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A four week 30 s weight training intervention improves 2000 m rowing ergometer performance of provincial and national collegiate female rowers

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Abstract

This study compared the effects of a 4 week, 30 s weight training program (30SEC), to a low-repetition weight training program (LoRep), on rowing performance and aerobic capacity in preconditioned, provincial and national collegiate female rowers. 30SEC (n=5) performed 5 sets of dumbbell deadlifts (DL) and dumbbell bench pulls (BP), executing a maximum of 18 repetitions in 30 s, three times per week. LoRep (n=5) performed 4-5 sets of 2-6 repetitions of weight training exercises twice per week. Both regimes performed an identical high volume of predominantly aerobic rowing ergometer training. 30SEC improved 1 Minute Test ($p<0.05$) and 2000 m rowing ergometer performance ($p<0.001$), whereas LoRep did not ($p\geq0.05$). VO_2max, peak power output at VO_2max, and ventilatory threshold did not change in either group ($p\geq0.05$). It is suggested that 30SEC improved 1 Minute Test performance indicated improved anaerobic capacity, which facilitated the improved 2000 m rowing ergometer performance.

Keywords: 30 second training, weight training, endurance training, concurrent training, rowing.

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I dedicate this thesis to my mom, who is beside me through all of my highs and lows.

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List of Abbreviations

30SEC – 30 second weight training group

ADP – Adenosine triphosphate

AMP – Adenosine monophosphate

ATP-PCr – Adenosine triphosphate-phosphocreatine

BP – Dumbbell bench pull

BPM – Beats per minute

C (C1 to C6) – Category system of training intensities

DL – Dumbbell deadlift

FISU – FISU World Rowing Championship Selection

HR – Heart rate

L – Liters

$L \cdot min^{-1}$ – Liters per minute

LoRep – Low-repetition weight training group

LW – Light-weight rowing class

m – Meters

min – Minutes

mL – Milliliters

$mmol \cdot L^{-1}$ – Millimoles per liter

mRNA – Messenger ribonucleic acid

NC – National competitor

O – Open-weight rowing class

PC – Provincial competitor

PCr – Phosphocreatine

PGC-1 alpha – Peroxisome proliferator-activated receptor-gamma coactivator

PPO_{RAMP} – Peak power output at VO_2max

RAMP – Incremental ramp test to exhaustion

RPE – Rate of perceived exertion

s – Seconds

SIT – Sprint interval training

SR – Stroke rate

U21 – Under 21 Canadian World Rowing Team Selection

VCO_2 – Expired carbon dioxide

V_E – Ventilation frequency

VO_2 – Oxygen uptake

VO_2max – Maximal oxygen uptake

W – Watts

$W \cdot min^{-1}$ – Watts per minute

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Chapter 1

1 Review of Literature

1.1 The 2000 m Rowing Race

The Olympic 2000 m rowing race is a full body cyclical rowing performance, requiring between 5-8 minutes to complete (28). This range of time to completion is dependent on various factors, including, among others, whether participants are male or female, the number of team members in a boat, and the rowers' classification (i.e. light-weight or open-weight) (44). Moreover, similar metabolic demands are necessary for a rower to complete the 2000 m rowing race indoors on rowing ergometers as compared to on-water (25). Consequently, indoor 2000 m rowing ergometer tests are used as an objective measure to track rowers' performance (5).

A common rowing pacing strategy for this 2000 m race, to begin, consists of a 30 – 40 s sprint (38), generating maximal power outputs (72), relying predominantly on anaerobic metabolism (63). Aerobic metabolism energy contribution increases in an exponential fashion, and at approximately 2 min takes over as the primary source of energy (58, 63). Furthermore, for the remainder of the test, oxygen uptake (VO_2) is within the vicinity of maximal oxygen consumption (VO_2max) (38). In totality, the 2000 m rowing ergometer test requires energy met by predominantly oxidative phosphorylation (~75%), although, as stated above, anaerobic glycolysis and high energy phosphates have a substantial contribution (~25%) (38). As such, factors highly correlated to 2000 m rowing ergometer performance include VO_2max (r=0.88), power output at VO_2max (PPO_{RAMP}) (r=0.95), maximal force (r=0.95) and peak power (r=0.95) (44).

1.1.1 Aerobic Factors Associated with Peak Performances

1.1.1.1 Maximal Aerobic Capacity – VO_2max

Maximal oxygen uptake (VO_2max) is defined as the greatest volume of oxygen that can be consumed during exercise (4). During exercise, oxygen is utilized as the hydrogen ion acceptor for the completion of the electron transport chain. Therefore, VO_2max reflects the maximal aerobic energy metabolism contribution to exercise. Typically, maximal incremental exercise tests (RAMP) on a cycle ergometer are utilized as a method of determining VO_2max. Specifically, the RAMP testing protocol for VO_2max identification begins with a 4 minute baseline at 20 Watts (W). Thereafter, power output increases by 25 $W \cdot min^{-1}$ for women, and 30 $W \cdot min^{-1}$ for men, until volitional fatigue (56). The peak power output from this test is recorded as PPO_{RAMP}. Following reaching volitional fatigue, participants then cycle at power output of 20 W for 4 min. VO_2max is then verified by a single step all-out ride to exhaustion at a fractionally higher work rate (61). VO_2max is recorded when no further increase in oxygen uptake occurs (4). The physiological parameters related to VO_2max are oxygen transport (stroke volume, heart rate, blood volume, and hemoglobin content), and oxygen utilization (capillarization, myoglobin concentration, and oxidative enzyme concentration and activity) (8, 69, 80).

1.1.1.2 Peak Power Output at Maximal Aerobic Capacity – PPO_{RAMP}

Peak power output at maximal aerobic capacity (PPO_{RAMP}) is the maximal power output achieved during the VO_2max incremental test, recorded at the point of volitional fatigue. Moreover, factors related to PPO_{RAMP} are VO_2max, exercise economy, muscle power, neuromuscular recruitment at high contraction frequencies, and anaerobic capacity (9, 12, 45, 66). The differentiating factor for success in performance of well-trained endurance athletes is the ability to generate power following a prolonged period of high intensity exercise, which may be reflected through PPO_{RAMP} (9, 59).

1.1.2 Anaerobic Factors Associated with Peak Performance

1.1.2.1 Anaerobic Capacity

Anaerobic capacity is the ability to generate adenosine triphosphate (ATP) without oxygen. This finite anaerobic energy source is derived from the breakdown of phosphocreatine (PCr) and glycogen. Consequently, factors related to anaerobic capacity are glycogen and PCr storage, as well as the activity and concentrations of their associative enzymes (58). As exercise intensity increases above the anaerobic-aerobic threshold, oxygen demand eventually exceeds aerobic energy contribution. At this point, a greater reliance on glycogen occurs for ATP production. Furthermore, lactate is a byproduct of glycogen metabolism, and therefore, blood lactate levels increase following this higher intensity exercise. In response to training interventions, a decrease in blood lactate at a given VO_2 has been demonstrated for well-trained endurance athletes (3). This anaerobic adaptation increases the athletes' tolerance to exercise (58).

1.1.2.2 Maximal Force

Maximal force is the muscle's capacity to develop force. This is accomplished by recruiting the maximal amount of motor units in a single contraction (47). Additionally, factors related to maximal force are muscle cross-sectional area (46), and the nervous system's ability to activate motor neurons (47, 67). Typically, for well-trained endurance athletes, maximal force is measured by 1 repetition maximal (RM) weight lifting tests (2, 77, 78) or maximal voluntary contractions (1, 66). During a rowing race, maximal forces are generated within the initial few strokes, as the rower overcomes inertia to propel their boats out of the starting gates (72).

1.1.2.3 Peak Power

Peak power is the maximal rate of force development, whereby the greatest amount of force is generated by the muscle contracting in the shortest amount of time (48). As such, peak power is calculated as force divided by time (26). Other factors related to peak power are neuromuscular firing rates of motor units (2, 9), anaerobic capacity (9), and muscle fiber type ratio (60, 67). Specifically, increased Type IIa muscle fibers with a decrease in Type IIx fibers (46, 48) has been demonstrated to be correlated with increased aerobic performance in well-trained endurance athletes (2, 78). During a 2000 m rowing race, peak power outputs occur during the initial starting sprint (72).

1.2 Rower's Training Program

Due to the range of the aforementioned energy system demands of rowing performance, rowers implement endurance training concurrently with strength training, specifically, in the form of low-repetition weight training (3-5 sets of 3-6 repetitions) (34, 51). Moreover, although concurrent training research has indicated diminished strength training adaptations compared to strength training alone (9, 40), performing endurance training in addition with strength training has demonstrated to increase aerobic performance (27, 40, 65).

1.2.1 Low-Repetition Weight Training

Low-repetition weight training (3-5 sets of 3-6 repetitions) is the most commonly implemented form of within season weight training for elite rowers (34), although, to the researcher's knowledge, no studies have examined its effects on well-trained rowers during their competitive season. This low-repetition weight training is extensively researched in well-trained endurance athletes, and has demonstrated post- intervention improvements in maximal muscle force (1, 2, 65, 66, 77, 78) and maximal muscle power (2, 65, 66, 77). These improvements are facilitated by increased motor unit firing frequency and coordination (1, 66), increased muscle cross-sectional area (2, 65, 77), and an increased ratio of Type IIa compared to Type IIx muscle fibers (1, 2, 78). Often, for well-trained endurance athletes, low-repetition weight training is performed concurrently with long duration endurance training. This concurrent training has resulted in increased rate of force development (1, 2, 66) and exercise economy (78), facilitating increased maximal muscle strength (1, 2, 65, 66, 77, 78), and peak power output during an all-out 30 s cycling test (2, 65, 78), as well as short (< 5 min) (1, 78) and long (> 40 min) performances (1, 2, 65, 78).

Although research is scarce on low-repetition weight training for rowers, Ebben et al. (27) and Gallagher et al. (33) have demonstrated that collegiate rowers increased 2000 m rowing ergometer performance by implementing low-repetition weight training with long duration endurance training, over eight weeks. However, athletes were not preconditioned prior to intervention commencement (27, 33). Therefore, the aforementioned athletes are suggested to respond to training as recreationally active participants, rather than well-trained endurance athletes which have already realized anaerobic and aerobic adaptations.

1.2.2 Endurance Training

Rowers' endurance training is typically performed on-water or on a rowing ergometer (31). A method of rowing ergometer exercise prescription is based on a category system from lowest (Cat VI) to highest exercise intensity (Cat I). The intensity, duration, and consequently, the targeted energy system of each intensity category is associated with a specific blood lactate response. The majority of a rower's training volume (~80%) is at Cat V and Cat VI, consisting of long duration, continuous aerobic exercise performed at an intensity slower than race pace, specifically, below the rower's lactate threshold (31, 58, 73).

Research has demonstrated that, as a result of interventions of similar high volume moderate intensity training, recreationally active participants improved number and size of muscle mitochondria, increased muscle myoglobin, increased capillary density, enhanced muscle oxygen extraction, and increase oxidative phosphorylation enzymes, as well as capacity to oxidize pyruvate and long chain fatty acids (9, 22, 41, 45, 70). Further adaptations consist of improved blood volume and erythrocyte mass (69, 80), as well as stimulating myocardial hypertrophy and contractility, in turn increasing stroke volume (7, 52, 79). Namely, research has demonstrated that the aforementioned adaptations of this endurance training results in a greater reliance on energy from aerobic metabolism (6, 18), thereby reducing lactate accumulation (41, 43) and increasing tolerance to exercise (57).

As such, high volume moderate intensity training interventions improve oxygen delivery and oxygen extraction to the active muscle, resulting in increased VO_2max (24). Not only do recreationally active participants demonstrate increases in VO_2max resulting from endurance training (18), but well-trained endurance athletes also experience aerobic capacity increments, although longer interventions (12 weeks) are necessary to realize these physiological adaptations (65). Albeit, physiological improvements in well-trained endurance athletes due to endurance training begin to plateau (50, 55), suggested to be due to the high aerobic capacity already attained prior to the training intervention (1, 65, 66, 78). Consequently, aerobic capacity of well-trained endurance athletes is, more often, unchanged following long duration (11-25 weeks) endurance training interventions (1, 2, 66, 77, 78).

Literature is scarce on well-trained rowers performing endurance training, and the effects on 2000 m rowing performance, although Gallagher et al. (33) demonstrated collegiate rowers performing solely high volume moderate intensity rowing increased 2000 m rowing ergometer performance. However, under further investigation, it appears that the performance enhancements of these rowers were due to the low performance levels, indicated by their pre- testing 2000 m rowing ergometer times (33), compared to typical high level rower competitive values (28). Therefore, it is suggested that the rowers of the aforementioned study were, in fact, not well-trained, and the observed performance enhancements were due to an increased capacity for training adaptations demonstrated from endurance training interventions performed by recreationally active participants (36).

1.3 30 s Sprint Interval Training

30 s sprint interval training (SIT) is defined as physical exercise with brief 30 s intermittent bursts of vigorous activity, most commonly interspersed by ~4 min periods of rest or low intensity exercise (35). Notably, 30 s SIT has been used as a method to increase both anaerobic and aerobic capacities simultaneously, in as little as 2-6 weeks for recreationally active participants (18, 36, 39, 49). Furthermore, research has demonstrated that 30 s SIT results in similar physiological adaptations as endurance

training (18, 36). Specifically, these interventions have resulted in an increased reliance on aerobic metabolism for energy production during exercise, demonstrated by a decreased respiratory exchange ratio (3, 18, 19).

Coincidentally, although a single bout relies predominantly on anaerobic energy (13, 14, 82), repeated bouts can elicit a near maximal VO_2 (~90%) response (15). The high aerobic demand of 30 s SIT has been demonstrated to increase VO_2max (3, 6, 18, 39, 49) and PPO_{RAMP} (6, 49) for recreationally active individuals following training interventions. The underlying mechanism of this aerobic capacity increase is proposed to be due to increased skeletal muscle mitochondrial content, indicated by oxidative enzyme activity, which has been cited by numerous 30 s SIT studies (18, 19, 36). Furthermore, Bailey et al. (6) demonstrated that 30 s SIT resulted in enhanced VO_2 kinetics, reducing the oxygen deficit occurred at the onset of moderate and severe intensity exercise, allowing for preservation of the finite anaerobic capacity to be utilized in the latter stages of exercise.

The underlying mechanism of said enhancements is suggested to be due to the regular and repeated stimulus increasing mRNA expression of a key regulator of mitochondrial biogenesis, peroxisome proliferator-activated receptor-gamma coactivator (PGC-1 alpha) (57). Furthermore, greater mRNA expression of PGC-1 alpha has been associated with the increased accumulation of high-intensity exercise byproducts, such as lactate, creatine, AMP, and ADP (57). Notably, these aforementioned accumulations have been observed following 30 s SIT bouts for recreationally active participants (13, 14, 82) and well-trained endurance athletes (20, 21, 81). To no surprise, increased PGC-1 alpha activity has been observed following both 30 s bouts for recreationally active participants (23, 37, 76) and well-trained endurance athletes (62). Even more, recreationally active participants have demonstrated increased PGC-1 alpha concentrations following training interventions (18, 62).

Moreover, research has concluded that increased PGC-1 alpha activity has been observed in conjunction with the increased transcriptional level expression of genes associated with enhanced lactate degradation (11, 75). Therefore, the regular and repeated increased PGC-1 alpha activity is suggested to facilitate enhanced muscle lactate buffering capacity demonstrated following 30 s SIT for recreationally active participants (18, 37, 75). Additionally, as accumulated muscle lactate diminishes the ability to perform glycolysis (57), increased muscle lactate buffering attenuates the drop in pH during exercise, allowing for higher power outputs and increased time to fatigue (29, 53). This increased skeletal muscle lactate buffering entails an increased capacity for anaerobic energy metabolism. Evidently, 30 s SIT interventions have demonstrated an increase in anaerobic (< 2 min) (3, 18, 36, 39, 49) and aerobic (> 9 min) (17, 36, 39, 54) performance measures. To the researcher's knowledge, however, no studies have examined the chronic effect on PGC-1 alpha concentration, and performance changes following interventions of 30 s SIT of well-trained endurance athletes.

Further research has additionally observed post- 30 s SIT anaerobic capacity adaptations to the ATP-PCr system, such as enhanced PCr kinetics (30, 49). This greater PCr kinetics would, in turn, accelerate the rate of ATP turnover for short bouts of exercise. Consequently, following 30 s SIT interventions, increased 30 s bout peak power output (18, 19, 30) and mean power output (18, 30, 49) have been observed, which may be due, in part, to the demonstrated enhanced PCr kinetics. Notably, as previously mentioned, the 2000 m rowing ergometer race typically starts with a 30-40 s sprint (38). Therefore, a combination of the aforementioned anaerobic capacity adaptations of increased peak power output, mean power output, and muscle lactate buffering would, in theory, increase the initial distance travelled at race onset, as well as reducing the anaerobic byproducts detrimental to exercise performance. This anaerobic capacity increase, therefore, would give the rower a competitive advantage.

Furthermore, although 30 s SIT is commonly implemented with maximal effort contraction frequencies at ~120 per minute (19, 36, 62, 76), Belfry et al. (10) implemented a six week, maximal effort 30 s weight training program with contraction frequencies of ~40 per minute, replicating the velocity and exercises associated with freestyle swimming. The recreationally active swimmers of the aforementioned study increased predominantly anaerobic (50 m) and aerobic (200 m) swimming performances (10). Similar to previous 30 s SIT, the performance increase demonstrated by Belfry et al. (10) was facilitated by enhanced aerobic enzyme activity, as well as a muscle fiber type transition to Type IIa, indicating an improved swimming economy. This improved exercise economy based on the repetition velocity specificity has been previously reported (68, 71).

Regardless, a common theme in 30 s SIT is the all-out maximal effort prescribed exercise bouts. Therefore, agreeing with previous literature reviewing the stimulus associated with 30 s SIT adaptations (53), it appears that increasing anaerobic capacity, aerobic capacity, and performance following training is influenced by the maximal effort bouts.

To the researcher's knowledge, no studies have examined the effect of 30 s SIT interventions on performance of well-trained endurance athletes. Albeit, training utilizing sprint-to-rest ratios divergent to 30 s SIT have demonstrated that well-trained endurance athletes increased aerobic performance occurs not due to aerobic capacity adaptations (50, 74). Instead, research supports these performance increments are facilitated by increased anaerobic capacity (16, 42, 50, 74). Regardless of how physiological adaptations occur, a major goal of strength and conditioning coaches for well-trained endurance athletes is to enhance performance. Although interval training has demonstrated to be a viable method to increase well-trained endurance athletes' performance, there are various methods of implementation. Consequently, literature is undecided on the optimal prescription to increase well-trained endurance athlete's performance (45).

1.4 Rowing Ergometer Testing

Rowing Canada Aviron uses rowing ergometer tests, known as RADAR testing, performed on the Concept2 rowing ergometer (Concept2, Morrisville, VT, USA) (72). These RADAR tests are performed in specification to Rowing Canada Aviron requirements, and are submitted twice per year to assess rowers' performance (72). A portion of RADAR testing consists of the 2000 m rowing ergometer test, a race where performance is used to assess aerobic capacity and as selection criteria for national team selection (31). Testing is also comprised of the 1 Minute Test, a 60 s all-out effort used as an indication of rowers' anaerobic capacity (74) resulting from the predominantly anaerobic energy requirements of performing said test (63).

1.5 Cycle Ergometer Testing

Typically, RAMP testing to determine VO_2max is performed on an electromagnetically braked cycle ergometer (Velotron Pro, Seattle, WA, USA), while simultaneously sampling for fluctuations in gas concentration of each breath. Furthermore, the cycle ergometer is an effective mode of testing as to not interrupt the sensitivity of the bidirectional flow-rate turbine used to monitor inspired and expired gases. This turbine, measured at the mouth, samples continuously using mass spectrometry (Innovision, AMIS 2000, Lindvedvej, Denmark), analyzing for concentrations of oxygen, carbon dioxide, and dinitrogen.

1.6 Study Rationale

Although research concludes that low-repetition weight training is the most common during season implemented strength training regime (34), no studies have assessed its effects on 2000 m rowing ergometer performance of well-trained rowers, within their competitive season. Regardless, increased strength associated with hypertrophy resulting from low-repetition weight training of well-trained endurance athletes requires long interventions (~12 weeks) (66, 77). For well-trained cyclists, muscle hypertrophy has been observed coinciding with increased aerobic performance (> 9 min) following 11 weeks low-repetition weight training (77). In rowing, muscle hypertrophy would increase power output per stroke, thereby increasing 2000 m rowing ergometer performance. Nonetheless, the high volume of endurance training performed by rowers during their competitive season would diminish increments in strength (40), and therefore 2000 m rowing ergometer performance enhancements associated with training regime may not be maximally optimized.

Instead, 30 s SIT has demonstrated increased both anaerobic and aerobic capacities simultaneously for recreationally active participants in a short period of 2-6 weeks (18, 36, 39, 49). Furthermore, an adapted 30 s weight training method resulted in similar 30 s SIT physiological adaptations (10), resulting in increased short and long distance performance. It is suggested here, due to previous 30 s SIT intervention anaerobic (< 2 min) (3, 18, 36, 39, 49) and aerobic (> 9 min) (17, 36, 39, 54) performance enhancements, that supplementing low-repetition weight training with a 30 s weight training regime would result in an increased anaerobic and aerobic capacity. As a result, this training would, consequently, enhance 1 Minute Test and 2000 m rowing ergometer performance. To the researcher's knowledge, the 30 s SIT physiological and performance adaptations have only been observed in recreationally active subjects. Research performed on well-trained endurance athletes is difficult, presumably due to the reluctance of competitive athletes to tamper with their scheduled training programs.

Therefore, the main purpose of this study was to examine the anaerobic, aerobic, and rowing performance effects resulting from a 30 s weight training program and a traditional rowing low-repetition weight training program performed by well-trained female rowers competing at the provincial to national level. Results of this study will determine if 30 s weight training is a superior short-term alternative method to low-repetition weight training for competitive rowers preparing for performance evaluation and rowing ergometer competitions.

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Chapter 2

2 A four week 30 s weight training intervention improves 2000 m rowing ergometer performance of provincial and national collegiate female rowers

2.1 Introduction

Two thousand meter rowing ergometer performances have been shown to be correlated with measures of maximal stroke force (r=0.95), maximal stroke power (r=0.95), maximal aerobic capacity (VO_2max) (r=0.88), and peak power output at VO_2max (PPO_{RAMP}) (r=0.95) (27). Accordingly, increased aerobic capacity has been observed concurrent with improved 2000 m rowing ergometer performance (17). It is important to note, however, that increased 2000 m rowing ergometer performance on well-trained male rowers has been supported via improvements in only anaerobic capacity (44).

Coinciding with the predominantly aerobic energy demands of the 2000 m rowing ergometer race (~80%) (25, 35, 37), the majority of a rowers' training regime consists of long duration aerobic work performed at power outputs below the rowers' lactate threshold (42). Strength training, however, is also incorporated as a part of most rowers' in season training. This training typically consists of low-repetition weight training (3 – 5 sets of 3 – 6 repetitions) performed two to three times per week (22). Whereas, to our knowledge, out of competitive season training studies are common, the effects of weight training performed within a rowers' competitive season have not been examined. For example, out of competitive season studies incorporating eight weeks of low-repetition weight training, concurrent with long duration training of collegiate rowers, has resulted in improved 2000 m rowing ergometer performances (17, 21). The fitness levels of these rowers would have been at their lowest as this study took place during their offseason. Accordingly, it has been shown that these detrained individuals exhibited expedited improvements in VO_2max and performance (17, 21).

It has also been suggested that the predominant adaptation for these improved performances would have been associated with early time course neural modifications accompanying the low-repetition weight training (34, 41, 43), as opposed to increases in muscular strength via muscle fiber hypertrophy (32, 34). Previous literature has suggested that for well-trained endurance athletes to demonstrate increased strength and power associated with muscle fiber hypertrophy (3, 49), longer weight training programs (~11 weeks) are required.

Other training methods have elicited physiological adaptations divergent to low-repetition weight training interventions, although resulting in similarly increased performance. For example, expeditious improvements of both anaerobic and aerobic capacity following 2-6 weeks of 30 s sprint interval training (SIT) interventions have been observed (13, 14, 23). A number of these 30 s training session protocols have typically utilized six sessions of four to six 30 s all-out cycle ergometer bouts interspersed with ~ 4 min of rest (4, 14, 23). Increased lactate buffering capacity (23), muscle oxidative enzyme activity (14, 23), and VO_2max (4, 26, 28) in recreationally active individuals have been observed post- 30 s SIT programs. Moreover, these adaptations have been suggested to underpin enhanced performances of < 2 min and > 40 min pre- to post- SIT training (23).

Increases of VO_2max (4, 26, 28) and oxidative enzyme activity (13, 14, 23) have also been linked to the near maximal VO_2 reached during each of these 30 s SIT bouts (12, 15). Typically, these bouts have utilised repeated bouts of maximal effort, high contraction frequency (~120 per minute) cycle ergometer bouts (23, 36, 47). Belfry et al. (6), however, have shown enhanced aerobic enzyme activity and anaerobic capacity as well as improved anaerobic and aerobic performances pursuant to a maximal effort 30 s weight training regime utilizing much slower contraction frequencies (~40 per minute) in recreationally active swimmers. This demonstrates that high contraction frequency 30 s bouts are not a prerequisite for these physiological and performance adaptations. To our knowledge, the effects of this 30 s SIT has not been studied in well-trained rowers.

As such, the novel purpose of this study was to compare 2000 m rowing ergometer performances, and anaerobic and aerobic capacity, of provincial and national female collegiate rowers before and after a four week, 30 s rowing specific weight training program to a low-repetition weight training program. This training intervention was performed after a seven week, early season, predominantly aerobic training phase. It was hypothesized that this 30 s weight training program would improve 1 Minute Test and 2000 m rowing ergometer performance, maximal oxygen consumption, and peak aerobic power output, whereas the low-repetition weight training program would not. These rowers were under the guidance of an international level rowing coach, in preparation for performance evaluation that is used for training control and Canadian national (Rowing Canada Aviron) ranking for carding and camp invitational purposes.

2.2 Methods

2.2.1 Experimental Approach to the Problem

Following a four week offseason period, the rowers began their new season with seven weeks of 7-11 hours per week of predominantly aerobic rowing ergometer training and two – two hour sessions per week of a whole body low-repetition weight training program (4-5 sets of 2-6 repetitions of various rowing specific weight training exercises). After the seven weeks participants were paired based on 2000 m rowing ergometer times and randomly assigned to either the 30 s weight training group or continued the rowing program prescribed low-repetition weight training regime. The 30 s weight training group (30SEC) performed five sets of a maximum 18 repetitions. When 18 repetitions could be completed in 30 s, the mass lifted was increased by 2.27 kg. The exercises consisted of the dumbbell deadlift (DL) and dumbbell bench pull (BP) both are specific to the rowing movement (29). The coach prescribed low-repetition weight training group (LoRep) performed 4-5 sets of 2-6 repetitions of various rowing specific weight training exercises two days per week. Both groups performed an identical high volume of aerobic rowing ergometer training during the study intervention.

Participants completed pre- and post- training anaerobic and aerobic performance tests, as a component of Canadian national ranking. These tests included 1 Minute and 2000 m rowing ergometer performances, as well as a ramp incremental exercise (RAMP) test on a cycle ergometer.

Ten provincial and national female collegiate rowers (mean age = 18.6 ± 0.8 y) volunteered and were informed of the benefits and risks of this investigation and gave written informed consent to participate in this study. It was a challenge for the rowers to "risk" changing the weight training program. This resulted in the small sample size of each group. The participants were healthy, non-smokers and presented no musculoskeletal or cardiopulmonary issues (1). All procedures were approved by The University of Western Research Ethics Board for Health Sciences Research Involving Human Participants and conformed to the declaration of Helsinki.

2.2.2 VO_2max Test

Pre- and post- VO_2max tests were performed on the week prior to and the week following the four week intervention, respectively. On the day of the scheduled tests, participants were asked to avoid consumption of a large meal within two hours of their testing appointment and to abstain from exercise or coffee consumption on the day of the test. All participants performed a ramp incremental cycle ergometer test (4 minute baseline at 20 W followed by an increase at a rate of 25 $W \cdot min^{-1}$) to volitional fatigue, on a Velotron electronic cycle ergometer (Velotron Pro, Seattle, WA, USA). Subjects were asked to maintain a cadence of 70 revolutions per minute throughout the test, and the test was terminated when the participant could no longer maintain this pedal frequency. Following RAMP termination, participants cycled at a 4 min baseline stage at 20 W before a single step to exhaustion at 101% of the maximal work rate from the preceding ramp to verify VO_2max (38). Similarly, participants were told to maintain a cadence of 70 revolutions per minute. The test was terminated when this cadence could no longer be maintained. VO_2max was defined as the highest 15 s of VO_2 during the RAMP ($L \cdot min^{-1}$) and the verification ride. The peak power output reached during RAMP was defined as peak aerobic power output (PPO_{RAMP}). Ventilatory threshold was estimated by visual inspection using standard gas-exchange and ventilatory parameters, previously described as a non-invasive method for determination of ventilatory threshold as an estimation of lactate threshold (5, 16, 48). Briefly, ventilatory threshold was determined to be the VO_2 ($L \cdot min^{-1}$) at which 5 s averaged plots for both expired carbon dioxide (VCO_2) and ventilation (V_E) began to increase out of proportion of VO_2. This point was confirmed with the observation of the increase of end-tidal oxygen, while V_E/VCO_2 and end-tidal carbon dioxide were unchanged. Plots were analyzed and evaluated between two independent investigators, and the mean of the two determinations was utilized.

2.2.3 Oxygen Uptake Measurements

O_2 uptake measurements were recorded by breath-by-breath gas-exchange analysis. Participants wore a nose clip and breathed through a suspended mouthpiece. Volumes of inspired and expired air and flow rates were measured using a low dead space bidirectional turbine (Alpha Technologies, VMM 110) and pneumotach (Hans Rudolph, Model 4813) secured to the mouthpiece. The total apparatus dead space was 150 mL. Expired air was sampled continuously at the mouth and analyzed by mass spectrometry (Innovision, AMIS 2000, Lindvedvej, Denmark) for fractional concentrations of oxygen and carbon dioxide. The volume turbine was calibrated before each test using a 3 L syringe at multiple flow rates. Gas concentrations were calibrated with gases of known concentration. The time delay between an instantaneous, square-wave change in fractional gas concentration at the sampling inlet was measured electronically using the computer. Respiratory volumes, flow rates and gas concentrations were recorded in real time and were used to digitally build and display a profile of each breath. The algorithms of Swanson were used to calculate alveolar gas-exchange breath by breath (46).

2.2.4 Preconditioning Rowing Ergometer Training

The intensity and durations of the seven weeks of pre-study rowing ergometer conditioning was classified into various categories of training intensity (Table 2), and was identical for participants in both 30SEC and LoRep (Table 2 and 3). The study intervention took place after this seven week period.

2.2.5 1 Minute Test and 2000 m Rowing Ergometer Test

Participants completed 1 Minute and 2000 m rowing ergometer tests on a Concept2 Model D rowing ergometer (Concept2, Morisville, VT, USA). Pre- and post- testing was performed as preliminary round of national sport governing body performance assessment, in early February and early April prior to, and following, the four week intervention, respectively. These tests were scheduled by coaches, and performed within a competitive team environment to promote best performances. Both the 1 Minute and 2000 m rowing ergometer tests were completed using a 110 Drag Factor on the Concept2 Rowing Ergometer. Participants were also instructed to perform their standard pre-race warm up before each test. The tests began with the rowers in the "ready position" (forward on the seat, arms stretched, legs and hips flexed), given the command "ROW". Participants were instructed to go all-out throughout the 1 Minute Test. Total distance travelled (m) was recorded from the 1 Minute Test. The 2000 m rowing ergometer test was completed at each participant's individual pacing strategies to facilitate peak performances. Time to completion (s) was recorded from the 2000 m rowing ergometer test.

2.2.6 30 s Weight Training Program (30SEC)

Each 30SEC training session began with a self-regulated dynamic whole body stretching and 5-10 minutes of light intensity exercise on a cycle ergometer. The researcher recorded, rate of perceived exertion (RPE), mass lifted, number of repetitions performed in each set, and ensured that proper technique was performed. The 30SEC group performed a DL warm up set consisting of ten repetitions using 50-75% of the weight used for the prescribed sets. Participants then performed five sets of DL to a maximum of 18 repetitions within a timed 30 s period, followed by three and a half min of recovery. This repetition target was somewhat slower than race stroke rate, but was deemed to be a cadence that would reduce the possibility of injury by the rowing coaches. Participants increased the dumbbell mass lifted by 2.27 kg on achievement of the 18 repetitions with a constant cadence. If participants reported a RPE of less than 8/10 (very hard) immediately post- set the mass lifted was also increased by 2.27 kg (11). Participants then repeated the above weight training procedure for BP on an incline bench. The first two strength training sessions were used to determine appropriate starting weight for each exercise. The last two weight training sessions were performed at a reduced intensity (RPE of 6/10; hard) to attenuate muscle soreness and/or fatigue due to the weight training intervention in anticipation of the post- testing protocols (11). A researcher certified in personal training with Canadian Society of Exercise Physiology was present at all sessions. Encouragement was given throughout the training session to make sure effort was appropriate. The training sessions were performed in the university's athletics training facility on Tuesdays, Thursdays and Saturdays.

2.2.7 Low-Repetition Weight Training Program (LoRep)

After a self-regulated dynamic whole body stretching warm up and 5-10 min of light intensity exercise on a cycle ergometer, participants completed 4-5 sets of 2-6 repetitions of various rowing specific weight training exercises twice a week. The complete LoRep weight training regime over the duration of the study is shown in Table 1. Training was monitored by a strength and conditioning professional to ensure appropriate efforts and techniques were performed. The load of each exercise was designed to fatigue the participants within the desired repetition range.

2.2.8 Concurrent Rowing Ergometer Training

A categorical scale was used to determine the intensity of the rowing ergometer training sessions relative to each participant's 2000 m race pace (Table 2) (20) concurrent with the weight training.

2.2.9 Blood Lactates

Blood lactate was measured 5 min before and between 15-30 s after the RAMP protocol. Rubbing alcohol was used to sterilize the left index finger and then a blood sample was collected using the ACCU-CHEK Safe-T-Pro Plus sterile single-use lancing device. The researcher wore a latex glove during this procedure. The blood lactate was measured using a Lactate SCOUT blood lactate analyzer (SensLab GmbH, Leipzig, Germany).

2.2.10 Exemplar 30SEC Session VO_2

One participant performed a session of the 30 s weight training protocol in the laboratory for gas-exchange and blood lactate analysis to determine oxygen consumption and blood lactate accumulation during exercise. Blood lactate was collected 5 min before exercise commencement, and 15-30 s post- sets 1 and 5 for both DL and BP.

2.2.11 Calculations

Aerobic and anaerobic energy system contributions were calculated by first calculating mean power output during the 30 s bout (PO_{30}) using the Equation 1:

2.2.11.1 Equation 1

PO_{30} (W) = distance mass lifted per repetition (m) x mass lifted (kg) x repetitions performed (reps x min^{-1}) ÷ conversion factor (6.12)

The power output corresponding to aerobic contribution (PO_{AC}) was then determined by calculating the difference of the PO_{30} over the PO associated with resting VO_2 values, using Equation 2:

2.2.11.2 Equation 2

PO_{AC} (W) = PO_{30} (W) – [resting VO_2 ($L \cdot min^{-1}$) x 100 ($W \cdot min \cdot L^{-1}$)]

The power output corresponding to anaerobic contribution (PO_{AnC}) accounted for the remainder of the exercise, calculated by Equation 3:

2.2.11.3 Equation 3

$$PO_{AnC}\,(W) = PO_{30}\,(W) - PO_{AC}\,(W)$$

2.2.12 Statistical Analyses

All statistical analyses were calculated using SigmaPlot 12.3 (Systat Software Inc., San Jose, CA, USA). Statistical significance was accepted at an alpha level of $p<0.05$. Pre- to post- differences within groups were calculated using paired-t tests. Two Way Repeated Measure ANOVA's (2Way RM ANOVA) were used compare blood lactate concentrations within and between groups, pre- and post- training. Cohen's d was used to determine effect sizes of pre- and post- training.

2.3 Results

Over the duration of the study, volume, intensity, and frequency of rowing ergometer training was identical between both the 30SEC and LoRep groups (Table 1). All participants in the 30SEC group completed 12 weight training sessions throughout the four week intervention. The DL mean mass moved per set increased by 104% from the first to last session of the weight training intervention ($p<0.05$), and BP mean mass moved per set increased by 63% from the first to last session of the weight training intervention ($p<0.05$) (Figure 1). All participants in the LoRep group completed eight weight training sessions over the four week training period.

Distance travelled during the 1 Minute Test improved for the 30SEC group pre- to post-training reflecting a medium effect ($p=0.014$; Cohen's d effect size = 0.53), whereas no difference was observed in the LoRep group ($p=0.385$; Cohen's d effect size = 0.214) (Figure 2 and Table 4). Pre- to post-training 2000 m rowing ergometer times improved for the 30SEC group and reflected a large effect size($p<0.001$; Cohen's d effect size = 0.93), the LoRep group improved however the change was not significant and the effect size was small ($p=0.062$; Cohen's d effect size = 0.372) (Figure 2 and Table 4).

VO_2max and PPO_{RAMP} did not change for either 30SEC ($p \geq 0.05$) or LoRep ($p \geq 0.05$) (Table 4). Verification times did not change for the 30SEC (Pre = 93.2 ± 23.2 s; Post = 91.5 ± 15.8 s) ($p \geq 0.05$) nor the LoRep group (Pre = 111.2 ± 9.8 s; Post = 109.3 ± 10.5 s) ($p \geq 0.05$). Pre- to post- ventilatory threshold was unchanged for both the 30SEC (Pre = 1.62 ± 0.21 $L \cdot min^{-1}$; Post = 1.52 ± 0.21 $L \cdot min^{-1}$) ($p \geq 0.05$) and LoRep groups (Pre = 1.63 ± 0.28 $L \cdot min^{-1}$; Post = 1.76 ± 0.25 $L \cdot min^{-1}$) ($p \geq 0.05$). Baseline blood lactates values were lower than Post-Ramp for both 30SEC ($p < 0.05$) and LoRep ($p < 0.05$). Pre- to post-baseline and Post-RAMP blood lactates were not different for either the 30SEC group ($p \geq 0.05$) or the LoRep group ($p \geq 0.05$) (Table 5).

Mean peak VO_2 of the exemplar subject during DL and BP reached 1.70 $L \cdot min^{-1}$, corresponding to 56% of their VO_2max, and a VO_2 of 0.84 $L \cdot min^{-1}$ corresponding to 27% of VO_2max respectively (Figure 3). Peak blood lactate concentration increased for both DL and BP from pre- to post-set 1 (DL; baseline = 2.1 $mmol \cdot L^{-1}$; post- set 1 = 4.3 $mmol \cdot L^{-1}$ and post- set 5 = 8.6 $mmol \cdot L^{-1}$ and BP; post- set 1 = 7.1 $mmol \cdot L^{-1}$; post- set 5 = 7.7 $mmol \cdot L^{-1}$). The average calculated power output during a 30 s bout of DL was 321 W (anaerobic contribution = 77%; aerobic contribution = 23%), whereas BP average power output was 254 W (anaerobic contribution = 87%; aerobic contribution = 13%).

Table 1. Low-Repetition Weight Training Program.

Session A (Tuesday)						
Exercise	Wk 1	Wk 2	Wk 3	Wk 4	Tempo**	Rest***
A. Wide Grip Deadlift	4 x 2-4	5 x 2-4	6 x 2-4	3 x 2-4	2-0-1-0	120 s
B1. Dumbbell Step-Up	4 x 4-6/side	5 x 4-6/side	5 x 4-6/side	4 x 4-6/side	2-0-1-0	60 s
B2. Leg Curl	4 x 4-6	5 x 4-6	5 x 4-6/side	4 x 4-6	5-0-1-0	60 s
C1. Barbell Upright Row	4 x 4-6	6 x 4-6	6 x 4-6	4 x 4-6	4-0-1-0	60 s
C2. Pull Up	4 x 4-6	5 x 4-6	5 x 4-6/side	4 x 4-6	4-0-1-0	60 s
D1. Ab Rollout	3 x 15	3 x 15	3 x 15	3 x 15	2-0-2-0	0 s
D2. Froggers	3 x 30 s	3 x 30 s	3 x 30 s	3 x 30 s	1-0-1-0	60 s
Session B (Thursday)						
A. Squat	4 x 2-4	5 x 2-4	6 x 2-4	3 x 2-4	3-0-1-0	180 s
B. Leg Press	4 x 4-6	5 x 4-6	5 x 4-6	4 x 4-6	4-0-1-0	90 s
C1. Incline Bench Press	4 x 4-6	5 x 4-6	5 x 4-6	4 x 4-6	4-0-1-0	60 s
C2. Reverse EZ Bar Curl	4 x 4-6	5 x 4-6	5 x 4-6	4 x 4-6	4-0-1-0	60 s
D. Ab Wheel Pike	3 x 15	3 x 15	3 x 15	3 x 15	2-0-2-0	30 s

Weight training prescription for the LoRep group. Exercises are prescribed for the given week as number of sets by number of repetitions per exercise (i.e. “4 x 2-4” denotes four sets of two to four repetitions). **Tempo = of each exercise is described per second in each contraction phase per repetitions (i.e. “2-0-1-0” denotes two seconds in the eccentric phase, zero seconds in the isometric phase, one second in the concentric phase, and zero seconds in the isometric phase of muscle contraction). ***Rest = number of seconds between succession of one set to the commencement of the next set. Exercises that are preceded by the same letter indicate that the exercises are to be done in succession before the prescribed rest time. Ab Rollout = grip handles on ab wheel, knees on the floor, start in upright position, extend arms in front of body the body, lower body to the floor until arms are fully extended, press back to start position; Froggers = with hands and feet on floor, torso and legs straight and elevated in a prone plank position, hop feet simultaneously to the outside of one hand, hop back, then repeat hopping to opposite hand; Ab Wheel Pike = using the ab wheel, begin with hands on the floor and feet on ab wheel handles in a prone plank position, pull the ab wheel up towards hands, while maintaining extension in legs and arms.

Table 2. Category system of training intensity used in common rowing training programs (33).

Category of Training Intensity	Definition of Training	Approximate Heart Rate (bpm)	Duration of One Bout (min)	Practical Examples with Stroke Rates (SR)	Ergometer Splits (estimated based on 2000 m test)	Blood Lactate Level ($mmol \cdot L^{-1}$)
1	Anaerobic Capacity	Maximum HR (i.e. 180-200)	0.5-1.5	-1-6 x 500 m (with start): series of 30-60 strokes or 1-2 min SR: > 2000 m SR	Maximum Speed	>10
2	Race Endurance	Maximum HR (i.e. 180-200)	2-7	-Race over 1500-2000 m -6 x 2 min -3 x 1000 m SR: 2000 m SR	Average Split per 500 m for 2000 m	8-14
3	Develop Aerobic Capacity	Maximum HR (i.e. 180-200)	6-10	-4 x 7 min -3 x 2000 m constant speed -5 x 5 min SR: 2-4 < 2000 m	Average Split per 500 m + 5 s	5-8
4	Anaerobic Threshold	165-175	10-45	-2 x 20 min with SR change -3 x 5000 m Time Controlled -3 x 12 min SR: 3-6 < 2000 m	Average Split per 500 m + 10 s	~4
5	Utilization of Aerobic Capacity	150-165	30-90	-30-90 min steady state SR: 10-12 < 2000 m	Average Split per 500 m + 15 s	~3
6	Basic Endurance	135-150	> 45	-45-120 min steady state at low intensity SR 12-18 < 2000 m	Average Split per 500 m + 20 s	< 2

HR: Heart Rate; bpm: beats per minute; min: minutes; SR: stroke rate; 2000 m: 2000 m rowing ergometer test; $mmol \cdot L^{-1}$; millimoles per liter of blood.

Table 3. Rowing ergometer training program during the early season conditioning period and the 4 week intervention period.

		Category of Training Intensity						
		C1 (min)	**C2 (min)**	**C3 (min)**	**C4 (min)**	**C5 (min)**	**C6 (min)**	**Total Time (min)**
Week	**P1**		60		60	120	180	420
	P2	60		60	120	120	180	540
	P3	60		60	120	120	240	600
	P4	120	60		60		180	420
	P5		120		120	60	240	540
	P6			60	180	60	300	600
	P7	60			120	120	360	600
	Wk 1		120		120	60	240	540
	Wk 2	60	120		120	60	300	660
	Wk 3	60	60		120	60	420	720
	Wk 4	120	60		120		240	540

Total minutes of rowing ergometer training per week during the preconditioning and four week study intervention periods. Preconditioning weeks 1-7 (P1-P7); Intervention period weeks 1-4 (Wk 1-Wk 4); Training category of intensity time performed in min (C1-C6 (min)).

Table 4. Pre- to Post- Results from Participants' 1 Minute Test, 2000 m rowing ergometer time, VO_2max value, Peak RAMP Power.

Group	Category	Level of Rowing	Pre- 2000 m Times (min:s)	Post- 2000 m Times (min:s)	Pre- 1 Minute Test (m)	Post- 1 Minute Test (m)	Pre- VO_2max ($L \cdot min^{-1}$)	Post- VO_2max ($L \cdot min^{-1}$)	Pre- PPO (W)	Post- PPO (W)
30SEC	LW	PC	8:02.4	7:47.1	286	295	2.93	2.88	295	293
	O**	PC	7:45.1	7:32.0	310	314	3.13	3.20	297	305
	O	NC	7:28.0	7:19.6	330	334	3.18	3.20	331	320
	LW	U21	7:42.4	7:32.2	284	298	3.29	3.02	316	314
	O	PC	7:55.4	7:45.4	297	310	2.63	2.68	260	266
	Group Mean (±SD)		**7:46.7 (±13.2)**	**7:35.5* (±11.3)**	**301 (±19)**	**310* (±15)**	**3.03 (±0.26)**	**2.96 (±0.19)**	**300 (±27)**	**300 (±21)**
LoRep	O	PC	7:59.7	7:42.5	287	299	2.69	2.97	292	311
	O	NC (FISU)	7:08.0	7:00.6	320	313	4.07	3.87	340	345
	LW	PC	8:04.8	8:00.4	284	284	2.77	2.43	259	261
	O	PC	7:48.6	7:33.9	305	317	2.96	2.70	301	291
	O	NC	7:26.6	7:27.7	303	304	2.64	2.98	305	298
	Group Mean (±SD)		**7:41.5 (±23.8)**	**7:33.0 (±21.9)**	**300 (±15)**	**303 (±13)**	**3.02 (±0.60)**	**2.99 (±0.54)**	**299 (±29)**	**301 (±31)**

30SEC: 30 s weight training group; LoRep: Low-repetition weight training group; 2000 m: 2000 m rowing ergometer test time to completion; min:s: minutes:seconds; 1 Minute Test: distance travelled during 1 Minute Test; m: meters; VO_2max: maximal aerobic capacity; $L \cdot min^{-1}$**:** Liters of oxygen per minute; PPO: peak power output during incremental exercise test; W: Watts; O: Open-weight class; LW: Light-weight class: 59.0 kg; PC: participant competed at the provincial championships; NC: participant competed at the national championships; U21: U21 Canadian World Rowing Selection; FISU: FISU World Rowing Championship Selection; *: statistically significant change pre- to post- training; **: denotes in-lab exemplar participant.

Table 5. Mean Pre- and Post- Training Baseline and Post-RAMP Blood Lactate Concentrations.

	30SEC		LoRep	
	Pre- Training	**Post- Training**	**Pre- Training**	**Post- Training**
Baseline (mmol·L^{-1}) (±SD)	2.0 (±0.66)	2.2 (±0.69)	2.0 (±0.42)	1.8 (±0.69)
Post-RAMP (mmol·L^{-1}) (±SD)	13.3* (±3.0)	13.0* (±4.1)	11.1* (±2.95)	10.4* (±2.02)

Mean blood lactate concentrations recorded pre- and post- training at Baseline and Post-RAMP. 30SEC: 30 s weight training group; LoRep: Low-repetition weight training group; Baseline: blood lactate concentration recorded prior to RAMP protocol; Post-RAMP: blood lactate concentration recorded immediately following RAMP protocol; *: statistically significant difference from pre-RAMP Baseline.

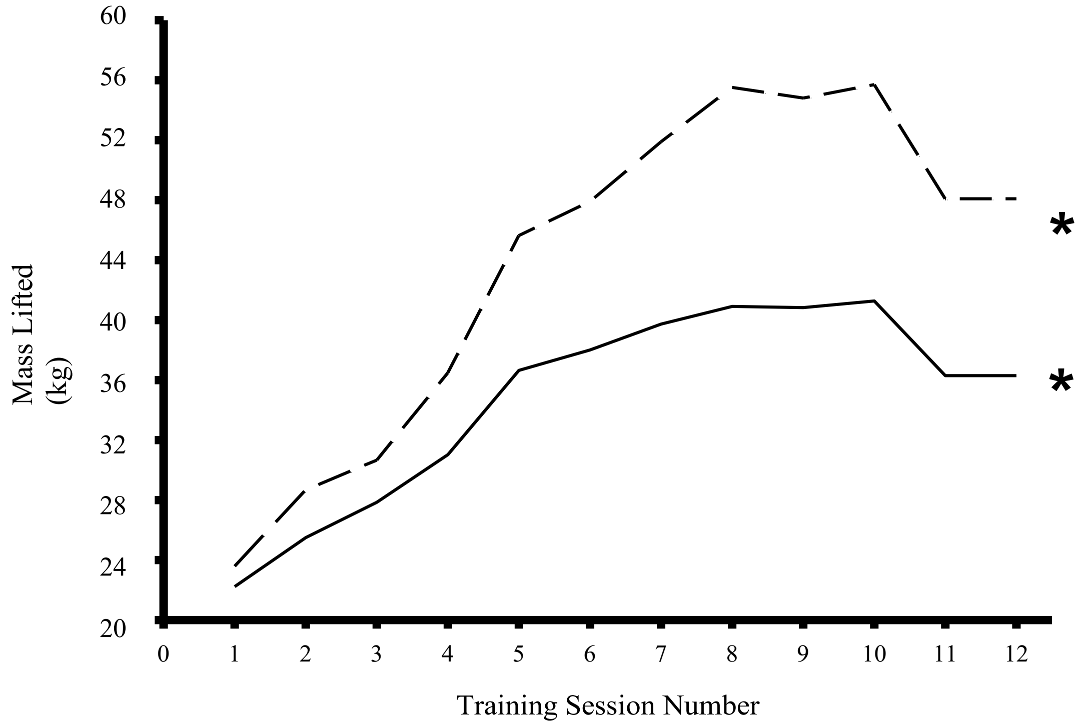

Figure 1. Mean dumbbell mass lifted per set from first to last training session. The dashed line represents the change in dumbbell deadlift (DL), and the solid line represents the change in dumbbell bench pull (BP). *Within-group pre- to post- training significant increase in mass lifted ($p<0.05$).

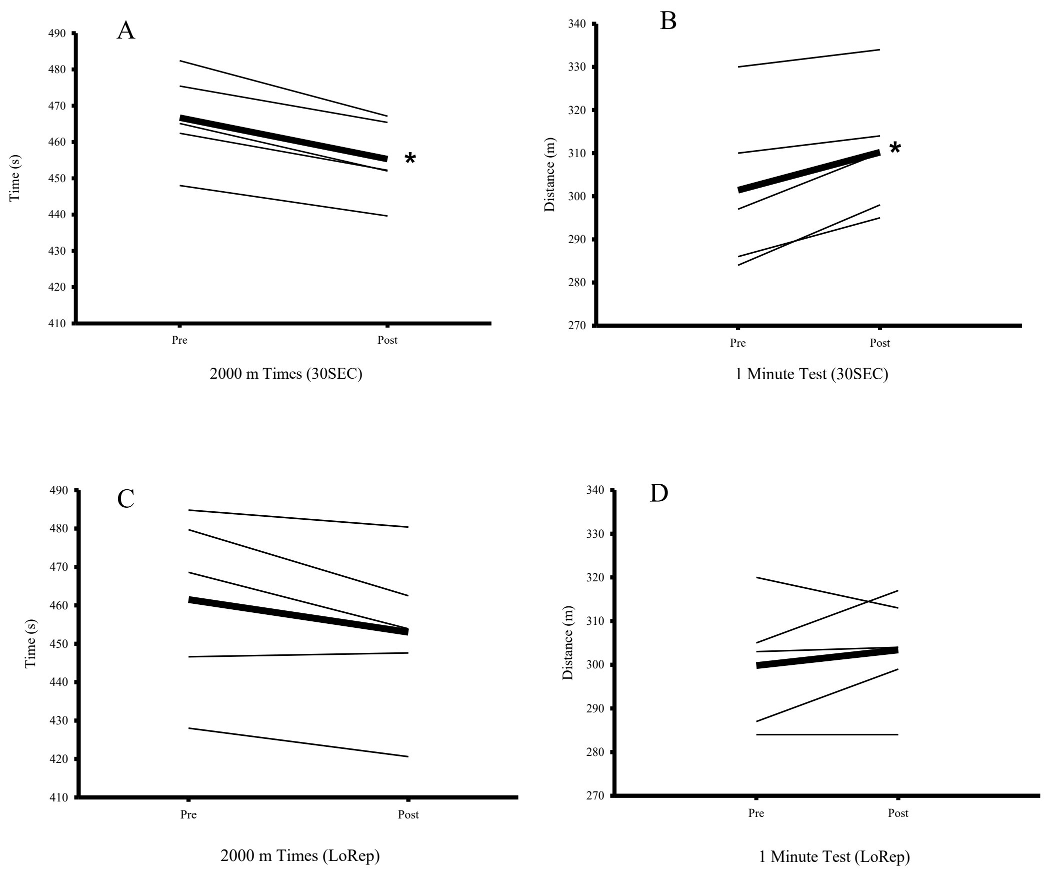

Figure 2. Pre- to post- performance measures; 30SEC: 30 second weight training group; LoRep: Low-repetition weight training group; 2000 m Times: 2000 m rowing ergometer test time to completion (s); 1 Minute Test: distance travelled during the 1 Minute Test (m); **A**: 30SEC change in 2000 m rowing ergometer times; **B**: 30SEC change in 1 Minute Test; **C**: LoRep change in 2000 m rowing ergometer times; **D**: LoRep change in 1 Minute Test. *Within-group pre- to post- training significant difference ($p<0.05$).

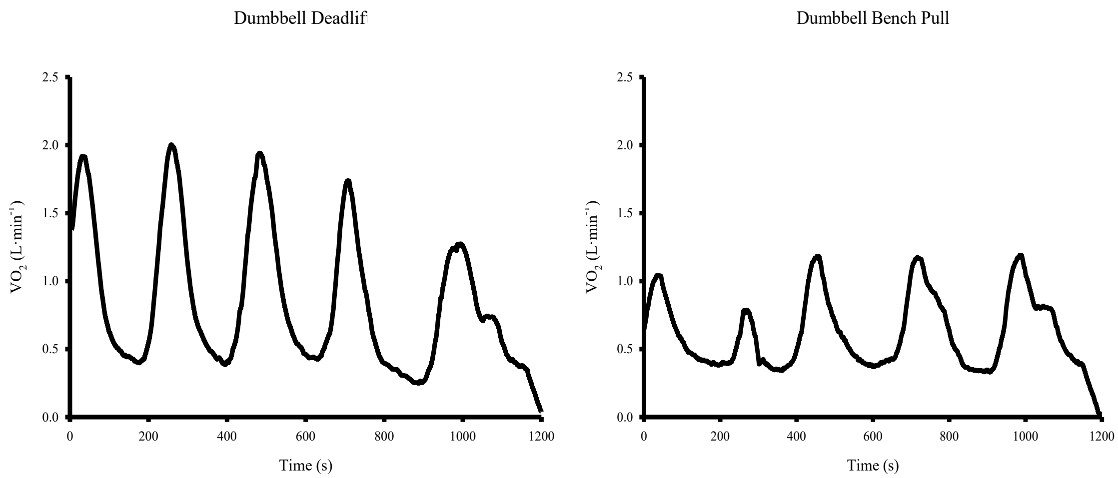

Figure 3. Oxygen uptake during the dumbbell deadlift and dumbbell bench pull for the exemplar subject. VO_2 ($L \cdot min^{-1}$): oxygen uptake in liters per minute; Time (s): seconds.

2.4 Discussion

This is the first study, to our knowledge, to compare the effects of four weeks of 30 s weight training sessions, performed over four weeks, to a coach prescribed low-repetition weight training regime performed over a similar time period. Both training programs were performed seven weeks into the preparatory season, by provincial and national level female collegiate rowers, under the direction of an international level rowing coach.

The main findings of this study confirmed our hypotheses that four weeks 30SEC would improve and achieve statistical significance, while reflecting a large effect size, for 2000 m rowing ergometer performance and 1 Minute Test. In contrast, four weeks of LoRep improved mean performances, but statistical significance was not achieved, and the effect size was small. No changes in VO_2max or peak aerobic power were observed in either group.

Previous research of well-trained rowers (44) has demonstrated that the 1 Minute Test used in the present study is an appropriate measure of anaerobic capacity (37). Hence, it is suggested that the observed improvement of anaerobic capacity following 30SEC stems from the high anaerobic energy system contributions from the 30SEC training sessions (DL 77% and BP 87%) as determined from the exemplar participant (Equation 1), and previous literature (37).

In further support of the high anaerobic glycolytic contribution of the 30SEC sessions, elevated blood lactate concentrations of an exemplar participant were observed (8.6 $mmol \cdot L^{-1}$) post-training session. It has been suggested that lactate accumulations from high intensity work, such as the 30SEC bouts in the present study, activate metabolic signalling cascades that elicit increases in peroxisome proliferator-activated receptor-gamma coactivator (PGC-1 alpha) (13, 24, 45). This protein expression has also been associated with enhanced muscle lactate buffering post-training (7, 23, 45). This increase of muscle lactate buffering capacity tempers the drop in pH, which has been shown to facilitate improved maximal effort performances such as the 1 min and 2000 m tests performed in the present study (18, 30). It is proposed that the improved 1 Minute Test and 2000 m rowing ergometer performances observed in the current study (Figure 2) has been buttressed, in part, by a similar enhancement of muscle lactate buffering capacity consequent to this 30SEC.

In addition to the high anaerobic glycolytic contribution to the 30SEC sessions, a high ATP-PCr energy system contribution to this training duration has also been observed (9, 10). Earlier work has shown that chronic exposure to 30 s SIT speeds phosphocreatine (PCr) breakdown, as well as subsequent adenosine triphosphate (ATP) synthesis and availability by increasing the activity of the enzyme catalysing this reaction (creatine kinase). This phosphagen energy system adaptation has been shown to preserve anaerobic glycolytic capacity for use in the latter stages of a maximal performances (19, 28). This adaptation would, in part, also support 30SEC improved 1 Minute Test and 2000 m rowing ergometer performances of the present study. Moreover, the observed increase in power output of both the DL and BP over the four week 30SEC (Figure 1) further highlights the 30SEC increased anaerobic capacity pre- to post- training.

Alternatively, the LoRep unchanged 1 Minute Test performance suggests that the stimulus of the coach prescribed four week intervention of the present study was of inadequate duration to induce performance enhancements associated with previously observed increased anaerobic capacity or maximal muscle strength (3, 50). It is generally accepted that 11-16 weeks of low-repetition, long rest weight training is required to elicit these adaptations (3, 50). Furthermore, our study design would suggest that the majority of the expected strength gains associated with neuromuscular adaptations during the initial weeks of training (34, 41, 43) would have been expressed during the initial seven week pre-training intervention conditioning period of the present study.

In summary, it is suggested that the increased anaerobic capacity subsequent to 30SEC facilitated the improved 2000 m rowing ergometer performance. These results are in line with Stevens et al. (44), who observed a similar post- training improvement in 2000 m performance, although in males, that was associated with an observed increase in anaerobic capacity.

It is suggested that the unchanged VO_2max after four weeks of 30SEC was coupled with the aerobic adaptations acquired over the seven weeks of pre-study conditioning, and the multiple years of training previously performed by these rowers. A reduced likelihood of observing continued improvements in VO_2max post-training has been associated with both of these training paradigms (2, 40, 50). For example, improvements in VO_2max and 2000 m rowing ergometer performance have been observed post-weight training in low performing female collegiate rowers (mean pre- 2000 m Time = 8:13 ± 22 s compared to 7:33 ± 17 in the present study) during their offseason (17). Their pre- to post-training improvements would not be unexpected (17), as this previous study was performed during the rowers' offseason when their fitness levels were at their lowest, and adaptations in VO_2max would be elicited more easily (2, 40, 50). Conversely, the 30SEC of the present study took place seven weeks into the competitive season under the tutelage of an international level coach. Evidently, the seven weeks rowing ergometer preconditioning training began with seven hours a week increasing to ten hours a week of moderate to high intensity aerobic training (Table 3), which therefore would have resulted in significant increases in VO_2max and performance (17, 21).

Additionally, the unchanged VO_2max of 30SEC could be attributed to the limited time during training that these rowers were in proximity of VO_2max during the 30SEC sessions. This high intensity level has been shown to be optimal for continued aerobic capacity adaptations in well-trained endurance athletes (8). It was initially expected, as others have shown (12, 15), that 30SEC would elicit this near maximal aerobic activation (VO_2 within ~90% of VO_2max). This training intensity has been associated with increased aerobic enzyme activity (23), VO_2max (26, 28, 40), and improved aerobic (> 2 min) performances (23, 26). The peak VO_2 during the 30 s bouts of the present study, however, reached only 56% and 27% during the DL and BP respectively (Figure 3). It is suggested that this attenuated 30SEC exercising VO_2 was a result of the non-maximal effort exercise bouts (RPE of 8/10) prescribed by the researcher. This effort prescription was given to reduce the risk of injury during the competitive season. The incidence of lower back injuries from rowing, in general, is common. Accordingly, caution is paramount when performing leg and back extension lifts, such as the deadlift movement of present study (51). The relationship and trust between the researchers of the present study, and the rowing coaches, has been built over a number of years of suggesting training interventions that have kept these athletes out of the local Athletic Injuries Clinic.

Notably, improved 2000 m rowing ergometer performances were observed by this training group, in spite of the non-maximal effort and the slower contraction frequency bouts 30SEC (~30-36 contractions per minute) compared to the contraction frequency of the typical maximal effort 30 s SIT cycle ergometer training (14, 36, 47). This highlights the efficacy of this specific weight training stimulus on 2000 m rowing performance.

In summary, and concurring with our hypothesis, a four week, novel 30 s weight training regime implementing dumbbell deadlifts and dumbbell bench pulls, performed three times per week, concurrent with a high volume of aerobic rowing ergometer training improved 2000 m rowing ergometer performance of provincial, and national collegiate female rowers. A similar cohort, however, performing a traditional rowing low-repetition weight training regime, concurrent with an identical volume and intensity of aerobic rowing ergometer training, did not improve significantly.

2.5 Practical Applications

This 30 s weight training regime is recommended for use by preconditioned female collegiate rowers over the continuum from provincial to national competitors, concurrent with a high volume of aerobic training, in preparation for rowing competition and/or performance evaluation. Utilizing this non-maximal, but efficacious anaerobic energy system stimulus, attenuates the risk of injury compared to maximal effort low-repetition weight training implemented to induce muscle hypertrophy. This will result in the ability of the rowers to compete at their highest level during testing or racing. Implementing this non-maximal effort 30 s weight training program in the final weeks in preparation for performance testing, or major competition, will not only have a more beneficial impact on performance than low-repetition weight training, but will also mitigate the increased risk of injury of maximal effort lifts concurrent with a high volume of rowing training.

2.6 Limitations

The present study was limited by the number of participants completing the weight training interventions (n=10). Due to the unwillingness of well-trained athletes to tamper with their coach implemented weight training regimes, participation was limited to five participants in each of the weight training groups. Although participation was limited, it is important to note that the statistical analysis of 30SEC enhanced 2000 m rowing ergometer performance ($p<0.001$; Cohen's d effect size = 0.93) demonstrates the greater impact that 30SEC had on performance over the four week intervention, compared to LoRep ($p=0.062$; Cohen's d effect size = 0.37).

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Appendices

Appendix A: Letter of Information

LETTER OF INFORMATION

A 4 week 30 s weight training intervention improves 2000 m rowing ergometer performance of provincial and national collegiate female rowers.

Principal Investigator: Glen Belfry PhD
Co-investigator: Matthew Lee MSc candidate

Purpose of Study:

You are being invited to participate in a study that will determine whether your muscles will see a greater improvement in their ability to use oxygen, as well as produce energy for physical work, by performing either a traditional low-repetition weight training regime (control group) or perform a novel 30 s bouts of a weight training regime (30 s training group) over a four week period.

Both of these groups of rowers will also be performing the regularly scheduled dryland rowing machine (rowing ergometer) training sessions as designed by your Head Coach.

Participation in this study involves visits to the laboratory of the Canadian Centre for Activity and Aging on two different occasions. These visits will require about 60 minutes of your time.

This laboratory is located at the University of Western Ontario, in the Health Science Building, room 313. This room is located on the third floor.

A total of 10 healthy 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.

If you decide to participate you will be then "randomized" into the control group or the 30 s bouts of weight training group. Randomization means that you are put into a group by chance (we will flip a coin). There is no way to predict which group you will be assigned to. There will be an equal chance you will assigned to either group. Neither you, nor the study investigators can choose what group you will be in.

Your first task, if you decide to participate, will be to complete the Physical Activity Readiness Questionnaire (PAR-Q) 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". You will be randomly assigned to either 1) the 30 s weight training group or 2) the control group for the following four week period. You will be informed of your group assignment one week after test completion.

If you are pregnant at this time or become pregnant during the study you will also be excluded from participating in this study.

Research Testing Protocol:
During the first visit to the laboratory you will complete a ramp incremental exercise test until you are unable to continue because the exercise intensity is either too high or too uncomfortable. This exercise test will be performed on a stationary bicycle (cycling ergometer). The test will begin with the exercise intensity being very light and easy (very little resistance). After a few minutes the exercise intensity will gradually and continuously increase until you are unable to continue because of fatigue, or until you wish to stop.

This visit will last approximately 1 hour. Six weeks later you will return to the lab to perform these identical tests.

Research Procedures:
During the ramp incremental tests you will be required to wear a nose-clip (to prevent you from breathing through your nose) and a rubber mouthpiece (similar to breathing through a snorkel or diving mask). These will be washed and sterilized between users. This will enable us to measure the volume of air that you breathe in and out, and measure the oxygen and carbon dioxide levels in that air. You may experience some initial discomfort from wearing the nose-clip and mouthpiece.

Before and after the ramp incremental test a pin prick will be administered to your left index finger and a drop of blood will be used to measure the muscle byproducts (lactic acid) of high intensity exercise.

Weight Training Programs:
The control group will perform your coach prescribed weight training program during your regularly scheduled weight training sessions on Tuesdays and Thursdays during your regularly scheduled rowing team weight training sessions for six weeks.

The 30 s weight training group will perform a maximum of 18 repetitions, within 30 s, of both the "bench pull" and "deadlift" exercises, with dumb bells. This program will be followed for four weeks.
You will perform five sets of this protocol, on Tuesdays and Thursdays during your regularly scheduled Western rowing team's weight training sessions.

The 30 s training group will perform an additional five sets of this 30 s protocol on Saturdays after your regular scheduled rowing ergometer training session. All weight training sessions for both groups will take place at the Western varsity weight training centre (Kirkley Centre) at TD Waterhouse Stadium.

A certified strength and conditioning coach will be present at all training sessions of both groups to ensure that the exercises are performed safely and with correct technique.

You will be familiar with both the “bench pull” (Figure A) and “deadlift” (Figure B) exercises as you will have been exposed to them throughout your rowing career here at Western. See pictures below.

Figure A

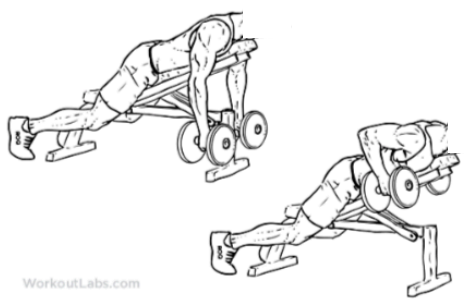

Figure B

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 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 are not unexpected consequences of exercise.

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 Canadian Centre for Activity and Aging facility are confidential and will be stored securely at the testing venue. 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 or status as a varsity athlete.
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 (Matthew Lee), who will ensure this data is deleted and no further testing will be done and your participation in the study will be discontinued.

Identifiable information will be stored on a pass word protected computer in the lab (HSB room 313) and will limited to your name and email for purposes of contacting you about study related questions or suggestions.
As per University policy information collected from this study will be kept for 5 years.

If you sustain an injury from this study you will be treated by the Medical and Physical Therapy staff at the Fowler-Kennedy Athletic Injuries Clinic located in the 3 M building on the Western University campus.

Questions:

If you have any questions regarding this study please contact Glen Belfry at [redacted]) or Matthew Lee ([redacted]). If you have any questions about the conduct of this study or your rights as a research participant you may contact the Office of Human Research Ethics, The University of Western Ontario, [redacted]).

Appendix B: Letter of Informed Consent

LETTER OF INFORMED CONSENT

A 4 week 30 s weight training intervention improves 2000 m rowing ergometer performance of provincial and national collegiate female rowers.

Principal investigator: Dr Glen Belfry PhD
Co-investigator: Matthew Lee

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

Appendix C: PAR-Q

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________

SIGNATURE OF PARENT ________________________ WITNESS ________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Curriculum Vitae

Name:	Matthew Lee
Post-secondary Education and Degrees:	Western University London, Ontario, Canada 2013-2017 B.Sc.
	Western University London, Ontario, Canada 2017-2019 M.Sc.
	Trent University Peterborough, Ontario, Canada 2019-2021 B.Ed.
Honours and Awards:	Western University Deans Honours List 2015-2017
	Western Graduate Research Scholarship 2017-2019
Related Work Experience	Teaching Assistant Western University 2017-2019
Publications:	