending researcher by increasing your stroke rate. You will be asked to carry on until you are unable to continue because the exercise intensity is either too high or you become fatigued. Following this incremental rowing ergometer test you will be instructed to row at low-intensity for six-minutes to recover.

During this incremental test you will asked to wear a mouth piece and nose clips. Your exhaled air will be sampled by a small gas analyzer that will enable us to find out how much oxygen you are using during the test.

**Testing Day 2. Peak Power and 60-second testing.** You will warm up on the rowing ergometer for 20 minutes at a moderate intensity. For the Peak power test, you will be instructed to take 10-12 strokes as fast and as hard as possible. Strokes per minute and highest power output will be recorded. Following this peak power test, you will recover for 15 minutes and then perform the 60-second test. To begin the test, you will be given the commands “Ready, row”. You will maintain the highest possible power output for 60 seconds.

**Testing Day 3. 2000 m rowing ergometer test.** You will warm up for 30 minutes at moderate intensity with the exception of performing two to four bouts of higher intensity for 10 seconds. You will perform this test with your preferred pacing strategy. When you are ready on the rowing ergometer, the command "Ready, row" will be given. Blood
lactate sampling will be taken 5-minutes before and 3-minutes after this test following the same procedures of blood lactate sampling as Testing day 1.

Testing days 4, 5, and 6 will be scheduled after you complete your ten training sessions. They will be identical to tests 1, 2, and 3.

**High-Intensity Interval Training Programs:**
For those of you in the control group, you will perform the coach prescribed training program during your regularly scheduled on-water rowing training sessions on Tuesdays and Thursday of each week. These will take place during your regularly scheduled rowing team training sessions for three weeks. The training group will perform 120 intervals of ten-second of High-intensity work (6 strokes hard), followed by five-seconds of Low-intensity work (2 strokes easy) for a total duration of 30-minutes three times per week on alternate days. This program will be followed for three weeks for a total of ten sessions. The rowing distance performed by each group will be matched by adding distance to the warm down period each day to the that may have performed a shorter training distance that day.

**Possible Risks and Discomforts:**
Any exercise carries a slight risk of heart attack or may be uncomfortable if you are unfit or not used to exercise. The risk, as stated by American College of Sports Medicine, is 6 in 10,000 for adverse outcome in people at higher risk – these risks would be much lower in healthy young adult athletes, who have no signs or symptoms which may contraindicate exercise. There is no reason to expect any harmful effects of exercise in healthy young, well trained individuals such as your-self.

There will be discomfort during the exercise testing. You may experience increased awareness of breathing, muscle pain and/or fatigue, increased sweating, or a general feeling of fatigue or nausea, all of which, as you know, are not unexpected consequences of exercise. Blood lactate will be sampled via a standard finger prick apparatus.

Whenever possible abide by Western University’s Covid-19 guide lines:
- Practice physical distancing, and when possible, stay two metres apart from others
- Wear a face covering and other protective gear when in the presence of others and in common and shared spaces on campus
- Stay home if you feel ill or after exposure to someone who is ill or has tested positive for COVID-19
- Be positive, attentive, and helpful to anyone around you who may be in need of support
Benefits of Participation:
This is a basic physiology study and, as such, there will be no direct benefits received as a consequence of participating in the study. However, due to the nature of the exercise training there may be some beneficial cardiovascular adaptations (increased fitness) and strength; however these may be only temporary and disappear within a few weeks of the completion of the study. If you are interested, the rationale for conducting the research and theory and significance of each of the tests will be explained, as will your individual results from each of the tests. You will also have the opportunity to learn about and better understand your physiological response to these exercise situations.

Confidentiality
Records from this study are confidential and will be stored securely at the Cardiorespiratory Research lab. Your records are listed according to an identification number rather than by your name. Published reports resulting from this study will not identify you by name. Representatives of the University of Western Ontario Health Sciences Research Ethics Board may require access to your study-related records or follow-up with you to monitor the conduct of this research.

Voluntary Participation:
Participation in the study is voluntary. You may refuse to participate, refuse to answer any questions and withdraw from the study at any time with no effect on your academic or employment status. If you no longer want your data to be used in this research, you should tell the researcher who is present during training and/or testing (Braden Reid), who will ensure this data is deleted and no further testing will be done and your participation in the study will be discontinued. You will be given a copy of this letter of information and consent form to sign. You do not waive any legal rights by signing the consent form. If you have any questions regarding this study, please contact Glen Belfry or Braden Reid. If you have any questions about the conduct of this study or your rights as a research participant you may contact the Office of Research Ethics, The University of Western Ontario.
LETTER OF INFORMED CONSENT

The effect of a High Intensity Interval training intervention on selected physiological variables and performance in varsity rowers

Principal investigator: Dr Glen Belfry PhD
Co-investigator: Braden Reid

I have read the Letter of Information and have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Participant:

_________________________________  __________________________________________
Name (please print)  Signature
_________________________________
Date

Investigator (Person Responsible for Obtaining Informed Consent):

_________________________________  __________________________________________
Name (please print)  Signature
_________________________________
Date
# Curriculum Vitae

**Name:** Braden Reid

**Post-secondary Education and Degrees:**

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