The Effects of Inspiratory Muscle Training on Physiological and Sensory Responses to Exercise in Healthy Males

by

Andrew Harry Ramsook

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ABSTRACT

Inspiratory muscle training (IMT) is an efficacious intervention to reduce dyspnoea in health and disease. Growing evidence also suggests that IMT can improve whole body exercise performance. However, the physiological mechanisms for these improvements are not well understood. We sought to examine the effects of IMT on dyspnoea, respiratory muscle electromyography (EMG), and respiratory and locomotor oxygenation to examine potential mechanisms of action for any IMT-related improvements in dyspnoea and exercise performance.

25 recreationally active healthy men completed two maximal incremental cycle exercise tests separated by 5 weeks of randomly assigned pressure threshold IMT or sham control training (SC). The IMT group (n = 12) performed 30 inspiratory efforts twice daily against a 30 repetition maximum intensity. The SC (n = 13) group performed a daily bout of 60 inspiratory efforts against 10% maximal inspiratory pressure (MIP), with no weekly adjustments. EMG electrodes on the sternocleidomastoid (SCM) and scalene muscles measured changes in muscle activity, and near-infrared spectroscopy (NIRS) optodes on the SCM, parasternal intercostals, 7th intercostal space, and vastus lateralis muscle measured changes in oxygenated and deoxygenated haemoglobin during each exercise test. Dyspnoea was measured throughout exercise using the modified Borg scale. Finally, a subset of participants (IMT: n = 11; SC: n = 11) were instrumented with a multi-pair oesophageal electrode catheter containing two balloons, to measure diaphragm EMG and respiratory pressures.

IMT significantly improved MIP (pre: -138±45 vs. post: -160±43, cm H₂O, p<0.01) whereas the SC intervention did not. A between group analysis determined the increase in MIP in the IMT group was greater than the change in the SC group (p<0.05). Moreover, after IMT, dyspnoea was significantly reduced at the highest equivalent work rate (pre: 7.6±2.5 vs. post:
6.8±2.9 Borg units, p<0.05), but not in the SC group with no between-group interaction effects. Finally, there were no significant differences in respiratory muscle EMG or respiratory and locomotor muscle oxygenation in either the IMT or SC intervention. Together, these findings suggest that while IMT can reduce dyspnoea, it is likely unrelated to changes in EMG or NIRS derived measurements.
PREFACE

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The experiment presented in this thesis received ethical approval from the Providence Health Care Research Ethics Board (UBC-PHC REB Number: H14-00067) and was registered with ClinicalTrials.gov (Identifier: NCT02243527). All data were collected at the Cardiopulmonary Exercise Physiology Laboratory at St. Paul’s Hospital, Vancouver, British Columbia.

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LIST OF ABBREVIATIONS

%Δ[HHb]: per cent change in the concentration of HHb

7IC: seventh intercostal space muscle

EELV: end-expiratory lung volume

EILV: end-inspiratory lung volume

EMG: electromyography

EMGdi: Diaphragm EMG

EMGsca: EMG of SCA muscle

EMGscm: EMG of SCM muscle

EMGvl: EMG of the VL Muscle

Fb: breathing frequency

FEV_{1}: forced expiratory volume in one-second

FVC: forced vital capacity

Hb: haemoglobin

HbO_{2}: concentration of oxygenated haemoglobin

HEWR: highest equivalent work rate

HHb: concentration of deoxygenated Hb

HR: heart rate

IC: inspiratory capacity

ICG: indocyanine green

ICET: incremental cycle exercise test

IFRL: inspiratory flow resistive loading

ITL: incremental threshold loading
IMT: inspiratory Muscle Training

IPAQ: international physical activity questionnaire

IRV: inspiratory reserve volume

MET: metabolic equivalent

MIP: maximal inspiratory pressure

MSNA: muscle sympathetic nerve activity

MVV: maximal voluntary ventilation

NIRS: near-infrared spectroscopy

O$_2$: oxygen

PAR-Q+: physical activity readiness questionnaire

Peso: oesophageal pressure

PETCO$_2$: partial pressure of end-tidal carbon dioxide

Pdi: transdiaphragmatic pressure

Pga: gastric pressure

P$_m$: mouth pressure

PIC: parasternal intercostal muscle

PO: power output

RMT: respiratory muscle training

RPE$_{legs}$: perceived exertion of the legs

RV: residual volume

SC: sham control

SCA: scalene muscle

SCM: sternocleidomastoid
sEMG: surface EMG

SD: standard deviation

tHb: total Hb

TLC: total lung capacity

Visit 1: V1

Visit 2: V2

Visit 3: V3

\( \dot{V}_E \): minute ventilation

\( \dot{V}_E/\dot{V}CO_2 \): ventilatory equivalent for carbon dioxide

\( \dot{V}_E/\dot{V}O_2 \): ventilatory equivalent for oxygen

VL: vastus lateralis

\( \dot{V}O_2 \): oxygen consumption

\( \dot{V}O_{2\text{peak}} \): peak oxygen consumption

\( V_T \): tidal volume

\( W_b \): work of breathing
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BACKGROUND & RATIONALE

Introduction

In health, the human respiratory system is more than capable of responding to the increased energetic demands of exercise. The ideal structural characteristics of the respiratory muscles, coupled with precise neural regulation of breathing, results in the appropriate response to the metabolic demands of exercise, at least in the untrained individual (Dempsey, 1986). Indeed, the healthy untrained individual is capable of increasing their minute ventilation ($\dot{V}_E$) nine-times resting values without experiencing significant ventilatory limitations (Henke et al., 1988). This response is most impressive in well-trained, elite endurance athletes, who can increase their $\dot{V}_E$ 20-fold resting values (Johnson et al., 1992). Unlike the untrained individual, these impressive increases in $\dot{V}_E$ may predispose the elite endurance athlete to developing important ventilatory limitations, such as expiratory flow limitation and corresponding increases in operating lung volumes, both of which contribute to an increase in the work of breathing ($W_b$) (Johnson et al., 1992; Guenette et al., 2007). This increase in $W_b$ may prompt an increase in respiratory muscle blood flow to maintain adequate supplies of oxygen and other energetic substrates. In fact, the respiratory muscles can use up to 16% of the total oxygen consumption and cardiac output during maximal exercise in humans (Aaron et al., 1992; Dominelli et al., 2015).

High ventilatory demands can result in respiratory muscle fatigue, which in turn affects exercise tolerance (Harms, 2000; Babcock et al., 2002). Additionally, respiratory muscle fatigue may trigger the respiratory muscle metaboreflex, which leads to a potential redistribution of blood flow between the locomotor and respiratory muscles. This compromised blood flow can
exacerbate fatigue of the active limb muscles, increase perception of effort, and subsequently impair exercise performance (Dempsey et al., 2008).

In addition to these haemodynamic consequences of high-intensity exercise, dyspnoea, defined as a subjective experience of breathing discomfort that consists of qualitatively distinct sensations that vary in intensity (Parshall et al., 2012), is unavoidable during vigorous exercise. Indeed, dyspnoea intensity increases progressively to near maximal levels in healthy humans during incremental cycling (Jones & Killian, 2000). While dyspnea is an important exercise limiting symptom in chronic respiratory diseases (O'Donnell et al., 2007; O'Donnell et al., 2009), it is rarely selected as the primary reason for stopping exercise in healthy humans (Schaeffer et al., 2014; Cory et al., 2015). Most healthy individuals stop exercising because of intolerable leg discomfort alone or in combination with breathing discomfort.

Strengthening the inspiratory muscles through inspiratory muscle training (IMT) has the potential to counteract some of the above-mentioned respiratory consequences of exercise. This could potentially result in enhanced exercise performance. The goal of IMT is to reduce the inspiratory muscles’ susceptibility to fatigue, and mitigate the negative effects of the respiratory muscle metaboreflex and dyspnoea on exercise performance. Of late, systematic reviews have endorsed IMT as a means to improve exercise performance in health (Illi et al., 2012; HajGhanbari et al., 2013) and to elicit numerous improvements across a breadth of disease states (Geddes et al., 2008; Reid et al., 2008; Lin et al., 2012). Despite these findings, the efficacy of IMT is still the subject of debate (McConnell, 2012; Patel et al., 2012). This controversy exists, in part, because of the lack of understanding of the physiological mechanisms that underlie any potential improvement to exercise performance following IMT.
Respiratory Muscles

Breathing is separated into two distinct phases: inspiration and expiration. Inspiration is an active process governed by a set of inspiratory muscles. The primary muscle of inspiration is the diaphragm. The diaphragm is a thin, dome shaped muscle that separates the abdominal and thoracic cavities. The fibres of the diaphragm insert at two points: the lumbar bodies (crural diaphragm) and the inner surfaces of the lower six ribs (costal diaphragm) (Ratnovsky et al., 2008). Upon contraction, the diaphragm flattens and the thoracic cavity expands. Additionally, the costal diaphragm applies a force that lifts and externally rotates the lower six ribs. The diaphragm is typically regarded as the only important active muscle during quiet inspiration; however, it should be noted that other muscles including the external intercostals (Derenne et al., 1978) and scalene (SCA) (De Troyer & Boriek, 2011) can be described as obligatory inspiratory muscles as well. Generally, the diaphragm is able to meet the ventilatory demands of exercise through its distribution of fibre types and its short capillary-mitochondria diffusion distance (Mizuno, 1991). The human diaphragm is estimated to contain primarily slow-twitch fibres (55%), with the remainder divided between fast oxidative (21%) and fast glycolytic (24%) (Polla et al., 2004). The greater proportion of slow-twitch fibres contribute to the diaphragm’s resilience to fatigue, as it is these slow fibres that are primarily recruited during quiet inspiration (Smith-Blair, 2002). In the diaphragm, the slow-twitch fibres are surrounded by four to six capillaries each, just as in limb skeletal muscle fibres in untrained individuals (Mizuno & Secher, 1989). Despite the similar amount of capillaries around both limb and diaphragmatic slow-twitch fibres, the calculated area surrounding each capillary is smaller in the diaphragm than in muscles of the leg or arm because each muscle fibre in the diaphragm is smaller relative to limb skeletal muscle (Mizuno & Secher, 1989).
When $V_E$ increases, as is the case with exercise, additional muscles become more active to meet the increased ventilatory demand. These additional muscles include obligatory respiratory muscles such as the external intercostals, parasternal intercostals (PIC), and SCA muscles as well as accessory respiratory muscles such as the sternocleidomastoid (SCM) (Campbell, 1955). The external intercostals are composed of thinly layered fibres that run obliquely downward and ventrally from one rib to the rib below. Contraction of these muscles raises the lower rib with respect to the higher rib, thus expanding the chest. The PIC contraction displaces the lateral portion of the ribs upwards and outwards (De Troyer & Boriek, 2011). The SCM and SCA are muscles in the neck, and during exercise, they serve to raise the sternum and first two ribs to assist in expanding the rib cage (Ratnovsky & Elad, 2005). The SCM descends from the mastoid process to the ventral surface of the manubrium and medial third of the clavicle while the SCA is comprised of three bundles of muscle fibres that run from the transverse process of the lower five cervical vertebrae to the upper surface of the first two ribs (Ratnovsky et al., 2008).

Expiration at rest is a passive process that relies on the elastic properties of the lung and chest wall (Ratnovsky et al., 2003). Conversely, during high levels of $V_E$, additional muscles such as the internal intercostals, rectus abdominis, external and internal oblique, and transverse abdominis muscles are recruited to meet this increased ventilatory demand. These muscles become involved at flow rates of approximately 5 L/second during expiration between 70% and 20% of vital capacity (Ratnovsky et al., 2003).

The recruitment pattern and actions of the respiratory muscles are precisely regulated to ensure a “minimum work” response to exercise (Dempsey, 1986). Despite this, there is compelling evidence of diaphragmatic fatigue using phrenic nerve stimulation techniques across
a wide range of ages and fitness levels in healthy humans performing high intensity exercise (Johnson et al., 1993; Mador et al., 1993; Babcock et al., 1996; Guenette et al., 2010). Additionally, a decrease in the electromyography (EMG) power spectra signal during a maximal inspiratory pressure manoeuvre after exercise suggests that the accessory inspiratory muscles are also susceptible to fatigue (Segizbaeva et al., 2013). While the inspiratory muscles as a group exhibit fatigue, the specific pattern of recruitment and fatigue during exercise is not well understood.

**Dyspnoea**

Despite the observation that dyspnoea is rarely a limiting factor for continuing a bout of exercise in healthy adults (Dempsey, 1986), there are data supporting dyspnoea as an independent predictor of mortality (Bodegard et al., 2005). For instance, a follow-up study on healthy middle-aged men 26 years after a symptom-limited incremental exercise test found that those who ceased exercise due to impaired breathing were at a 1.6-fold greater risk of all-cause mortality, relative to those who ceased exercise due to leg fatigue or a combination of leg and breathing discomfort (Bodegard et al., 2005).

The Borg scale is a commonly used tool to assess dyspnoea during exercise (O'Donnell et al., 1997; O'Donnell et al., 1998; Laveneziana et al., 2011; Schaeffer et al., 2014; Cory et al., 2015). The Borg scale combines numbers and phrases that allows for the assessment of exercise related sensations such as effort, pain, and dyspnoea (Jones et al., 1985).

During a maximal exercise test or constant load exercise at submaximal intensities, the healthy participant will experience greater perceived effort of the exercising limb muscles than dyspnoea. Both sensations will gradually increase until the subject is unable or unwilling to continue exercise (Jones & Killian, 2000). While dyspnoea is rarely the limiting factor to
continuing exercise in the healthy subject, the highly motivated athlete is capable of reaching
“maximal” levels of dyspnoea (i.e., scoring 10 on the Borg scale) while subjects with low
tolerance for discomfort can stop at dyspnoea levels as early as 4 on the Borg scale (Killian et al., 1992).

The central motor cortex is the location of the brain where effort sensations originate
and effort sensations increase in intensity as the number of active motor units increase (Jones &
Killian, 2000). A subject’s awareness of this increased neural drive contributes to the
development of dyspnoea over the course of an exercise test. This feeling is exacerbated at near
maximal intensities when the subject also becomes aware of a decrease in power output (Killian
& Gandevia, 1996) and the combination of these two phenomena result in the sensation of
fatigue.

While the physiological mechanisms of exertional dyspnoea in health are incompletely
understood, we can draw some insight from the current literature in chronic respiratory disease.
One possible contributor to dyspnoea, at least in chronic obstructive pulmonary disease, is a
diminished inspiratory reserve volume (IRV). During incremental exercise, subjects reach a
minimal IRV at which point no further increase in tidal volume is possible; at this point,
perceived dyspnoea sharply increases (O'Donnell & Webb, 1993). Concurrently, there is an
increase in the drive to breathe to meet the new requirements of exercise. However, the
pressure-volume relationship of the respiratory system follows a sigmoid pattern such that,
beyond a critical volume, increases in pressure have little to no effect on volume. As a result,
breathing frequency increases to compensate for the inability to increase tidal volume. This
point is graphically represented by an inflection point, when tidal volume ($V_T$) is graphed against
$\dot{V}_E$. Despite these limitations to volume expansion, the neural drive to breathe continues to
increase. This crucial mismatch between neural drive and the ability to increase $V_T$ is referred to as neuromechanical dissociation, and is thought to contribute, at least in part, to dyspnoea (O'Donnell et al., 2006; O'Donnell et al., 2007).

Dyspnoea is also closely tied to the $W_b$. As an example, reducing the $W_b$ using a proportional-assist ventilator decreases both perceived dyspnea and leg exertion compared to control conditions (Harms et al., 2000). Conversely, when mesh screens were introduced to the breathing circuit, meant to increase the $W_b$, both dyspnoea and perceived leg exertion are rated higher (Harms et al., 2000).

Qualitative Aspects of Dyspnoea

Dyspnoea, by definition, is a subjective experience. In both health and disease, subjects are capable of selecting qualitative descriptors of dyspnoea from a list of standardized statements (Simon et al., 1989; Simon et al., 1990). Originating as 19 qualitative descriptors designed to address the multidimensional nature of dyspnoea (Simon et al., 1990), a modified version of 15 descriptors has been used as well (O'Donnell et al., 1997; O'Donnell et al., 1998; Cory et al., 2015). In both cases, the questionnaire is administered immediately after exercise cessation when the intensity of dyspnoea is most severe. The descriptors can then be grouped into various qualitative dyspnoea clusters (O'Donnell et al., 2009). An increased sense of “work” and “effort” are commonly selected in healthy humans during exercise (Cory et al., 2015). In contrast, patients with chronic respiratory diseases experience more distressing sensations of dyspnoea in addition to an increased sense of “work” and “effort”. For example, in both chronic obstructive pulmonary disease and interstitial lung disease, patients more frequently select descriptors that allude to sensations of “unsatisfied inspiration”, “inspiratory difficulty”,...
“shallow” breathing (chronic obstructive pulmonary disease), and “rapid” breathing (interstitial lung disease) when compared to healthy controls (O'Donnell et al., 1997; O'Donnell et al., 1998).

**Peripheral Muscle Fatigue**

Fatigue can be described as peripheral or central, measured by contractile function (e.g., by electrical stimulation) or voluntary activation, respectively. Fatigue of the working muscle can be influenced by both the W_b (Romer et al., 2006b) and haemodynamic changes, such as exercise induced arterial hypoxemia (Romer et al., 2006a). For example, Romer et al.(2006b) manipulated the W_b during cycle exercise by having participants exercise to exhaustion under both unloaded and loaded breathing conditions that decreased or increased the W_b, respectively. The researchers induced potentiated twitches of the quadriceps (Q_tw) ~30 min before exercise, as well as 2.5, 35, and 70 min after exercise to assess fatigue. In control conditions (i.e., no W_b manipulation), Q_tw was reduced significantly below baseline when the femoral nerve was supramaximally stimulated. In contrast, unloaded breathing (i.e., reduced W_b) attenuated the magnitude of muscle fatigue by nearly one-third; while increasing W_b resulted in greater muscle fatigue. These findings suggest that the increased W_b associated with high-intensity exercise is enough to induce peripheral muscle fatigue, and provide further insight into the potential factors that link respiratory muscle work and exercise performance.

To examine the haemodynamic impact on peripheral muscle fatigue, the same group (Romer et al., 2006b) induced unpotentiated Q_sw in a group of 11 competitive endurance athletes. In a subset of the subjects whom experienced exercise-induced arterial hypoxemia, estimated by pulse oximetry, Q_tw force was reduced by nearly one-third below baseline after completing a bout of exercise ≥ 90% peak oxygen consumption (\(\dot{V}O_2^{peak}\)). When hypoxemia was prevented
by increasing the fraction of inspired oxygen, quadriceps fatigue was reduced by more than one-half. While exercise-induced arterial hypoxemia is not common to all athletes, the effect of a reduced arterial saturation on limb fatigue is apparent.

**Respiratory Muscle Blood Flow Responses to Aerobic Exercise**

While it is well established that locomotor muscle blood flow increases to meet the energetic demands of exercise, the haemodynamic response of the respiratory muscles is not well understood. During exercise, there appears to be competition for blood flow between the peripheral exercising muscles and the respiratory muscles. It is estimated that the respiratory muscles command between 14-16% of blood flow in maximal exercise conditions (Harms *et al.*, 1998). When the $W_b$ is increased, the demand imposed on the respiratory muscles is greater; hence, a larger proportion of blood flow is directed away from the exercising limbs. Conversely, when the load on the respiratory muscles is lower (i.e., decreased $W_b$) the relative amount of blood directed to the legs is significantly higher (Harms *et al.*, 1997). To further address the question of competition between the respiratory and peripheral muscles, Vogiatzis *et al.* (2009) examined intercostal muscle blood flow during 60, 80, 90, and 100% of maximal work rate achieved during a graded exercise test and compared the results to hyperpnoeic breathing that mimicked the exercise ventilatory response at the same work rates. Using a combination of near-infrared spectroscopy (NIRS) and the light absorbing tracer indocyanine green (ICG), the authors found that intercostal muscle blood flow was lower during exercise compared to hyperpnoea. Likewise, they observed that intercostal muscle blood flow was lower at maximal exercise compared to sub-maximal exercise, suggesting maximal cycle exercise affects respiratory muscle blood flow (Vogiatzis *et al.*, 2009).

This competition for blood flow appears to be limited to maximal exercise intensities.
When exercising at 80% of their maximal capacity, blood flow to the intercostal muscles was measured using the above-mentioned NIRS-ICG method. The researchers observed that intercostal muscle blood flow was $49.9 \pm 5.9 \text{ mL/100 mL/min}$, while mean $\dot{V}_E$ was $128 \pm 41 \text{ L/min}$ at the above work rate. In a separate study conducted by Guenette et al. (2008), subjects performed a hyperpnoea task to assess intercostal blood flow without the influence of whole body exercise. This study found intercostal blood flow was $50.1 \pm 12.5 \text{ mL/100 mL/min}$ when $\dot{V}_E$ was $123 \pm 41 \text{ L/min}$ (Guenette et al., 2008). Taken together, these findings suggest no difference in blood flow between sub-maximal exercise and a non-exercising condition at similar $\dot{V}_E$ values.

**Respiratory Muscle Metaboreflex**

It is thought that a muscle metaboreflex sympathetically mediates the haemodynamic response in both respiratory and locomotor muscles (Boushel et al., 1996; St Croix et al., 2000; Sheel et al., 2001). This reflex is activated during muscular contraction through local factors and metabolic by-products such as lactic acid (St Croix et al., 2000) and diprotonated phosphate (Sinoway et al., 1994). Consequences of this respiratory muscle metaboreflex include peripheral limb vasoconstriction, increases in peripheral limb fatigue, increases in perceived exertion, and sympathetic-based physiological changes such as increases in heart rate (HR) and mean arterial pressure (Dempsey et al., 2006). Alam and Smirk (1937) were the first to present this idea in humans during a plantar flexion exercise trial where metabolic byproducts of exercise, such as lactic acid, were contained in the area of the exercising muscle through cuff occlusion. After exercise, blood pressure measured in the arm remained elevated, suggesting the trapped metabolites of the contracting muscle produced a cardiovascular regulatory response (Alam & Smirk, 1937). Subsequent work has shown that this response is mediated through muscle sympathetic nerve activity (MSNA). For example, in a similar experiment, lactic acid and
MSNA were measured during wrist extensor exercises (Cui et al., 2008). Both MSNA and blood pressure were increased when lactic acid was allowed to accumulate in the area of the exercising muscle. Experiments in animal models (Kaufman et al., 1983) and humans (Freund et al., 1979; Strange et al., 1993) identified that group III and IV afferent nerves were involved in the increase in MSNA.

Given that the diaphragm is also innervated by group III and IV afferent nerve fibres, (Road, 1990) it is not surprising that the diaphragm also exhibits a metaboreflex. Indeed, fatiguing inspiratory work, such as a resistive breathing task, reduces leg blood flow measured by Doppler ultrasound, even when the leg is at rest (Sheel et al., 2001). Sheel et al. (2001) asked subjects to breathe against a resistance equal to 60% of their maximal inspiratory pressure (MIP) at a specific duty cycle ($T_i/T_{tot} = 0.7$) and frequency ($f_b = 15$) to induce diaphragm fatigue. From as early as the second minute, and following until task failure, leg blood flow decreased by an average of 23%, concurrent with a 45% mean increase in limb vascular resistance. This decrease in blood flow corresponds to the time of increased MSNA, supporting the diaphragm as exhibiting a muscle metaboreflex (St Croix et al., 2000). The previous two examples were resistive breathing tasks, in which the respiratory muscles are the only active muscles working to complete the task.

By examining the changes in ratio between blood flow and oxygen uptake of the legs ($\dot{V}O_{2\text{legs}}$) and total $\dot{V}O_2$, Harms et al. (1997) were able to assess how the $W_b$ affected leg blood flow during exercise. When exercising without any manipulation of $W_b$, $\dot{V}O_{2\text{legs}}$ accounted for 81% of total $\dot{V}O_2$. Under the influence of a proportional-assist ventilator to reduce the $W_b$, this number increased to 89%. Finally, when the $W_b$ was increased, the $\dot{V}O_{2\text{legs}}$ was only 71% of
total $\dot{V}O_2$. These findings have led to the speculation that the decrease in $\dot{V}O_2^{\text{legs}}$ is the result of redistribution of cardiac output from the legs to the respiratory muscles.

**Non-Invasive Measurements of Haemodynamic Trends during Exercise**

Measuring haemodynamic changes during exercise has traditionally been an invasive process. For example, when using thermodilution techniques to measure blood flow, two catheters are placed in the femoral vein, with one threaded distally toward the knee, and the other threaded proximally toward the heart (Harms *et al.*, 1997). NIRS has therefore been developed as a less invasive alternative to examine haemodynamic responses *in vivo*.

NIRS was first used by Jobsis in 1977 to non-invasively assess oxygen utilization in living tissue (Jobsis, 1977). Light in the near-infrared range (700-1000 nm) penetrates through bone, skin, and muscle with relative ease. The light travels in a banana-shaped curve that penetrates to a depth of roughly half of the distance between the transmitting optode and the receiving optode. The amount of light that returns to the receiving optode depends on how much light is scattered through the tissue and how much is absorbed by chromophores in the microvasculature. In the near-infrared range, three naturally occurring biologic chromophores affect NIRS absorption: haemoglobin (Hb), myoglobin, and cytochrome c oxidase (Boushel & Piantadosi, 2000). When examining oxygenation parameters of the exercising muscle, Hb is the primary chromophore of interest (Mancini *et al.*, 1994). However, NIRS is unable to distinguish differences between myoglobin and Hb because the absorption spectra of the two overlap (Boushel *et al.*, 2001); although the estimated contribution of myoglobin to Hb signals is estimated to be roughly 10% (Boushel *et al.*, 2001). Relative changes in deoxygenated haemoglobin (HHb) are continuously measured during exercise to provide a surrogate measure
of tissue oxygen extraction. This continuous measure allows researchers to characterize haemodynamic trends in the muscle during exercise.

*Deoxygenation Trends during Exercise*

Without the use of a light-absorbing tracer, NIRS is not able to give measures of blood flow. That is not to say the utility of NIRS on its own is limited. Measuring deoxygenation patterns of various muscles during exercise provides insight into exercising muscle (Mancini et al., 1994). There is some debate regarding which model best describes the deoxygenation profile of the vastus lateralis (VL) muscle, the most widely used representative locomotor muscle, during an incremental exercise test. Previous studies have applied both sigmoidal (Boone et al., 2009, 2010) and “double-linear” (Spencer et al., 2012) models to describe deoxygenation patterns of the locomotor muscles during exercise, both with excellent agreement. Both of these models indicate a non-linear relationship between muscle blood volume and oxygen uptake during incremental exercise. The more recent double-linear model identifies three distinct deoxygenation phases, whereas the sigmoid model encompasses the entire response over time. Phase A of the double-linear model, occurring at the onset of exercise, is characterized by increases in $\dot{V}O_2$ and power output (PO) without any appreciable percent-change in HHb concentration ($%\Delta[HHb]$). This phase is indicative of a period where local $O_2$ delivery matches, or even exceeds, $O_2$ utilization. This is followed by phase B, a period of linear increase in $%\Delta[HHb]$ relative to changes in PO and $\dot{V}O_2$, suggesting a more pronounced reliance on $O_2$ extraction. Finally, phase C is characterized by a plateau where there is little change in $%\Delta[HHb]$ in spite of increases in $\dot{V}O_2$ and PO. This phase implies a point at which $O_2$ extraction is unable to increase to match the increases in $\dot{V}O_2$. It has been suggested that this rise in total
body $\dot{V}O_2$, a point corresponding to phase C, results from the recruitment of additional locomotor muscles such as the gluteus, during cycling (Harms et al., 1997). No difference in the trends exists between step and ramp incremental tests (Boone et al., 2010).

The haemodynamic response of the respiratory muscles is less well understood, partially because of the difficulty in performing non-invasive measures of the deeply situated diaphragm. As such, the more superficial accessory respiratory muscles are commonly measured using NIRS, due to their accessibility for instrumentation. The most common muscle groups interrogated here are the intercostals and the serratus anterior, followed by the SCM (Terakado et al., 1999; Nielsen et al., 2001; Moalla et al., 2005; Cannon et al., 2007; Legrand et al., 2007a; Legrand et al., 2007b; Guenette et al., 2008; Moalla et al., 2008; Vogiatzis et al., 2008; Vogiatzis et al., 2009; Athanasopoulos et al., 2010; Louvaris et al., 2014). In the intercostals there exists two apparently linear phases of deoxygenation. The initial phase is an increase with a relatively low slope, followed by a second phase where the rate of deoxygenation is greater compared to the initial phase. It is worth noting that no noticeable deoxygenation plateau occurs in the respiratory muscles, as is seen in the VL (Vogiatzis et al., 2009). In a separate study, a similar point of inflection in the deoxygenation signal was observed in the serratus anterior; this change in rate corresponded to a significant decrease in blood volume (Legrand et al., 2007b).

Changes in the pattern of blood distribution to the respiratory and locomotor muscles are influenced by changes in the $W_b$. Shadgan et al. (2007) tested the response of the respiratory muscles to incremental threshold loading (ITL) in humans. They monitored several respiratory muscles (intercostals, PIC, and SCM) and a non-active muscle (VL) during ITL, with subjects in a seated position. As expected, during the seated ITL protocol the VL displayed no changes to oxygenated haemoglobin ($HbO_2$), whereas total haemoglobin (tHb) and HHb decreased.
However, the HHb of the SCM continuously increased as the ITL progressed. Combined with an increase in tHb at higher levels of ITL, this indicates an increase in blood distributed to the SCM and an increase in O$_2$ extraction. These results provide important insight into the haemodynamic responses of accessory respiratory muscles. However, these findings, which employed a threshold-loading model cannot be extrapolated to the haemodynamic response of the respiratory muscles during whole body exercise, where other muscles such as the muscles of the leg are competing for a finite cardiac output.

**Inspiratory Muscle Training**

Classically, the respiratory system is described as being overbuilt for the physiologic challenges of exercise (Dempsey, 1986). While this may be the case in the normal healthy young adult, it is becoming more accepted that in certain populations, such as elite endurance athletes (Guenette et al., 2007) or patients suffering from cardiopulmonary diseases (Hamilton et al., 1996), the respiratory system can be a limiting factor to exercise tolerance. As alluded to earlier, the respiratory muscles can become fatigued and, like any other fatigable muscles, can respond to training. However, the varied results of IMT have made the utility of training respiratory muscles in health and disease the subject of debate (McConnell, 2012; Patel et al., 2012).

Training the respiratory muscles takes many forms. Respiratory muscle training (RMT) has been examined from an expiratory (Suzuki et al., 1995; Roth et al., 2010) and a combined inspiratory and expiratory perspective (Wells et al., 2005) but the most commonly used protocols involve only IMT. Studies have used IMT in healthy humans (Enright et al., 2006; Guenette et al., 2006; Guy et al., 2014), elite athletes (Romer et al., 2002; Griffiths & McConnell, 2007), and clinical populations (Covey et al., 2001; de Jong et al., 2001; Correa et al., 2011). Three types of RMT, and particularly IMT, are most common. The first being pressure threshold loading.
Pressure threshold loading refers to a technique where each participant is required to generate enough negative inspiratory pressure to overcome the resistance of a load. This allows for precise management of the inspiratory load and provides resistance independent of flow. Two other, less common types of RMT are voluntary isocapnic hyperpnoea and inspiratory flow resistive loading (IFRL). Voluntary isocapnic hyperpnoea requires the participant to continuously breathe at a high $\dot{V}_E$ for an extended period. In order to prevent hypocapnia, the participant re-breathes through dead space to maintain isocapnia while breathing supplemental $O_2$ to avoid hypoxemia (Spengler et al., 1999; McConnell & Romer, 2004). This technique allows the participant to closely mimic exercise induced hyperpnoea but is also time consuming and requires a high level of participant motivation (McConnell & Romer, 2004). The final technique, IFRL, involves breathing through an orifice of varying diameter. For any given flow, there is more resistance for a smaller diameter. This technique is simple to implement and the intensity is easily modifiable. A limitation of this approach is that the training load is affected by flow. Thus, breathing frequency must be monitored and maintained, in order to sustain a consistent resistance. Of the three types of RMT, pressure threshold loading is the most user-friendly and the simplest to implement a sham treatment condition. Consequently, pressure threshold loading is an attractive method for studying IMT in a research or field setting (McConnell & Romer, 2004).

The evidence supporting the efficacy IMT is varied. While IMT can increase diaphragm thickness, measured at total lung capacity (Enright et al., 2006), the primary result of IMT is an increase in MIP. Despite the physiological changes to the diaphragm it appears that the improvements to inspiratory muscle strength are mediated by secondary respiratory muscles (Brown et al., 2014). Indeed, during a session of pressure threshold loading IMT, several
Accessory respiratory muscles, including the SCM, SCA, 7IC and PIC, are all co-active with the diaphragm (Ramsook et al., 2016). Reports are scattered between providing a positive effect of IMT on exercise performance in athletes (Romer et al., 2002; Griffiths & McConnell, 2007; Guy et al., 2014) and patients with respiratory disease (Scherer et al., 2000; Covey et al., 2001; Koppers et al., 2006), or providing no benefit (Larson et al., 1999; de Jong et al., 2001; Forbes et al., 2011).

A substantial limitation of some of the earlier “null finding” studies is their poor statistical power, which increased their probability of committing a type II error (Edwards & Walker, 2009). A second criticism of some of these IMT studies is the exercise modality chosen to characterize exercise performance. Specifically, exercise tests performed at high intensities (≥ 85% \( \dot{V}O_{2\text{max}} \)) lack applicability to real-life exercise conditions. As such, this may also impact the validity of these tests and result in type II error (McConnell & Romer, 2004).

Even among the studies that show an impact on exercise performance, the precise physiological mechanisms that dictate these improvements are not well understood. Some proposed mechanisms include a delay in respiratory muscle fatigue; whereas others cite a redistribution of blood flow; or a decreased influence of psycho-physiological factors such as dyspnoea and limb discomfort (Romer & Polkey, 2008).

Attenuating the respiratory muscle metaboreflex is another proposed mechanism for improving exercise performance following IMT. After a five-week IMT intervention, Witt et al. (2007) indirectly evaluated sympathetic responses by measuring HR and mean arterial pressure. While the changes to HR and arterial pressure are primarily influenced by mechanoreceptors responding to the mechanical deformation of the diaphragm, and have an earlier onset than their metaboreceptor counterparts, the mechanoreceptors are still governed by type III afferent nerves,
just as in the metaboreflex. After IMT, participants performed the same resistive breathing task at an intensity designed to induce diaphragmatic fatigue, thus eliciting a metaboreflex response (Witt et al., 2007). The authors found a significant reduction in HR and mean arterial pressure, while inspiratory force generation remained unchanged. This attenuation of fatigue-induced increases in HR and mean arterial pressure suggests that IMT can reduce sympathetic responses to the fatigued diaphragm. Some of the methodological limitations to this study warrant caution when generalizing its findings to the exercising population. Namely, subjects performed the resistive breathing task while seated; thus, no inferences can be made regarding blood flow competition, as the limb muscles were inactive and not competing with the respiratory muscles (as would occur during whole body exercise). Nevertheless, the above study provides a foundation for future work to examine the dynamic and complex interrelationship between breathing and exercise, as well as the potential role that IMT can play in improving exercise performance (Witt et al., 2007).

In addition to its inconsistent effect on exercise performance, IMT has seen conflicting results regarding its ability to reduce dyspnoea in healthy adults (Suzuki et al., 1993; Volianitis et al., 2001; Romer et al., 2002). Though a recent systematic review found a mean difference in favour of IMT over control interventions, it should be noted that this standardized mean difference was the result of small study mean differences with high variability (HajGhanbari et al., 2013). Nonetheless, the physiological rationale for decreasing dyspnoea after IMT could be the result of a decrease in the perception of load intensity (McConnell & Romer, 2004). IMT is known to increase respiratory muscle strength, as seen through improvements in maximal inspiratory pressure. This results in a decrease in the fractional utilization of the maximum tension generated per breath, which in turn may reduce the perception of respiratory effort.
(Kellerman et al., 2000). However, because dyspnoea is rarely a measured outcome in IMT studies, further investigation is required. This includes examining both the intensity and the qualitative aspects of dyspnoea, akin to studies in clinical populations.

**Conclusions**

Despite the traditional view of the lung being “overbuilt” for exercise, it is clear there are several circumstances where the respiratory system can limit exercise performance in humans. The haemodynamic response elicited through the respiratory muscle metaboreflex potentially limits the locomotor muscles through a redistribution of blood flow to the respiratory muscles. This reduction in blood flow to the locomotor muscles means a decrease in energetic substrates, and can limit the locomotor muscle’s ability to perform external work. The sensory response to exercise includes dyspnoea and peripheral muscle fatigue. While dyspnoea itself is not the primary reason for stopping exercise, the interrelated nature between peripheral limb fatigue and dyspnoea can have an additive effect that ultimately leads to premature exercise cessation. Both of these factors have been attenuated in the past through manipulating $W_b$, resulting in improved exercise performance. Albeit the evidence is more varied, some believe that IMT can similarly mitigate these negative responses to exercise.

Although the ability of IMT to improve inspiratory muscle strength is well established, results on exercise performance are more controversial. Adding to the debated efficacy of IMT is the poor understanding of the physiologic adaptations that follow a typical IMT program. A number of mechanisms are contenders to improve exercise performance following training. These include improving the competition for blood flow between respiratory and locomotor muscles, attenuating respiratory muscle fatigue as well as reducing dyspnoea.
Aims & Hypotheses

The overall aim of this study was to perform a comprehensive evaluation of the physiological and sensory adaptations following a period of IMT in healthy, non-elite, male subjects. We had three specific aims.

_Aim 1_

Our primary aim was to explore any changes to EMG in the diaphragm (EMGdi) and extradiaphragmatic inspiratory muscles (SCM and SCA) following IMT. We measured EMG of all three muscles during an incremental exercise test to exhaustion to track the evolution of respiratory muscle activation during exercise.

_Hypothesis 1_

We hypothesized that there would be a reduction in EMGdi after IMT, that would not be present in the control group. With respect to the extradiaphragmatic inspiratory muscles, we hypothesized a decrease in EMG after IMT. Combined these two findings would reflect inspiratory muscles performing the same absolute work at a lower relative intensity.

_Aim 2_

Our second aim was to examine if reductions in dyspnoea after IMT would be related to any changes in EMG. We similarly measured dyspnoea perceived leg discomfort throughout an exercise test to track the evolution of these two sensations.

_Hypothesis 2_

We hypothesized that a reduction in EMGdi would coincide with a reduction in dyspnoea. This is based on previous work that showing a strong relationship between EMGdi
and dyspnoea intensity across the spectrum of health and chronic respiratory diseases (Schaeffer et al., 2014; Jolley et al., 2015; Faisal et al., 2016).

*Aim 3*

Our third aim was to explore any haemodynamic changes measured by NIRS in respiratory muscles (SCM, PIC, 7IC) and limb locomotor muscles (VL).

*Hypothesis 3*

We hypothesized that we would see increases in HHb in the respiratory muscles. This would reflect an improved O$_2$ extraction at the muscle vascular beds, a mark of muscular metabolic efficiency. Additionally, we hypothesized that we would observe increases in tHb in the VL after IMT. Increases in tHb would reflect an increase in blood volume. In the VL this could represent the early stages of a delay in the respiratory muscle metaboreflex and thus, a delay in the vasoconstriction that limits locomotor blood flow that accompanies a period of great respiratory work.

**METHODS**

This study received ethical approval from the Providence Health Care Research Ethics Board (UBC-PHC REB Number: H14-00067) and was registered with ClinicalTrials.gov (Identifier: NCT02243527). All data were collected at the Cardiopulmonary Exercise Physiology (CPEP) Laboratory located at St. Paul’s Hospital in Vancouver, British Columbia, Canada.

**Subjects**

In total, 25 subjects completed this study. Subjects were recruited from the public through flyers and advertising around the University of British Columbia, and various social
media outlets. Additionally, six subjects provided written informed consent to participate, but did not complete the study. All six subjects withdrew after completing visit one, but before completing visit two (see: Results – Participant Characteristics). All subjects who enrolled in the experiment were healthy young adults, who were categorized as moderate-to-high using the last seven days self-administered International Physical Activity Questionnaire (IPAQ) short form (Craig et al., 2003) (Appendix i). Details regarding the subject inclusion and exclusion criteria can be found below in Table 1.

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
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<tr>
<td>Male</td>
<td>History of or currently smoking</td>
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<tr>
<td>19-39 years (inclusive)</td>
<td>History of or current symptoms of cardiopulmonary disease</td>
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<tr>
<td>Recreationally active, scoring “Moderate” or “High” on IPAQ questionnaire</td>
<td>Currently participating or training in a sport at a provincial, national, or international level</td>
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<td>Able to read and understand English</td>
<td>Ulcer or tumour in the esophagus</td>
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<td>Pulmonary function within normal limits</td>
<td>Recent nasopharyngeal surgery</td>
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<td>Allergies to latex or local anesthetic</td>
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<td>Contraindications to exercise testing</td>
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*Table 1. Inclusion and exclusion criteria. Abbreviation: IPAQ, international physical activity questionnaire*

**Experimental Overview**

Subjects were randomly assigned to either an experimental inspiratory muscle training group (IMT) or a sham-control (SC) group. All participants were blinded to their group allocation, and were told they were in either a ‘strength’ group (i.e., IMT) or an endurance group (i.e., SC). Participants reported to the CPEP Laboratory for seven visits. These visits were split between three exercise visits and four training visits. The first exercise visit (V1), served to screen and familiarize each participant. During this session, written informed consent was obtained prior to the completion of physical activity classification (IPAQ), exercise participation
eligibility (Physical Activity Readiness Questionnaire, PAR-Q+ (Appendix ii), and medical history. Following participant screening, anthropometrics (i.e., body mass, height, and skinfold thickness) were measured, along with maximal handgrip strength and detailed pulmonary function testing, including measurements of spirometry, maximal voluntary ventilation (MVV), and maximal inspiratory (MIP) and expiratory (MEP) pressures. V1 concluded with a maximal incremental cycle exercise test (ICET) performed until volitional exhaustion. This initial ICET served to familiarize participants with maximal exercise testing and to familiarize subjects with dyspnoea evaluation, as well as to cue participants on the posture necessary when performing an ICET while instrumented with sEMG and NIRS optodes. Specifically, participants were asked to fix their vision straight ahead, to minimize any head or neck movement, and to keep a loose grip on the handlebars.

No less than 48 hours after completing V1 participants returned to the laboratory for their second exercise visit (V2). V2 involved a subset of the pulmonary function tests performed on V1 and an ICET. During this ICET, each participant was instrumented with a multi-pair oesophageal electrode catheter to measure crural diaphragm EMG (EMGdi), as well as oesophageal (Peso) and gastric pressures (Pga); surface EMG (sEMG) electrodes to record muscle activity; and NIRS optodes to measure NIRS-derived variables (HbO₂, HHb, tHb) during incremental exercise. These instruments and their respective physiological outcomes are outlined in greater detail below. Throughout the ICET, subjects were asked to rate their dyspnoea and perceived leg discomfort (RPE_legs), and to select from a list of descriptors that identify the qualitative aspects of their breathing sensations. The final exercise visit, visit 3 (V3) was identical to V2 and took place after five weeks of either IMT or SC training. Participants
were asked to refrain from both IMT/SC training and vigorous physical activity 48 hours before V3.

Over the course of the five-week training period, participants would return to the laboratory once per week, for a total of four supervised training visits. These visits were required to ensure the IMT group was training at an appropriate intensity, and to reinforce the legitimacy of the SC group. If a participant in the IMT group was training at an intensity lower than a 30-repetition maximum, the intensity was increased by the researcher to ensure an adequate training load. During each of the supervised training visits, sEMG electrodes were positioned over respiratory muscles to monitor the electrical activity of these muscles during IMT. Upon completing the study, each participant was debriefed as to the true nature of their respective intervention group, as well as the true purpose of the study.

Exercise Protocol

The ICET protocol for V1, V2, and V3 were identical. Each test was performed on an electronically braked cycle ergometer (VIAasprint 200P; Ergoline, Bitz, Germany). The test began with a steady state resting period lasting no less than 6 minutes. In this time a baseline measurement of dyspnoea and RPE\textsubscript{leg} were recorded, as well as a minimum of three inspiratory capacity manoeuvres (IC). A one-minute warm-up of unloaded pedaling preceded the exercise test, which began at a work rate of 25 W and increased in a stepwise fashion by 25 W every two minutes until volitional exhaustion. Participants pedaled at a freely chosen cadence (> 60 rpm), and all ergometer measurements (i.e., seat height, seat position, handlebar angle/height) were recorded and reproduced for all subsequent tests.
Inspiratory Muscle Training

Both IMT and SC groups performed their respective versions of training with a POWERbreathe K3 device (HaB International Ltd., Southam, Warwickshire, UK). The K3 model is a variable flow resistive device that employs an electronically controlled valve to apply a variable resistance over the course of inspiration. This allows the K3 to reduce the absolute load over the course of an inspiration, so as to maintain the same relative load on the inspiratory muscles in accordance with the pressure-volume relationship of the inspiratory muscles (Charususin et al., 2013). The IMT group trained five days per week for five weeks, at two sessions per day (morning and evening). Each session included 30 sharp inspiratory efforts from residual volume (RV). The POWERbreathe K3 includes a respiratory muscle warm-up for the first four breaths, which are completed at an intensity less than the target training intensity. Repetitions 5-30 were completed at the targeted intensity. Any repetition that failed to meet the target intensity did not count towards the total completed repetitions for that session. Following V2 the initial intensity was set at 50% of the participant’s MIP, determined on V2. Participants in the IMT group were instructed to increase the training intensity freely, such that they were training at a 30-repetition maximum intensity. The SC group also trained for a total of five weeks. The intensity of the SC group was fixed at 10% of MIP, determined on V2. The SC group participants trained once per day for a total of 60 repetitions, five days per week. Each training breath was described as being a slow, protracted, deliberate breath. Previously, a six-week intervention at 15% of MIP has been shown to be an effective sham protocol that elicits no training effect on the subjects (Romer et al., 2002).
Measurements

Questionnaires

After providing informed consent during V1, all participants completed various questionnaires to help characterize the study sample, and to confirm their eligibility to participate in this study. Questionnaires included the IPAQ, to categorize each participant’s physical activity level throughout the entirety of the study; the PAR-Q+, to confirm each participant would be safe to participate in an exercise study; and a custom questionnaire to record medical history. During the training period, participants were asked to keep a physical activity log, quantifying hours of vigorous exercise, moderate-intensity exercise, and walking.

Pulmonary Function

Measures of spirometry and respiratory pressures were conducted on a commercially available cardiopulmonary testing system (Vmax 229d with Autobox 6,200 DL; SensorMedics, Yorba Linda, CA) according to standard recommendations (American Thoracic Society/European Respiratory, 2002; Miller et al., 2005). Values have been expressed relative to previously established predicted values in a Canadian population (Gutierrez et al., 2004; Tan et al., 2011).

Handgrip Strength

Handgrip strength was measured before starting and after completing training. This measure was intended to assess each participant’s ability and motivation to perform a maximal voluntary contraction. The maximal handgrip strength test involves muscle groups unaffected by IMT. Therefore, an improvement in MIP without an increase in handgrip strength test was indicative of a true improvement in MIP, as opposed to a greater voluntary effort in performing MIP manoeuvres.
Cardiopulmonary Responses to Exercise

Standard metabolic, pulmonary gas exchange, and ventilatory responses (O₂ consumption, ŶO₂; CO₂ production, ŶCO₂; partial pressure of end-tidal CO₂, PETCO₂; minute ventilation, ŶE; tidal volume, VT; and breathing frequency) were measured using a commercially available metabolic cart (Vmax 229d with Autobox 6,200 DL; SensorMedics, Yorba Linda, CA). These variables were recorded on a breath-by-breath basis and then averaged over 30-second epochs. During rest and at the end of each stage of exercise, participants performed IC manoeuvres to calculate both end-inspiratory (EILV) and end-expiratory lung volumes (EELV) as previously described (Guenette et al., 2013). Operative lung volumes are expressed as %total lung capacity (TLC) where TLC was calculated as the sum of functional residual capacity (measured using plethysmography) and IC measured during pulmonary function tests measured on the same day. Heart rate (HR) was continuously measured using a commercially available heart rate monitor (Polar T34; Polar Electro, Kempele, Finland). Arterial O₂ saturation was monitored continuously during exercise via pulse oximetry (Radical-7 Pulse CO-Oximeter, Masimo Corporation, Irvine, California).

Dyspnoea Evaluation

Every minute during exercise participants identified their dyspnoea, defined simply as “a feeling of laboured or difficult breathing” using the modified 0-10 category ratio Borg Scale (Borg, 1982). Points 0 and 10 on the Borg scale were subjectively defined as “no breathing discomfort at all” and “the most intense breathing discomfort [they] have every experienced or could ever imagine experiencing”, respectively. Each participant was asked to point to a number on the scale (Appendix viii) when prompted with the question “What is your breathing discomfort, overall”. The two previous measurements were also made immediately after each
exercise test ended. Additionally, at the end of exercise participants were asked to: first, state their primary reason for stopping exercise (i.e., breathing discomfort, leg discomfort, a combination of the two, or another reason); second, attribute a percentage, to both breathing and leg discomfort, that contributed to exercise cessation; and finally, choose appropriate qualitative descriptors of breathlessness using a modified version of a previously established questionnaire (Appendix vii) (Simon et al., 1990).

Perceived Exertion

Immediately after being asked about their dyspnoea, each participant similarly rated the perceived exertion of their legs (i.e., RPE\textsubscript{legs}), simply defined as “the feeling of fatigue in [their] leg muscles”, omitting any contribution of discomfort from their joints. Rating of perceived exertion of the legs (RPE\textsubscript{legs}) was anchored in the same way as dyspnoea (i.e., a 0 on the Borg scale would equate to no leg discomfort at all, and a 10 on the scale would equate to the most intense leg discomfort the participant had every experienced or could ever imagine experiencing).

Electromyography

Activation of two respiratory muscles (SCM and SCA) and the VL muscle was assessed using a wireless sEMG system with bipolar Ag/AgCl electrodes (inter-electrode spacing: 2.0 cm) (TeleMyo DDTS, Noraxon USA, Inc., Scottsdale, AZ, USA). Electrodes were placed midway along the long axis between the mastoid process and medial clavicle for the SCM (Shadgan et al., 2011). The SCA EMG electrode was placed in the posterior triangle of the neck at the level of the cricoid cartilage (Segizbaeva et al., 2013). Finally, the electrode for the VL was placed 2/3 of the distance from the anterior superior iliac spine to the lateral patella in accordance with SENIAM recommendations (Hermens, 1999). Placement of all electrodes was confirmed by
visual inspection and by palpating the associated area during respiratory manoeuvres (SCM and SCA) and knee flexion/extension (VL). All measurements were made on the right side of the body in an effort to minimize cardiac artifact.

A multi-pair oesophageal electrode catheter was used to measure EMGdi. The catheter contains nine recording electrode coils and one grounding coil. The nine recording coils form five recording pairs (1:5, 2:6, 3:7, 4:8, and 5:9) with an inter-electrode distance of 4.4 cm. The placement of the catheter is determined using the multiple EMG pairs. When the largest amplitude of EMG activity during tidal breathing appears in pairs 1 and 5 in combination with lower amplitude in pairs 2 and 4, and the lowest amplitude in pair 3, the catheter is considered to be placed at the level of the diaphragm (Luo et al., 2011). Multiple recording pairs are required to compensate for changes in posture or lung volumes during exercise. This redundancy ensures an appropriate measure of EMGdi throughout exercise. A topical anesthetic in the form of a non-aerosol lidocaine hydrochloride spray (Lidodan® Endotracheal Spray, Odan Laboratories Ltd., Montréal, QC, Canada) was used to minimize patient discomfort during insertion of the oesophageal catheter.

All raw EMG signals were sampled at 2000 Hz, amplified and processed through a notch filter at 60 Hz (bio-amplifier model RA-8, Yinghui Medical Technology Co. Ltd., Guangzhou, China), and further processed via band-pass filter between 20 and 1000 Hz. Filtered EMG data were then transformed into root mean square (RMS), averaged over 0.1 second. The peak RMS of the EMG data for SCM (EMGscm), SCA (EMGsca), and EMGdi were selected during periods of inspiration, free of visible cardiac artifact on a breath-by-breath basis for periods of data collection. In an effort to improve the signal-to-noise ratio in the EMGscm and EMGsca signals, the mean RMS of the EMG data of these respective muscles during expiration at baseline were
subtracted from all subsequent EMG data. This was done because both SCM and SCA are not notably active on expiration. In the case of EMGdi, the electrode pair that measured the greatest EMG activity for any given breath was used in the analysis. These data were then expressed relative to the maximal activation achieved during any IC manoeuvre performed at rest or during exercise on that visit to the laboratory (%max), as well as in absolute terms (µV). For the EMG of the VL (EMGvl) the average of the peak RMS for each contraction per stage was expressed relative to the maximal RMS generated against a maximal isometric knee extension (%max), and in absolute units (µV).

*Respiratory and Locomotor Muscle Oxygenation*

Changes in concentration of haemoglobin in its oxygenated (HbO$_2$), and deoxygenated (HHb) states were measured using continuous-wave NIRS (Oxymon MkIII, Artinis Medical Systems, BV, The Netherlands). The sum of the HbO$_2$ and HHb signal is total haemoglobin (tHb), and is used as a surrogate for blood volume (Mancini *et al.*, 1994). Optodes were placed on the left SCM, parasternal intercostals (PIC), 7$^{th}$ intercostal space (7IC), and VL. Optodes for SCM and VL were positioned in the same fashion as the EMG electrodes on the contralateral side. The PIC optodes was positioned 3 cm lateral to the sternum in the second intercostal space. The 7IC optode was placed in the intercostal space below the 7$^{th}$ rib along the anterior axillary line (Shadgan *et al.*, 2011). All optodes were held in place at a fixed interoptode distance (SCM, PIC, 7IC = 2.5 cm, VL = 4.0 cm) with a black plastic holder that minimized outside light interfering with the NIRS signal. Skinfold measurements were made at each NIRS optode site on each visit, to ensure the amount of subcutaneous adipose tissue would not interfere with the NIRS signal. The limit on skinfold thickness was set at 10 mm (Shadgan *et al.*, 2011). NIRS
data were sampled at 50 Hz and then averaged into 30-second epochs. The values were all expressed as a change from baseline.

*Respiratory Mechanics*

The oesophageal catheter used to measure EMGdi also houses two balloons that measured Peso and Pga. Both balloons were connected to calibrated differential pressure transducers (model DP15-34, Validyne Engineering, Northridge, CA, USA). After insertion, participants evacuated the balloons by performing a *valsalva* manoeuvre. After confirming the balloons were empty of air by testing with a glass syringe, a known volume of air (0.5 mL and 1.2 mL in the oesophageal and gastric balloons, respectively) were introduced via a syringe. Transdiaphragmatic pressure (Pdi) was the calculated difference between Pga and Peso. \( W_b \) was determined as the area within an averaged tidal Peso-volume loop as described by previously (Dominelli & Sheel, 2012). This value was then multiplied by breathing frequency to calculate the total \( W_b \) in joules/min (i.e., unit of power). To assist in comparing \( W_b \) across a variety of \( V_E \) values, \( W_b \) curves were created for each individual participant on each visit assuming the relationship of:

\[
W_b = aV_E^3 + bV_E^2
\]

Where the term \( aV_E^3 \) represents the work done to overcome resistance to turbulent flow and \( bV_E^2 \) represents the work done to overcome the mechanical work done in overcoming the viscous resistance to deformation and the respiratory tract to the laminar flow of air (Milic-Emili *et al.*, 1962). Averages of constants \( a \) and \( b \) that significantly contributed to the generation of the \( W_b \) curve were then used to create a composite \( W_b \) curve for each group both before and after intervention.
Analysis of Exercise End-Points

All physiological exercise variables were averaged in 30s bins. The time between 60-90 seconds of each stage was designated as our primary window of data collection. During this time, participants were reminded to look straight forward, minimizing any head or neck movement, keep a loose grip on the handlebars, and to avoid talking or swallowing to minimize contamination of our outcomes of interest. The data obtained during this period of each stage was linked to dyspnoea and perceived leg discomfort ratings during the last 30 seconds of each stage (i.e., from 90-120 seconds). Lastly, as close to the end of the stage as possible subjects would perform their IC manoeuvre.

Statistical Analyses

An initial sample size calculation was performed on the basis of previous work (Schaeffer et al., 2014) showing a decrease in EMGdi by 10%max correlated with a difference in dyspnoea by 1 Borg unit with an alpha of 0.05 and a beta value of 0.8. This calculation yielded a sample size of 11 subjects per group to detect a significant decrease in EMGdi. Statistical tests were performed using SPSS Statistics (Version 21.0.0.0, IBM Corporation, Armonk, New York, USA). Baseline comparisons of pulmonary function and exercise responses between groups were made using unpaired t-tests. Pre-post comparisons of subject characteristics, pulmonary function, anthropometry, and exercise measurements were made using paired t-tests. Between study group differences in the pre-post differences for MIP, dyspnoea, RPE\textsubscript{legs}, and all NIRS- and EMG-derived variables were tested using repeated measures analysis of variance with Greenhouse-Geisser correction. The between subjects factor tested was SC versus IMT group and the within subjects factor was the pre-post difference in the outcomes across work rates. The
interaction term was evaluated first, and when significant, post-hoc comparisons in the pre-post differences between groups were performed. In the current data set no significant interaction effects were observed. As a result, only the between subjects factors were considered. These t-tests were performed at 0, 25, 50, 75, 100, 125, and 150 W; the highest equivalent work rate (HEWR) completed by an individual on both visits; and peak exercise, where peak exercise was defined as the highest work rate maintained for at least 30 seconds. Constants $a$ and $b$ in the $W_b$ equations for each individual that significantly correlated to their specific $W_b$ curve were averaged and compared pre- vs. post using an unpaired t-test. Differences in qualitative descriptors of dyspnoea and reasons for stopping exercise were performed with a paired McNemar’s test. Significance was set at $p \leq 0.05$ and all data are presented as mean ± standard deviation (SD). All exercise data were stored under pseudonyms to hide each subject and visit identifier effectively blinding the assessor for processing. Upon completing all data processing under these pseudonyms, all files were reverted to their original identifiers to allow for data analysis.
RESULTS

Participant Characteristics

A total of 31 males were enrolled in this study. Of the 31, six did not complete the study. One subject was excluded during visit 1 as he presented with contraindications to exercise during the ICET (systolic blood pressure >220 mmHg). The remaining five subjects chose not to return after completing V1. The remaining 25 were randomly assigned to either IMT (n = 12) or SC (n = 13) groups. A detailed summary of the participant characteristics can be found in Table 2. Participants in the SC group were similar to their IMT counterparts at baseline for age, anthropometrics, baseline physical activity levels, and pulmonary function. All participants had normal pulmonary function. Self-reported physical activity levels were not different between groups at any point or within group after IMT or SC.
Table 2. Participant characteristics before and after intervention. Values are mean ± SD. † Significantly different from baseline (pre), p < 0.01. Abbreviations: MET, metabolic equivalent; FEV₁, forced expiratory volume in one-second; FVC, forced vital capacity; MIP, maximal inspiratory pressure. No significant differences were observed within or between group.

Peak exercise data can be found in Table 3. There were no statistically significant group differences in any baseline peak exercise responses. Peak data suggests that, on average, both groups exerted maximal effort on each ICET (e.g. heart rate approaching age-predicted maximum, perceptions of leg discomfort approaching maximal levels, and respiratory exchange ratio close to 1.10). There were no statistically significant differences in any peak exercise responses following IMT in both the IMT and SC groups.
Table 3. Peak exercise responses. Abbreviations: $\dot{V}O_2$, oxygen consumption; $\dot{V}CO_2$, carbon dioxide production; RER, respiratory exchange ratio; $\dot{V}_E$, minute ventilation; $V_T$, tidal volume; $F_b$, breathing frequency; $\dot{V}_E/\dot{V}O_2$, ventilatory exchange ratio for oxygen; $\dot{V}_E/\dot{V}CO_2$, ventilatory equivalent for carbon dioxide; PETCO$_2$, partial pressure of end-tidal carbon dioxide; EELV, end-expiratory lung volume; TLC, total lung capacity; EILV, end-inspiratory lung volume; HR, heart rate. No significant differences were observed within group-pre vs post or between groups at baseline.

Training

Adherence to interventions was good in both groups. The IMT group completed 94% whereas the SC group completed 88% of assigned training sessions. MIP was significantly improved after five-weeks of IMT in the IMT group but not in the SC group (see also Table 2 and Figure 1). There was no significant difference in handgrip strength in both the IMT and SC groups (Table 2).
Figure 1. Maximal inspiratory pressure before and after IMT and SC interventions. Values are mean ± SD. †, p < 0.01 within group. *, p < 0.05 between groups.

**EMG During Training**

Figures 2 through 5 illustrates the EMG response of the SCM, SCA, PIC, and 7IC, respectively during the supervised training visits, while performing a session of IMT or SC training. The IMT intervention resulted in significantly greater EMG activity in each muscle, at all time points, compared to the SC intervention. When expressed as µV, there was a significant increase in the SCM at weeks two and four compared to week one in the IMT group (see Figure 2).
Figure 2. EMG of SCM during a session of IMT or SC training. Data were taken from the supervised training session each week. EMG data are expressed relative to maximum voluntary contractions performed during each training session (%max). Abbreviations: EMGscm, sternocleidomastoid electromyography; IMT, inspiratory muscle training group; SC, sham control group. Values are mean ± SD. *, p < 0.05 between groups for given week. †, p < 0.05 within group compared to previous week.
Figure 3. EMG of SCA during a session of IMT or SC training. Data were taken from the supervised training session each week. EMG data are expressed relative to maximum voluntary contractions performed during each training session (%max). Abbreviations: EMGsca, scalene electromyography; IMT, inspiratory muscle training group; SC, sham control group. Values are mean ± SD. *, p < 0.05 between groups for given week.
Figure 4. EMG of PIC during a session of IMT or SC training. Data were taken from the supervised training session each week. EMG data are expressed relative to maximum voluntary contractions performed during each training session (%max). Abbreviations: EMGpic, parasternal intercostal electromyography; IMT, inspiratory muscle training group; SC, sham control group. Values are mean ± SD. *, p < 0.05 between groups for given week.
Figure 5. EMG of 7IC during a session of IMT or SC training. Data were taken from the supervised training session each week. EMG data are expressed relative to maximum voluntary contractions performed during each training session (%max). Abbreviations: EMG7IC, seventh intercostal electromyography; IMT, inspiratory muscle training group; SC, sham control group. Values are mean ± SD. *, p < 0.05 between groups for given week.

Training Intensity

Training intensity, assessed in absolute terms using mouth pressure (P_m), significantly increased from the initial training session by week three, and continued to increase through week four in the IMT group, and remained unchanged in the SC group (Figure 6). By design, there was a significant difference in training intensity every week of training between the IMT and SC groups (p < 0.001).
Exercise

Ventilatory Responses to Exercise

Baseline values across all time points for $f_b$, $V_T$, and $\dot{V}_E$ were not different between groups (Table 3). Neither IMT nor SC groups displayed any changes to breathing patterns after their respective intervention (Table 3). The $\dot{V}_E$, $V_T$, and $f_b$ responses are shown in Figures 7, 8 and 9, respectively.
Figure 7. Minute Ventilation during exercise in IMT (top) and SC (bottom) groups. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group. Values are mean ± SD. No significant differences were observed.
Figure 8. Tidal volume during exercise in IMT (top) and SC (bottom) groups. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group. Values are mean ± SD. No significant differences were observed.
Figure 9. Breathing frequency during exercise in IMT(top) and SC(bottom) groups. Abbreviations: IMT, inspiratory muscle training; SC, sham control group. Values are mean ± SD. No within group differences were observed.
**EMG During Exercise**

Of the 12 IMT subjects, only 11 were able to tolerate the oesophageal catheter. EMGdi during exercise before and after IMT can be seen in relative terms in Figure 10, and in absolute terms in Figure 11. The EMGdi response during exercise followed similar trends in both groups, both pre- and post-intervention. Briefly, the EMGdi displayed little activity at baseline and followed a linear increase until peak exercise. There was a significant decrease in EMGdi at the 50 W stage of exercise after IMT (pre: 20.2 ± 9.5 vs. post: 15.3 ± 8.1 μV, p < 0.05) but at no other points were EMGdi values significantly different, nor were any trends present. However, this difference was not observed when expressed in relative terms. No significant differences were present at any time points in the SC group when expressed as absolute or relative values.
Figure 10. Normalized EMGdi response during exercise in IMT (top) and SC (bottom) groups. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGdi, crus diaphragm electromyography; IMT, inspiratory muscle training group; SC, sham control group; HEWR, highest equivalent work rate. No significant points were observed in either group.
Figure 11. Absolute EMGdi during exercise for IMT (top) and SC (bottom) groups. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGdi, crural diaphragm electromyography; IMT, inspiratory muscle training group; SC, sham control group; HEWR, highest equivalent work rate. *, p < 0.05 within-group comparison.
Surface EMG data for selected work rates were excluded in 4 subjects for SCM and 5 subjects for SCA within the IMT group and 1 subject from SCM in the SC group. The decision to exclude a subjects’ data was based on the judgement of the assessor. Reasons for exclusion include poor signal quality (most often the result of sweat pooling around the electrode site) or electrodes not sticking to the participant throughout exercise. The SCM remained relatively inactive throughout the early stages of exercise. In the IMT group, only at the HEWR and peak exercise did we observe a noticeable increase in activity relative to resting values (Figure 12 and Figure 13). Similarly, in the SCM a significant decrease in EMGscm was found also at 50 W after IMT (pre: 2.1 ± 1.7 vs. post: 1.0 ± 0.9 µV and pre: 1.1 ± 1.0 vs. post: 0.4 ± 0.3 %max, n = 11, p < 0.05). Despite this, there were no significant differences at any other work rates after training.
Figure 12. Normalized EMGscm during exercise for IMT (top) and SC (bottom) groups. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGscm, sternocleidomastoid electromyography; IMT, inspiratory muscle training group; SC, sham control group, HEWR, highest equivalent work rate. Values are mean ± SD. No significant differences were observed.
Figure 13. Absolute EMGscm during exercise in IMT (top) and SC (bottom). First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGscm, sternocleidomastoid electromyography; IMT, inspiratory muscle training group; SC, sham control group, HEWR, highest equivalent work rate. Values are mean ± SD. *, p < 0.05.
The EMGsca displayed a similarly shaped curve to the EMGscm. The EMGsca activity was low at rest and remained so until 125 W. From this point onward, the activity in the SCA appeared to be curvilinear with increasing work rates until peak exercise (Figure 14 and Figure 15). We observed no statistically significant changes in EMGsca in the IMT group. However, in the SC group, a statistically significant increase in activity occurred at the HEWR (pre: 26.5 ± 20.5 vs. post: 33.7 ± 23.2 µV, n = 13, p < 0.05) and peak exercise (pre: 38.1 ± 27.6 vs post: 42.6 ± 26.1 µV, n = 13, p < 0.05); although these differences were not seen when data were expressed relative to maximal activation.
Figure 14. Normalized EMGsca responses during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGsca, scalene electromyography; IMT, inspiratory muscle training group; SC, sham control group; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Figure 15. Absolute EMGsca during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGsca, scalene electromyography; IMT, inspiratory muscle training group; SC, sham control group; HEWR, highest equivalent work rate. *, p < 0.05.
EMGvl responses in the IMT and SC groups are shown in Figure 16. There was no meaningful activity at baseline. At the onset of exercise, EMGvl increased greatly relative to baseline, and continued to increase in a linear manner until peak exercise. We observed no changes in EMGvl in either group.
Figure 16. Normalized EMGvl response during exercise for both IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: EMGvl, vastus lateralis electromyography; IMT, inspiratory muscle training group; SC, sham control group; HEWR, highest equivalent work rate. No significant differences were observed in either group.


**Respiratory Pressures**

Peso swings during exercise are shown in Figure 17. In both IMT and SC Peso increases continuously from the onset of exercise until peak. After IMT, Peso was significantly lower only at 75 W (pre: 10.0 ± 1.9 vs. post: 8.6 ± 2.6 cmH$_2$O, p < 0.05). No other points were significantly different in the IMT group. Additionally, the SC group did not experience a change in Peso swings during exercise after their intervention.
Figure 17. Peso swings during exercise in IMT (top) and SC(bottom). Values are mean ± SD. Abbreviations: IMT, inspiratory muscle training; SC, sham control; Peso, oesophageal pressure. *, $p < 0.05$. 
Pdi swings during exercise can be found in Figure 18. The IMT group generated less Pdi after IMT at 50 W (pre: 12.0 ± 3.5 vs. post: 10.0 ± 3.0 cmH\(_2\)O, \(p < 0.05\)) and 125 W (pre: 18.1 ± 4.0 vs. post: 15.6 ± 3.3 cmH\(_2\)O, \(p < 0.05\)). Also at 125 W, the SC group generated greater Pdi (pre: 12.2 ± 3.5 vs. post: 13.8 ± 3.2 cmH\(_2\)O, \(p < 0.05\)) compared to their baseline values.
Figure 18. Pdi swings during exercise in IMT (top) and SC (bottom). Values are mean ± SD.
Abbreviations: IMT, inspiratory muscle training; SC, sham control; Pdi, transdiaphragmatic pressure swing. *, p < 0.05.
Work of Breathing

Figure 19 shows group mean curves before (solid line) and after (dashed line) IMT or SC interventions. Mean values for constants $a$ and $b$ can be found in Table 4. There were no differences in baseline $W_b$ between groups, nor did either group display a significant change in $W_b$ after their respective intervention.
Figure 19. Work of Breathing. Group data for IMT (top) and SC (bottom) groups created from constants a and b (see Table 4). Data have been extrapolated to 150 L/min. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group. No significant differences were observed in either group.
Table 4. Constants for $W_b$ equations for IMT and SC groups before and after training. Constant $a$ represents work to overcome resistance to turbulent flow, and $b$ represents work to overcome viscous resistance. Values are mean ± SD. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; $W_b$, work of breathing. No significant differences were observed in either group.

Respiratory and Locomotor Muscle Oxygenation

Similar to the EMG of the extradiaphragmatic respiratory muscles, not all subjects had complete NIRS datasets for each muscle of interest (SCM: IMT, $n = 9$; SC, $n = 11$, PIC: IMT, $n = 12$; SC, $n = 11$, 7IC: IMT, $n = 12$; SC, $n = 10$, VL: IMT, $n = 11$; SC, $n = 12$). The changes in concentration for all NIRS-derived variables in the SCM are shown in Figure 20, Figure 21, and Figure 22. The SCM HbO$_2$ response was relatively stable until the HEWR, with values staying slightly lower than baseline until this point. At the HEWR and at peak, there was a small decrease in SCM HbO$_2$. These changes coincided with a small, but statistically significant increase in the IMT group at 25 W after training (pre: $-2.1 ± 3.7$ vs. post: $0.8 ± 4.9$ ΔµM, $n = 12$, $p < 0.05$). However, this difference disappeared as exercise progressed. In the SC group, no changes were observed in HbO$_2$ at any work rates. HHb increased from baseline but remained relatively stable from 50 W until 150 W. HHb increase linearly from 150 W to peak. Changes in HHb were not significantly different in the SCM in either group after IMT or sham-training.

<table>
<thead>
<tr>
<th></th>
<th>Pre-IMT</th>
<th>Post-IMT</th>
<th>Pre-SC</th>
<th>Post-SC</th>
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<tbody>
<tr>
<td>$a$ (J×min$^{-1}$/L×min$^{-1}$)$^3$</td>
<td>$6.7 \times 10^{-5}$ ± $7.5 \times 10^{-5}$</td>
<td>$6.7 \times 10^{-5}$ ± $7.5 \times 10^{-5}$</td>
<td>$4.6 \times 10^{-5}$ ± $6.5 \times 10^{-5}$</td>
<td>$7.5 \times 10^{-5}$ ± $5.3 \times 10^{-5}$</td>
</tr>
<tr>
<td>$b$ (J×min$^{-1}$/L×min$^{-1}$)$^2$</td>
<td>$7.3 \times 10^{-3}$ ± $5.1 \times 10^{-3}$</td>
<td>$7.5 \times 10^{-3}$ ± $6.5 \times 10^{-3}$</td>
<td>$9.1 \times 10^{-3}$ ± $5.2 \times 10^{-3}$</td>
<td>$5.7 \times 10^{-3}$ ± $4.9 \times 10^{-3}$</td>
</tr>
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</table>
As tHb is measured as the sum of HHb and HbO₂, the tHb remained relatively constant until 150 W. Only at the HEWR and peak was there an increase from rest. At 25 W there was a significant increase in the change of tHb in the IMT group after training (pre: -2.5 ± 3.8 vs. post: 0.8 ± 5.8 ΔμM, n = 12, p < 0.05) that was not seen in the SC group.
Figure 20. $\text{HbO}_2$ response in the SCM during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; $\text{HbO}_2$, oxygenated haemoglobin; SCM, sternocleidomastoid; HEWR, highest equivalent work rate. *, p <0.05.
Figure 21. HHb response measured in the SCM during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HHb, deoxygenated haemoglobin; SCM, sternocleidomastoid; HEWR, highest equivalent work rate. No significant differences were observed.
Figure 22. tHb measured at the SCM during exercise in IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; tHb, total haemoglobin; SCM, sternocleidomastoid; HEWR, highest equivalent work rate. *, p < 0.05.
All NIRS-derived variables measured in the PIC are displayed in Figure 23, Figure 24, and Figure 25. Between 25 and 150 W, PIC HbO₂ remained slightly below baseline levels, and was stable until 150 W. The exception was in the case of the SC group, where there was a slight increase in PIC HbO₂ above resting levels at 150 W. The evolution of the HHb changes in the PIC was similar to the SCM. Specifically, during the early stages of exercise, there was little change from baseline – though the HHb concentration was slightly positive – and a rapid linear increase occurred after 150 W, progressing until peak exercise. Changes in tHb concentration were relatively similar to baseline until the HEWR. At the HEWR, there was an increase in tHb followed by a peak value lower than the HEWR. The magnitude of the decrease was not large enough to bring the tHb back to resting levels. Some specific statistically significant differences were noted in the PIC as well. At 50 W there was a significant increase in changes of HbO₂ in the PIC of the IMT group (pre: -3.6 ± 2.8 vs. post: -0.7 ± 2.7 ΔµM, n = 12, p < 0.05). These differences were no longer present as exercise continued above 50 W. Also in the PIC, the SC group displayed a lesser decrease in the change of HHb at 25 and 50 W after their sham-intervention (pre: 1.3 ± 2.3 vs. post: -0.2 ± 1.3 ΔµM, n = 11, p < 0.05 and pre: 1.7 ± 3.2 vs. post:-0.1 ± 1.9 ΔµM, n = 11, p < 0.05, respectively). In the IMT group, the only significant difference in PIC HHb was observed at 150 W (pre: 1.5 ± 1.1 vs. post: -0.4 ± 2.7 ΔµM, n = 12, p < 0.05). Lastly, for the PIC, no significant changes were observed in changes to tHb in either group.
Figure 23. HbO$_2$ response in the PIC during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HbO$_2$, oxygenated haemoglobin; PIC, parasternal intercostals; HEWR, highest equivalent work rate. *, $p < 0.05$. 
Figure 24. HHb response in the PIC during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HHb, deoxygenated haemoglobin; PIC, parasternal intercostals; HEWR, highest equivalent work rate. *, p < 0.05.
Figure 25. tHb response in the PIC during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; tHb, total haemoglobin; PIC, parasternal intercostals; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Within the 7IC, HbO₂ concentration remained relatively unchanged throughout the early stages of exercise (Figure 26). After 150 W, the 7IC experienced a continuous decrease in HbO₂ until peak. The 7IC increased in HHb at the onset of exercise that remained relatively stable, and appeared to decrease slightly as exercise continued (Figure 27). The increase in HHb at the onset of exercise was reflected in the tHb trace as well. This increase was followed by a decrease that resulted in tHb nearing resting levels at 150 W. After 150 W, there was a decrease in tHb that continued through HEWR to peak (Figure 28). Specifically, for the 7IC, no changes were observed in HbO₂ or tHb in either group. In the SC group there was a significant decrease in changes to HHb at the HEWR (pre: 4.6 ± 7.4 vs. post: 2.4 ± 6.8 ΔµM, n = 10, p < 0.05) that persisted at peak work rates (pre: 6.6 ± 9.2 vs. post: 3.8 ± 8.0 ΔµM, n = 10, p < 0.05).
Figure 26. HbO₂ response in the 7IC during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HbO₂, oxygenated haemoglobin; 7IC, 7th intercostals; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Figure 27. HHb response in the 7IC during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training; SC, sham control group; HHb, deoxygenated haemoglobin; 7IC, 7th intercostals; HEWR, highest equivalent work rate. *, p < 0.05.
Figure 28. tHb response in the 7IC during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; tHb, total haemoglobin; 7IC, 7th intercostals; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Finally, in the VL no significant differences were observed in any NIRS-derived parameter in either group at any work rate. There was a steady linear decrease in HbO$_2$ during exercise that continued until peak (Figure 29). Initially, HHb decreased from resting levels. During exercise, the HHb response appeared to adopt a linear increase that plateaued towards the end of exercise (Figure 30). As the magnitude of the changes in HHb was greater than that of the HbO$_2$ changes, the tHb response was nearly identical to that of the HHb response (Figure 31). The exception was at peak exercise, where there appeared to be a decrease in tHb relative to HEWR, as opposed to the plateau seen in HHb.
Figure 29. HbO₂ response in the VL during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HbO₂, oxygenated haemoglobin; VL, vastus lateralis; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Figure 30. HHb response in the VL during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HHb, deoxygenated haemoglobin; VL, vastus lateralis; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Figure 31. tHb response in the VL during exercise for IMT (top) and SC (bottom) groups. Values are mean ± SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; tHb, total haemoglobin; VL, vastus lateralis; HEWR, highest equivalent work rate. No significant differences were observed in either group.
Sensory Responses during Exercise

Dyspnoea

Figure 32 shows the ratings of dyspnoea in both IMT and SC groups. In all cases, the shapes of the curves were the same. Initially, participants displayed no breathing discomfort; however, beginning at 75 W, dyspnoea ratings then increased linearly until peak exercise. Subjects in the IMT group reported significantly lower dyspnoea ratings at 125 and 150 W after IMT (pre: 2.2 ± 1.4 vs. post: 1.6 ± 1.5 Borg units, p < 0.05; pre: 3.2 ± 1.5 vs. post: 2.3 ± 1.4 Borg units, p < 0.01) as well as at the HEWR (pre: 7.6 ± 2.5 vs. post: 6.8 ± 2.9 Borg units, p < 0.05). No changes to dyspnoea during exercise were present in the SC group after their intervention. At peak work rates, dyspnoea was unchanged in both IMT and SC groups. There was a significant difference in the Borg/V̇E slope after IMT (pre: 0.075 ± 0.019 vs. post: 0.066 ± 0.019 Borg scale units/L·min⁻¹, p < 0.001) however, Borg/V̇E slopes were not different in the SC group (pre: 0.080 ± 0.021 vs. post: 0.076 ± 0.031 Borg scale units/L·min⁻¹, p > 0.05).

At baseline we observed no differences between groups in their selection frequency of dyspnoea descriptors. Moreover, after IMT (Figure 34) or SC (Figure 35) there were no observed changes in descriptor selection frequencies. In the IMT group at baseline the most commonly selected phrases were “My breathing requires more work” and “Breathing in requires effort” (92% of participants) at baseline. Following IMT “Breathing in requires more work” remained the most frequently selected phrase (100% of participants) and “My breathing requires effort” was again selected by 92% of participants. Selection frequencies in the SC group were similar to the IMT group with 100% of participants describing their breathing as requiring “more work” and “my breathing is heavy”. After the SC training all participants labelled their
breathing “heavy”, while a single participant did not feel their breathing required more work (i.e., 92% felt their breathing required more work).
Figure 32. Breathing discomfort during exercise in IMT (top) and SC (bottom) groups. Abbreviations: IMT, inspiratory muscle training group SC, sham control group; HEWR, highest equivalent work rate. Data are presented as mean ±SD. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak exercise. *, p < 0.05.
Figure 33. Breathing Discomfort vs. Minute Ventilation during exercise in IMT (top) and SC (bottom) groups. Data are taken from each stage of exercise and expressed as mean ± SD. First dashed line connects the ventilation corresponding to 150 W to the ventilation corresponding to the HEWR; second dashed line connects ventilation corresponding to the HEWR to the ventilation corresponding to peak exercise.
Figure 34. Selection frequency of qualitative descriptors of dyspnoea at maximal exercise in IMT group. No statistical differences were present.
Figure 35. Selection frequency of qualitative descriptors of dyspnoea at maximal exercise in SC group. No statistical differences were observed.
*Leg Discomfort*

No differences were observed in $\text{RPE}_{\text{legs}}$ at any time during exercise in either group after their respective interventions. Perceptions of leg discomfort were similar in all cases, and were similar to the responses in dyspnoea. Specifically, between baseline and 75 W very little leg discomfort was reported. After this point leg discomfort increased in a linear fashion until peak exercise.
Figure 36. Leg discomfort during exercise in IMT (top) and SC (bottom) groups. First dashed line connects 150 W to HEWR; second dashed line connects HEWR to peak work rate. Abbreviations: IMT, inspiratory muscle training group; SC, sham control group; HEWR, highest equivalent work rate. Data are mean ± SD. No statistical significant differences were observed in either group.
Reasons for Stopping Exercise

The reasons for stopping exercise can be seen in Figure 37. The majority of subjects in both groups stopped because of leg discomfort alone with no changes in selection frequencies following either IMT or SC training. In the IMT group, participants initially reported that breathing discomfort contributed 29%, while the remaining 71% was due to leg discomfort. This distribution remained similar after IMT, becoming 34% and 66% due to breathing and leg discomfort, respectively. In the SC group, the reasons for stopping were spread similarly, 39 and 61% before SC, and 32 and 68% after SC, due to breathing and leg discomfort, respectively. No statistically significant differences in the above selection frequencies were observed either after IMT or SC, or between groups.

Figure 37. Reasons for stopping exercise. Data taken upon exercise cessation. Abbreviation: IMT, inspiratory muscle training group; SC, sham control group. No statistically significant differences observed either after IMT or SC or between groups. Combination refers to a combination of breathing and leg discomfort. No significant differences were observed in either group.
DISCUSSION

To our knowledge, this is the most comprehensive physiological characterization of respiratory muscle adaptations to IMT during exercise. The main results of this study are as follows. First, respiratory muscle EMG and the $W_b$ remained relatively unchanged after IMT. Second, respiratory and locomotor muscle oxygenation did not change after five-weeks of IMT. Finally, despite the lack of change in respiratory muscle EMG and oxygenation, there was a modest reduction in dyspnoea intensity ratings during exercise at submaximal work rates. Together these findings suggest that, in a group of recreationally active, healthy adult males, five-weeks of variable flow resistive pressure threshold loading did not result in any physiological adaptations that may improve exercise performance. Despite the lack of physiological adaptations, there appeared to be modest improvements in dyspnoea ratings, which were likely related to desensitization rather than due to any physiologically based mechanisms.

EMG and Work of Breathing

The current study showed no effect of IMT on EMG in either the primary (i.e., diaphragm) or the selected secondary (i.e., SCM and SCA) respiratory muscles. This suggests that the neural drive to these muscles remained unchanged after IMT. Despite no changes to EMG, we did observe a decrease in dyspnoea. This may be explained by the inability of EMG to distinguish from certain structural or physical changes that may have occurred with IMT. Rat models of IMT show increased cross-sectional area of type I, IIa, and IIx/b fibres in the diaphragm (Rollier et al., 1998), increased diaphragm surface area, and hypertrophy (Prezant et al., 1993). Diaphragm thickness has been increased after IMT in humans both in health (Enright et al., 2006) and cystic fibrosis (Enright et al., 2004). If these morphological changes occur, they
may not be reflected in EMG measurements, as a muscle with a greater physiological cross-sectional area will produce a greater force than a smaller muscle for a similar level of activation (Hug et al., 2015). In other words, although force producing capability would be enhanced by IMT, we may not see a change in the EMG signal. We see some evidence of this when examining the EMG data during MIPs; despite increased MIP in the IMT group, absolute EMG during MIPs were unchanged before and after training.

There were also no observed changes to $W_b$ after IMT. When we use the term $W_b$, we are referring to the mechanical work required from the respiratory muscles (Otis, 1954). We separate the components of $W_b$ into work required to overcome turbulent flow, work required to overcome laminar flow, and deformation of lung tissue, which combined can be considered viscous resistance (Milic-Emili et al., 1962). Comparing the individual constants, no differences were found either between SC and IMT groups or after the respective IMT or SC interventions. Improving ventilatory efficiency has been a proposed rationale for improving overall exercise performance. Previously, reducing the $W_b$ through proportional assist ventilation (PAV) (Harms et al., 2000), or a gas mixture where the nitrogen balance of gas is replaced with the less dense helium (heliox) (Wilkie et al., 2015), has garnered some success in improving exercise performance. However, reducing the $W_b$ through the PAV or heliox operates under very different principles than what could be expected through IMT. Heliox, by virtue of its lower density compared to atmospheric air, yields less turbulent flow and consequently a lower resistive component of $W_b$ (Dominelli & Sheel, 2012). The PAV can reduce $W_b$ at any point during the inspiratory phase (Younes et al., 1987) by providing a positive pressure proportional to the previous unaided breaths after the user initiates inspiration. This in turn “unloads” the inspiratory muscles allowing for a global reduction in $W_b$. By comparison, IMT is meant to
strengthen the inspiratory muscles, and as such would not have any impact on the total mechanical work required to breathe. The physical properties of the inspired air have not been altered during IMT, as is the case with heliox. Accordingly, we would not expect to see a change in the resistive components of $W_b$. Though the inspiratory muscles are stronger after IMT (as evidenced by increased MIP), they are still performing similar amounts of work during exercise. Again, this does not translate to any changes in $W_b$. However, strengthening the inspiratory muscles may reduce the effort perceptions of performing this work, translating to a reduction in dyspnoea while total $W_b$ remains unchanged.

In summary, while we did not observe any changes to either EMG or $W_b$ after our five-week IMT intervention, we do not suggest that IMT was ineffective at producing change. Rather, our findings suggest that the adaptations to IMT are not captured by measuring EMG and $W_b$.

**Respiratory and Locomotor Muscle Oxygenation**

Assessing muscle oxygenation using NIRS was an exploratory outcome for this study. To our knowledge, this is the first study to 1) examine NIRS derived variables after IMT, and 2) measure NIRS-derived variables in the SCM and PIC during an ICET. Despite points of statistical significance in various NIRS-derived variables, it is unlikely these translated to any meaningful physiological changes. This is likely because these effects are transient; and while they may appear for one or two stages at sub-maximal intensities, they soon disappear at greater intensities including the HEWR and peak exercise. The exception to this is the HHb response in the 7IC in the SC group. Here we saw a statistically significant decrease in HHb at HEWR and peak that was not seen in the IMT group. This change was not concurrent with any other statistically significant changes in any measured variable.
Previous studies using ICETs show values in good agreement with our measurements of NIRS-derived variables in the VL (Spencer et al., 2012) and 7IC (Vogiatzis et al., 2009). To our knowledge, no other studies have examined SCM and PIC with NIRS during an ICET. Nonetheless, given the similarity between these muscles at baseline and after the SC intervention, it is reasonable to say the measurements were reproducible.

Exercising muscle has a greater oxygen demand than resting muscle. In order to meet this increased demand there is an increase in blood volume, represented in a NIRS measurement by tHb. This is evident in the VL, PIC, and SCM, but not so in the 7IC. This observation may be the result of redistributing blood flow away from the torso to the working leg muscles. Indeed, studies with NIRS-ICG measurements of 7IC blood flow during exercise show that, after an initial increase in blood flow from a $\dot{V}_E$ of 80 L/min onwards, blood flow begins to decrease (Vogiatzis et al., 2009). This lack of increase in tHb is driven by changes in HbO$_2$. In the 7IC, the magnitude of the decrease in HbO$_2$ is greater than the increase in HHb, leading to a relative decrease in tHb. The remaining muscles experience a reduction in HbO$_2$, but this decrease is far less than that of the increase in HHb, and the result is an increased measure of tHb. This relatively lower tHb is also seen during ITL (Shadgan et al., 2011).

It must be noted that there are a number of differences between ITL and dynamic whole body exercise. This is particularly apparent in the 7IC and PIC muscles, as they function as postural muscles in addition to respiratory muscles. In addition to the inevitable cross talk between the vascular beds of neighbouring muscles, it is difficult to differentiate respiratory work from postural work. As an example, during ITL, the PIC experiences the opposite response to what we see in exercise, an increase in HbO$_2$ and a slight decrease in HHb (Basoudan et al., 2016). It is possible that the differences between ITL and exercise for these respiratory muscles
are rooted in their alternate functions. Despite the limitations of using 7IC as a site for respiratory muscle oxygenation patterns with NIRS, we must acknowledge that given the current available methods, it is the most widely used site for respiratory muscle oxygenation and among the best options for a non-invasive measure of changes to oxygenation patterns in the intercostal muscles. A within subject design minimizes the variability in NIRS of the 7IC and likely improves its utility.

In the locomotor muscles, here represented by the VL, the dominant trend is a decrease in HbO$_2$ and an increase in HHb as exercise progresses. This follows the expected trend based on the effect of exercise on the oxyhaemoglobin dissociation curve. As temperature increases and pH decreases haemoglobin’s affinity for O$_2$ is reduced to facilitate offloading of O$_2$. Here we see a similar effect in the respiratory muscles as well. The greatest difference is that the respiratory muscles demonstrate an increase in HHb while the concurrent decrease in HbO$_2$ does not happen immediately at the onset of exercise. In the case of the SCM, this follows a similar pattern to the breathing actions of the SCM, which is not active until higher exercise intensities, a likely explanation for the connection between EMGscm and SCM HHb increasing at similar points during exercise. The effect is similar in the 7IC and PIC muscles as well. Again, this is likely due to activation of these muscles. With greater ventilation, the muscles are more active and thus the muscles’ need for O$_2$ is facilitated by the Bohr Effect that results in an increase in HHb. However, as noted above, the increased activity of the 7IC and PIC is likely a combination of increased respiratory and postural work.

The evidence collected in this study suggest that IMT does not result in changes to a muscle’s ability to extract O$_2$ (i.e., HHb) or redistribution of available blood volume (i.e., tHb). While no conclusions of blood flow can be made using continuous-wave NIRS, changes in tHb
may have indicated changes in patterns of blood volume delivery. For example, if the effects of the respiratory muscle metaboreflex were present we could infer a decline in tHb to reflect vasoconstriction of the vessels around the limb locomotor muscles reducing flow. However, we did not observe a significantly lower tHb in the VL, nor do we see a significant increase in tHb in any of the respiratory muscles. However, it can be argued that metaboreflex-related changes in blood volume would not be identified during an incremental test as diaphragm fatigue is unlikely to be present (see: Limitations – Exercise Protocol).

A previous, endurance-based, training study in male cyclists examined changes in NIRS-derived HHb in the vastus medialis during both incremental and 20 km time-trial (Neary et al., 2002). Interestingly, no changes in HHb were observed during the incremental test despite a significant increase in VO$_{2\text{max}}$. However, during the time-trial, in addition to a significant improvement in performance time, without a significant increase in VO$_2$, muscle HHb was significantly lower (Neary et al., 2002). Neary et al., suggest that the improvements to the incremental test were likely governed by central factors whereas time-trial performance time was improved through local changes in muscle oxygenation. While Neary et al., used an endurance training program where our intervention is akin to a resistance training program, albeit for the respiratory muscles, it is possible our participants experienced similar responses. That is during our incremental test no changes in oxygenation were apparent but if subjected to a simulated time-trial an effect of IMT may be observed. Exploring NIRS-derived variables in a simulated time-trial is a valuable future direction for IMT research.

**Dyspnoea and Leg Discomfort**

In accordance with previous research, we report a reduction in dyspnoea during submaximal work rates; however, contrary to other evidence, a similar reduction was not
observed in RPE\textsubscript{legs}. A systematic review in athletes (Illi \textit{et al.}, 2012) found both dyspnoea and peripheral muscle discomfort were reduced as a result of IMT. However, there has been considerable variability in the literature regarding the perceptual adaptations to IMT, which may be due, at least in part, to the wide variety of exercise testing protocols used across studies. To our knowledge, there is only one study that has reported on dyspnoea during an ICET after a “strength-based” (i.e., pressure threshold) IMT protocol in health (Romer \textit{et al.}, 2002). Using an IMT protocol similar to the one presented in this study (30 breaths, twice daily, 30 repetition maximum intensity), Romer \textit{et al.} (2002) observed a decrease in dyspnoea of less than one Borg-unit (p < 0.01) at 80\% of peak work rate. This reduction in dyspnoea persisted until peak work, with the greatest reduction in dyspnoea of approximately 1.7 Borg units occurring at 90\% peak work rate. Comparatively, our greatest improvement in dyspnoea, a reduction of 0.8 Borg units, occurred at the HEWR, which corresponds to 91\% of peak work rate. It should be noted that a reduction of one Borg unit is the established minimal clinically important difference (Ries, 2005) but it is unknown if the same standard would apply to a young healthy male in the absence of chronic respiratory disease. The difference in the magnitude of the response may be attributed to the respective study samples. We recruited a less fit ($\dot{V}O_{2\text{max}}$ of Romer \textit{et al.}’s (2002) IMT group: 4.6 L/min), non-competitive group of men with a varied athletic background compared to the trained road cyclists in the study by Romer \textit{et al.}, (2002). This may also account for our lack of reduction in RPE\textsubscript{legs} that Romer \textit{et al.} (2002), reported from 50 to 90\% peak work rate.

Two primary hypotheses exist to justify IMT as a means to improve dyspnoea during exercise. The first identifies the association between a combination of respiratory muscle afferents and cortical motor command or corollary discharge, and respiratory perceptions of work/effort (Sheel, 2002). Thus, improving respiratory muscle strength or force-generating
capacity would result in a relatively lower stress on the respiratory muscles for a given $\dot{V}_E$ or $W_b$ (Romer et al., 2002). However, the results of our study do not support this hypothesis, as the relative activation of the diaphragm, SCM, and SCL were unchanged after IMT. Previous studies in health (Schaeffer et al., 2014) and in patients with chronic respiratory diseases (Jolley et al., 2015; Faisal et al., 2016) show a close association between EMGdi and dyspnoea intensity. It follows that any intervention that reduces EMGdi should translate into reductions in dyspnoea ratings. However, contrary to our original hypothesis, our study was not able to detect consistent differences in EMG of the respiratory muscles during exercise, whether expressed in absolute ($\mu$V) or relative (%max) terms. The lack of difference in respiratory muscle EMG, $\dot{V}_E$, and $W_b$, suggest that ventilatory responses remained unchanged following IMT. Thus, an alternate rationale for the decrease in dyspnoea is required.

The second hypothesis suggests that IMT may provide a desensitizing effect on dyspnoea. The act of the dynamic inspiratory manoeuvres from RV during IMT may influence perceptions dyspnoea. In a study by Wilson and Jones (1990), subjects breathed at various levels of $\dot{V}_E$ while cycling, and rated their dyspnoea. First subjects breathed through an unobstructed inspiratory circuit, then through a loaded inspiratory circuit designed to artificially increase $W_b$, and finally through an unobstructed circuit identical to their first bout. The authors found a marked decrease in dyspnoea when comparing the bout of cycling after inspiratory load to the initial unloaded bout (Wilson & Jones, 1990). This suggests that repeated large inspiratory efforts, as seen in resistive breathing and IMT, may in fact desensitize the subject to their perceptions of dyspnoea. Unfortunately, it is not known if these effects persist, or if after a given time the subject would return to their baseline dyspnoea sensitivity.
Two factors that may relate to perceptions of dyspnoea are load-detection (LD) and magnitude estimation (ME). LD, in respiratory terms, refers to a subject’s ability to detect when an external load has been placed in the breathing circuit (Kellerman et al., 2000). More generally, it would refer to the moment when someone notices breathing becoming more difficult or requiring more work/effort. ME is akin to our approach in measuring dyspnoea via the 10-point modified Borg scale in that it asks a subject to assign a number proportional to the perceived magnitude of the load (Kellerman et al., 2000). Kellerman et al. (2000) strengthened inspiratory muscles through pressure-threshold IMT and found that increased respiratory muscle strength resulted in a decrease in ME for a given resistive load, even though LD remained unchanged. This evidence could support why our study observed a decrease in dyspnoea ratings at a given ventilation/work rate and a difference in Borg/$\dot{V}_E$ slope, while the onset of dyspnoea (i.e., the first non-zero rating of dyspnoea) remained the same.

We observed no difference in RPE$_{\text{legs}}$ in the current study. This is inconsistent with the previously reported study during an ICET after IMT (Romer et al., 2002). Notably, Romer et al. (2002) found a significant reduction in RPE$_{\text{legs}}$ from 50% of peak work rate through 90% peak work rate, only disappearing at 100%. The current study shows nearly identical RPE$_{\text{leg}}$ scores before and after IMT and SC interventions. Similar RPE$_{\text{legs}}$ measurements at peak are not surprising, given that the primary reason for stopping exercise was leg discomfort in the vast majority of cases. However, based on the previous literature not only in ICET, but during intermittent (Tong et al., 2008) and high-intensity constant load cycle exercise tests (Bailey et al., 2010), it was reasonable to hypothesize a reduction in RPE$_{\text{legs}}$ after IMT. Reductions in RPE$_{\text{legs}}$ in previous studies have been attributed to a favourable shift in acid-base balance (Romer et al., 2002). Indeed, after IMT, Romer et al (2002) reported a non-significant trend toward a
reduction of blood lactate during an ICET after IMT. However, we did not measure blood lactate in the current study, and other physiological data we collected (i.e., EMG and NIRS) are not capable of inferring any modulations of acid-base equilibrium during ICET after IMT. If IMT provided a desensitization effect on dyspnoea, it stands to reason that our IMT protocol would not impact $\text{RPE}_{\text{legs}}$ because IMT would not provide a similar effect to the limb locomotor muscles. Our participants did not change their physical activity practices during their training time and IMT itself would not impart any desensitizing effect on the legs during cycling. Therefore, it is reasonable to say that our intervention did not provide a justification for reducing $\text{RPE}_{\text{legs}}$ at submaximal work rates.

**Limitations**

Some limitations must be taken into account when interpreting the results of the current study, including considerations regarding the population studied, exercise protocol, and the sample size.

**Population**

By design, we chose to limit our study to male participants. Thus, the findings of this study cannot be extended to the female population. Sex differences in dyspnoea (Schaeffer *et al*., 2014; Cory *et al*., 2015), breathing patterns (Schaeffer *et al*., 2014; Cory *et al*., 2015), the work and oxygen cost of breathing (Guenette *et al*., 2007; Guenette *et al*., 2009; Dominelli *et al*., 2015), expiratory-flow limitation (Guenette *et al*., 2007), diaphragmatic fatigue (Guenette *et al*., 2010), and airway size (Sheel *et al*., 2009) have all been reported in recent years. Given these sex differences, we chose to keep our sample as homogenous as possible by including only male subjects. Future studies are needed to evaluate the efficacy and mechanisms of adaptation following IMT in women.
Another concern regarding our sample is the choice to include only recreationally active and healthy men, as opposed to elite athletes or patients with chronic respiratory disease. Elite athletes and patients with respiratory diseases are more likely to develop respiratory limitations to exercise and may be more likely to derive benefits from IMT compared to sedentary or recreationally active individuals. We chose to focus on recreationally active subjects rather than studying the extremes of fitness (i.e., elite athletes or patients with respiratory disease) in order to make our findings more applicable to the general male population.

Exercise Protocol

We chose to employ an ICET as opposed to a constant work rate test to explore any changes in sensory and physiological responses across the full range of ventilatory requirements during exercise. However, ICET may not be the ideal exercise protocol to induce diaphragmatic fatigue (Romer et al., 2007) and trigger the respiratory muscle metaboreflex. Thus, our NIRS derived variables may have shown a different response had we used high intensity constant work rate exercise testing, which is an effective protocol for inducing diaphragm fatigue (Johnson et al., 1993; Mador et al., 1993; Babcock et al., 2002). However, studying a fixed intensity would not allow us to track the evolution of our primary outcome variables across the full range of exercise intensities.

Sample Size

The primary aim of our study was to observe any changes to EMGdi after IMT. As such, our sample size of n = 11 per group was adequately powered to detect changes in our primary outcome, EMGdi. However, we did not include NIRS and sEMG of the secondary respiratory muscles in our initial power calculations. Previous IMT studies have used similar sample sizes (Romer et al., 2002; Edwards & Walker, 2009; Bailey et al., 2010; Segizbaeva et al., 2014).
Also a complete sample of n = 12 (IMT) and n = 13 (SC) was not obtained for NIRS and sEMG. This means the results for these secondary outcomes may have been underpowered.
CONCLUSIONS

We found that while our five-week IMT protocol did reduce dyspnoea at submaximal work rates, we were unable to observe any meaningful change in RPE\textsubscript{legs}, respiratory muscle EMG, or oxygenation changes in the respiratory and locomotor muscles. It is conceivable that the changes in dyspnoea were not driven by any physiological adaptations, but rather a psychological one.

This study was novel on a number of fronts. Firstly, this was the first study to assess EMG\textsubscript{di} responses to IMT in young healthy men via an oesophageal catheter. There is at least one other study that reports EMG\textsubscript{di} after IMT (Segizbaeva \textit{et al.}, 2013); however, these authors only reported EMG measures of fatigue, did not quantify the EMG\textsubscript{di} response during exercise, and crudely estimated diaphragm EMG using surface electrodes in the 8\textsuperscript{th} intercostal space. We have provided a more comprehensive analysis of EMG\textsubscript{di}, with a more sensitive tool in the current study. Secondly, this was the first study to investigate the effects of IMT on respiratory and locomotor muscle oxygenation during an ICET. Recently, another study has examined respiratory and locomotor oxygenation during whole body exercise (Turner \textit{et al.}, 2016); however, they limited their respiratory muscles to only the 7IC and performed constant load bouts of exercise. Our study offers new insight into the evolution of deoxygenation patterns throughout exercise in multiple inspiratory muscles following IMT.

This study provides a solid foundation upon which further IMT studies can be launched. Despite not providing a definitive answer to the debate of “does training the respiratory muscles improve exercise performance” (McConnell, 2012; Patel \textit{et al.}, 2012) we believe that there is sufficient evidence to warrant further investigation using similar study protocol, especially in
females, persons with chronic respiratory disease, and elite athletes, beyond typical performance outcomes.
REFERENCES


Segizbaeva MO, Timofeev NN, Donina ZA, Kur'yanovich EE & Aleksandrova NP. (2014). Effects of Inspiratory Muscle Training on Resistance to Fatigue of Respiratory Muscles


Appendix i: Informed Consent

THE UNIVERSITY OF BRITISH COLUMBIA

Participant Information and Consent Form

Effects of Inspiratory Muscle Training on Respiratory Muscle Mechanics and Haemodynamics in Healthy Adults

Principal Investigator: Jordan Guenette, Ph.D.
UBC Physical Therapy
Centre for Heart Lung Innovation

Co-Investigators: Andrew Ramsook, B.PHE
Michele Schaeffer, M.Sc
Sabrina Wilke, M.Sc
Yannick Molgat-Seon, M.Sc, Ph.D. candidate

Contact Person: Andrew Ramsook

Emergency Telephone Number: Andrew Ramsook

Invitation:
You are being invited to take part in this research study because you are between the ages of 19-39 (inclusive), healthy and recreationally active. This research study will fulfill the research component requirements of the co-investigator, Andrew Ramsook’s Master of Science degree.

Your participation is voluntary. You have the right to refuse to participate in this study. If you decide to participate, you may still choose to withdraw from the study at any time.

Before you decide, it is important for you to understand what the research involves. This consent form will tell you about the study, why the research is being done, what will happen to you during the study and the possible benefits, risks and discomforts. If you wish to participate in this study, you will be asked to sign this form. We are looking to enroll 20 individuals in total for this study.
**Who is conducting this study?**
This study is being conducted by Dr. Jordan A. Guenette at the UBC Centre for Heart Lung Innovation located in St. Paul’s Hospital. The study is funded by the Natural Sciences and Engineering Research Council of Canada.

**Background information:**
During intense exercise the muscles that help you breathe are used much more than at rest. Due to this, some people believe that training those muscles, similar to training your legs or arms, can make exercise easier. However, how the body adapts to this training has not been explored. There are many possible explanations as to why this type of training may or may not improve exercise, including changing blood distribution, lowering the work it takes to breathe, or shifting the contribution of the types of breathing muscles used.

Understanding what changes occur as a result of this training will help us understand how to best improve exercise capacity.

**What is the purpose of this study?**
The purpose of this study is to determine how training the respiratory muscles can change the body’s response to intense exercise.

**Who can participate in this study?**
You may be able to participate in this study if you are:

- Male
- 19-39 years of age (inclusive)
- Normal lung function as per percent predicted values for age
  - Your lung function will be tested on visit 1 to determine your eligibility to participate
- Body mass index greater than 18 or less than 30 kg/m²
  - Your body mass index will be measured on visit 1 to determine your eligibility to participate
- Able to read and understand English
- Physically active greater than 180 min per week
- Maximal aerobic capacity equal to or greater than 80% predicted
  - Your maximal aerobic capacity will be tested on visit 1 to determine your eligibility to participate
- Able to ride an upright stationary bicycle

**Who should NOT participate in this study?**
You cannot participate in this study if you have a:

- History of or currently smoking
- History of or current symptoms of cardiopulmonary disease including asthma and exercise-induced asthma
- Problem with your heart; a serious infection within your body; a neuromuscular or musculoskeletal disorder; or other health problem that will be made worse with exercise testing
- Ulcer or tumor in the esophagus, a nasal septum deviation, or recent nasopharyngeal surgery
- Allergies to latex or local anaesthetic
- Currently participating and training in a sport at a provincial, national or international level

**What does the study involve?**

**Overview of the Study:** This study involves two different exercise approaches and will investigate how training your breathing muscles affects exercise performance. There is an equal chance of being placed into either group and the differences between each group will not be revealed until the study has been completed. You will report to the Cardiopulmonary Exercise Physiology (CPEP) laboratory for a total of 7 visits. Three visits will involve exercise and four will be training sessions. On visit 1 you will complete a demographic information form. This information is necessary so that researchers can compare how your lungs are functioning relative to predicted values based on your age, sex and race. Age, sex, and race are important because they affect lung function. This will be followed by surveys about your health and physical activity history. We will record height and weight and then begin a detailed assessment of your lung function. Then you will begin exercising on a stationary bicycle, starting at a low intensity and becoming more difficult as time progresses until you are unable to continue. On visits 2 and 3, you will perform the same exercise tests as visit 1 however this time there will be the addition of three measurement tools. These tools include small stickers and disks placed on your neck, ribs, and legs as well as a thin flexible tube (less than 2mm in diameter) placed through your nose and into your esophagus before the exercise portion of the test. The stickers (electrodes) will measure muscle activation and the disks (optodes) will measure muscle oxygen consumption. Each of these visits will take approximately 3 hours. Visits 2 and 3 will be separated by 5-weeks of training. Training consists of breathing through a small device in one of two randomly assigned groups. You have an equal chance of being assigned to either group. This training will take approximately 10min per day, 5 days a week for 5 weeks total. Every week you will return to the CPEP lab to monitor changes from the training protocol. These visits should take approximately 30 min. During this visit we will look at the device and record the adherence to training. The training device records the number of trials completed and the intensity of training. We will also measure the maximum force you can produce while breathing in to monitor improvements in respiratory muscle strength. Completing this study will involve approximately 12 hours at the CPEP lab. Refer to the table below for an overview of the experiment.
## EXPERIMENTAL PROTOCOL

### VISIT 1

- Sign consent form
- Demographic form
- Medical history questions
- Physical Activity questions
- Shortness of breath questions
- Lung function tests
- 10 minute rest
- 5 min warm-up on stationary bike
- Exercise test on a stationary bike (intensity gets progressively harder)

*Visit 1 will take approximately 3 hours*

### VISITS 2 & 3

- Lung function tests
- Thin flexible tube placement
- Electrode/optode placement
- 10 minute rest
- 5 minute warm-up on a stationary bike
- Exercise test on a stationary bike (intensity gets progressively harder)

*Visits 2 & 3 will take approximately 3 hours*

### TRAINING

- 5 days a week
- 5 total weeks
- Follow up visit to CPEP lab weekly
- Two different training programs (randomly assigned)

* Training will take approximately 15 minutes per day.

---

### If you decided to join this study: specific procedures

If you agree to take part in this study, the procedures and visits will include the following:

**Visit 1:** After signing the consent form, you will complete a:
- Demographic form (for example: *date of birth, race, medical doctor’s name*)
- Lung Function form (for example: *Have you smoked before?*)
- Set of medical history questions (for example: *Do you have any allergies?*)
- A medications sheet (for example: *Report all medications taken for the last 2 months*)
- A set of questions about your physical activity (for example: *During the last 7 days how many days did you do vigorous physical activity?*).

You can choose not to answer any questions that make you feel uncomfortable. Basic height and weight measurements will be taken. This will be followed by simple, non-invasive breathing tests to measure how your lungs are functioning. This requires you to breathe quickly and deeply through a mouthpiece while wearing nose clips (so that you are only breathing out of your mouth).

Second, you will sit on an upright stationary bicycle for 10 minutes while resting information about your breathing is collected. This requires you to breathe through a mouthpiece while wearing nose clips so your breathing can be monitored.

Third on an upright stationary bike, you will perform a 5 minute warm-up followed by an exercise test. The test will begin with unloaded pedaling (no resistance) and become
more difficult until you feel that you cannot cycle any more. The exercise test should last approximately 10 to 25 minutes. During the test it is necessary that you breathe through a mouthpiece while wearing nose clips so that your breathing can be monitored. A small clip will also be placed on your finger to non-invasively monitor the amount of oxygen in your blood. An inflatable cuff will be placed around your arm to measure your blood pressure. A strap (heart rate monitor) will be positioned underneath your chest to measure your heart rate. After the exercise test is completed you will be asked to complete a set of questions about how your breathing felt during the exercise test (for example: *(Yes/No)* My breathing feels shallow). This is a maximal effort exercise test. Visit 1 of testing should take approximately 3 hours.

**Visits 2 & 3:** Visits 2 & 3 will begin by you performing lung function tests similar to visit 1 and a handgrip strength test. Next, a very thin tube (less than 2 millimeters in diameter) will be placed through your nose and into your esophagus (the tube connecting your nose to your stomach) and stomach. The tube will be inserted by a member of the study team that has received extensive training on this procedure. The purpose of the tube is to measure your breathing and how your main breathing muscle (diaphragm) is working. We will numb your nose and throat with an anaesthetic (numbing) spray or gel to minimize any discomfort. In addition small pads will be stuck to the outside of your rib cage and upper neck to non-invasively measure how and when your muscles are contracting as well as small light transmitters to non-invasively measure relative oxygen consumption of the muscles.

Second, you will sit on an upright stationary bicycle for 10 minutes while resting information about your breathing is collected. This requires you to breathe through a mouthpiece while wearing nose clips so your breathing can be monitored.

The exercise test is identical to visit 1. A small clip will also be placed on your finger to non-invasively monitor the amount of oxygen in your blood. An inflatable cuff will be placed around your arm to measure your blood pressure. A strap (heart rate monitor) will be positioned underneath your chest to measure your heart rate. These visits should also take approximately 3 hours.

**Respiratory Muscle Training:** In between visits 2 and 3 you will perform 5 weeks of training for your breathing muscles. You will be randomly assigned to one of two training programs. You have an equal chance to be assigned to either group. A POWERbreathe K-3 portable breathing trainer will be used in both programs in two different ways. In both programs you will use the device and breathe at varying intensities five days a week for the full five weeks. One of the training sessions will be supervised in the CPEP laboratory to monitor the progress of your training. You will be told which of the two groups you took part in at the end of visit 3. Each training session will take approximately 10 minutes per day. This training will not interfere with any regular activities and you will be able to continue any other regular activities during this
time. Training intensity varies with each group but may leave you with a mild feeling of being out of breath, similar to moderate-to-high intensity exercise. Note that the risks of either group are the same.

**What are my responsibilities?**
Avoid exercise the day before testing and the day of testing. Avoid caffeine (e.g. coffee, tea, pop) the day of exercise, and do not eat 2 hours prior to exercise tests (Visits 1, 2 and 3) (water is okay). Please wear sturdy shoes and comfortable clothing to exercise in.

**What happens with the results of this study?**
The results of this study will be reported in the co-investigator’s thesis project report. The main findings of this study will be published in academic journal articles, and presented at academic conferences. No personal identifying information will be published or presented; only coded information will be published (or presented).

**What are the possible harms and discomforts?**
In the unlikely event of a medical emergency during the study, immediate care will be provided by the researchers, all who have current emergency first-aid, cardiopulmonary resuscitation (CPR C) and Automated External Defibrillator (AED) certificates. For any major medical problems, the St. Paul’s Hospital emergency team will be called. The research laboratory is located 3 floors above the St. Paul’s Hospital Emergency Room.

How people respond to exercise is not always predictable, and sometimes unexpected problems happen that would require medical attention. You are asked to report immediately any unusual symptoms during the test. You may stop the test when you wish to if you feel tired or uncomfortable. Every effort will be made so that the tests are comfortable and as safe as possible. Potential risks from maximal exercise in the general population include:

- vomiting (5 in 100)
- abnormal blood pressure (less than 1 in 100)
- fainting (less than 1 in 100)
- very rare instance of death caused by heart suddenly stopping (1 in 67,000 – 159,000)

If you feel that you are experiencing any side effects as a result of the study you should immediately report this to the people conducting the test.

In response to the thin flexible tube:
- You may feel mild discomfort or soreness in your nose and the back of your throat when the thin flexible tube is inserted through your esophagus and into your stomach
• You may also experience slight discomfort as a result of “gagging” while swallowing the tube and during the removal of the tube (less than 5 in 100). This may cause some people to vomit (less than 1 in 100)
• There is also a risk of a nosebleed when the tube is inserted or removed (less than 1 in 500.)
• There is a risk of the tube being placed in the wrong position or coil (less than 1 in 200). If this happens you may experience mild discomfort and cough. At which point the tube will be removed and repositioned.
• The presence of the catheter in your esophagus may interfere with the esophagus’s opening/closing valve resulting in aspiration or breathing in stomach contents (we are unaware of any laboratory that has experienced a participant aspirating)

A numbing spray called Lidocaine will be used to minimize any discomfort. Adverse reactions to Lidocaine are **very rare** but include: light-headedness; blurred/double vision; sounds become louder; ringing in ear; nervousness; excitement; confusion; dizziness; seizure; drowsiness; confusion; twitching; tremors; convulsions; unconsciousness; breathing problems; sensations of heat, cold, burning, tingling, prickling or numbness; slower heart rate which may lead to heart stopping; and/or allergic reactions (skin abnormality, hives, swelling, anaphylactic shock).

You will not be allowed to participate in the study if you are known to be sensitive to local anaesthetics (numbing or freezing medications) or if you have allergies to latex. We are unaware of any laboratory that has experienced any of these adverse reactions to such a small amount of Lidocaine.

**What are the potential benefits of participating?**

All participants will receive detailed copies of their pulmonary function and exercise test results. There may or may not be direct benefits to you from taking part in this study such as learning more about your lung function and your current aerobic fitness level.

We hope that the information learned from this study can be used in the future to benefit people with breathing problems.

**What happens if I decide to withdraw my consent to participate?**

You may withdraw from the study at any time without giving reasons. If you choose to enter the study and then decide to withdraw at a later time, all data collected about you during your enrolment in the study will be retained for analysis.

**Can I be asked to leave the study?**

If you are not able to follow the requirements of the study or for any other reason, the study investigator may withdraw you from the study. If your health status changes for
any reason during the study so that you satisfy an exclusion criteria or do not meet the inclusion criteria you will be withdrawn from the study.

**Will my taking part in this study be kept confidential?**

Your confidentiality will be respected. However, research records or other source records identifying you may be inspected in the presence of the Investigator or his or her designate by representatives of the UBC Centre for Heart Lung Innovation and the UBC Providence Health Care Research Ethics Board for the purpose of monitoring the research. No information or records that disclose your identity will be published without your consent, nor will any information or records that disclose your identity be removed or released without your consent unless required by law.

You will be assigned a unique study number as a participant in this study. Only this number will be used on any research-related information collected about you during the course of this study, so that your identity [i.e. your name or any other information that could identify you] as a participant in this study will be kept confidential. Information that contains your identity will remain only with the Principal Investigator and/or designate. The list that matches your name to the unique study number that is used on your research-related information will not be removed or released without your consent unless required by law.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to insure that your privacy is respected and also give you the right of access to the information about you that has been provided to the sponsor and, if need be, an opportunity to correct any errors in this information. Further details about these laws are available on request to your study doctor.

Studies involving humans now routinely collect information on race and ethnic origin as well as other characteristics of individuals because these characteristics are associated with lung structure and function. Providing information on your race or ethnic origin is voluntary.

**What happens if something goes wrong?**

By signing this form, you do not give up any of your legal rights and you do not release the study investigators or other participating institutions from their legal and professional duties. There will be no costs to you for participation in this study. You will not be charged for any research procedures. **If you are insured by the provincial medical plan, and your coverage is in effect, it may cover any injuries incurred as a result of participation.** If you are not covered by the provincial medical plan, either you or your third party insurer (if you have one and depending on terms of coverage) will be responsible for the cost of injuries incurred as a result of participation. Medical care is extremely costly. Because of hospital policy, the hospital is not able to offer financial compensation if you are injured as a result of participating in this study.
research. However by signing this form you are not precluded from seeking to collect compensation for injury related to malpractice, fault, or blame on the part of those involved in the research.

What will the study cost me?
You will be reimbursed $35 per visit to the research laboratory to help cover the cost of transportation and parking up to a total of $105 for the completion of visits one, two and three. Additionally, each training visit will receive a reimbursement of $15. The total reimbursement of this study is up to $195 for the completion of each visit.

Who do I contact if I have questions about the study during my participation?
If you have any questions or desire further information about this study before or during participation, or if you experience any adverse effects, you can contact Andrew Ramsook at 604-806-8835.

Who do I contact if I have questions or concerns about my rights as a participant?
If you have any concerns or complaints about your rights as a research subject and/or your experiences while participating in this study, contact the Research Subject Information Line in the University of British Columbia Office of Research Services by e-mail at RSIL@ors.ubc.ca or by phone at 604-822-8598 (Toll Free: 1-877-822-8598).
Effects of Inspiratory Muscle Training on Respiratory Muscle Mechanics and Haemodynamics in Healthy Adults

Participant Consent

My signature on this consent form means:

• I have read and understood the participant information and consent form.
• I have had sufficient time to consider the information provided and to ask for advice if necessary.
• I have had the opportunity to ask questions and have had satisfactory responses to my questions.
• I understand that all of the information collected will be kept confidential and that the results will only be used for scientific objectives.
• I understand that my participation in this study is voluntary and that I am completely free to refuse to participate or to withdraw from this study at any time without changing in any way the quality of care that I receive.
• I understand that I am not waiving any of my legal rights as a result of signing this consent form.
• I understand that there is no guarantee that this study will provide any benefits to me.

By checking this box I would like to donate my participant reimbursement back to the research program.

Participant Initials: __________

By checking this box I give permission to be contacted for future studies that may be of interest to me.

Participant Initials: __________

I will receive a signed copy of this consent form for my own records.
I consent to participate in this study.

Participant’s Signature __________________________ Printed name __________________________ Date __________

Signature of Person Obtaining Consent __________________________ Printed name __________________________ Study Role __________________________ Date __________
Appendix ii: International Physical Activity Questionnaire

Participant ID: _____________________

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE
(August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

**Background on IPAQ**

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

**Using IPAQ**

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

**Translation from English and Cultural Adaptation**

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

**Further Developments of IPAQ**

International collaboration on IPAQ is on-going and an International Physical Activity Prevalence Study is in progress. For further information see the IPAQ website.

**More Information**


SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.
INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the vigorous activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   
   ____ days per week

   [ ] No vigorous physical activities  ➔ Skip to question 3

2. How much time did you usually spend doing vigorous physical activities on one of those days?

   ____ hours per day
   ____ minutes per day

   [ ] Don't know/Not sure

Think about all the moderate activities that you did in the last 7 days. Moderate physical activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   ____ days per week

   [ ] No moderate physical activities  ➔ Skip to question 5

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.
4. How much time did you usually spend doing moderate physical activities on one of those days?

____ hours per day
____ minutes per day

☐ Don’t know/Not sure

Think about the time you spent walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the last 7 days, on how many days did you walk for at least 10 minutes at a time?

____ days per week

☐ No walking ➔ Skip to question 7

6. How much time did you usually spend walking on one of those days?

____ hours per day
____ minutes per day

☐ Don’t know/Not sure

The last question is about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the last 7 days, how much time did you spend sitting on a week day?

____ hours per day
____ minutes per day

☐ Don’t know/Not sure

This is the end of the questionnaire, thank you for participating.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.
## Appendix iii: Physical Activity Readiness Questionnaire

**PAR-Q+**

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

### SECTION 1 - GENERAL HEALTH

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Has your doctor ever said that you have a heart condition OR high blood pressure?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Are you currently taking prescribed medications for a chronic medical condition?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Has your doctor ever said that you should only do medically supervised physical activity?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you answered NO to all of the questions above, you are cleared for physical activity.

- Go to Section 3 to sign the form. You do not need to complete Section 2.

  - Start becoming much more physically active – start slowly and build up gradually.
  - Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
  - You may take part in a health and fitness appraisal.
  - If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP).
  - If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.
# SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you have Arthritis, Osteoporosis, or Back Problems? If yes, answer questions 1a-1c</td>
<td>☐ if yes, answer questions 1a-1c</td>
<td>☐ if no, go to question 2</td>
</tr>
<tr>
<td>1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/ or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Do you have Cancer of any kind? If yes, answer questions 2a-2b</td>
<td>☐ if yes, answer questions 2a-2b</td>
<td>☐ if no, go to question 3</td>
</tr>
<tr>
<td>2a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2b. Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm If yes, answer questions 3a-3e</td>
<td>☐ if yes, answer questions 3a-3e</td>
<td>☐ if no, go to question 4</td>
</tr>
<tr>
<td>3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3b. Do you have an irregular heart beat that requires medical management? (e.g. atrial brillation, premature ventricular contraction)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3c. Do you have chronic heart failure?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3d. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3e. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes</td>
<td>☐ if yes, answer questions 4a-4c</td>
<td>☐ if no, go to question 5</td>
</tr>
<tr>
<td>4a. Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4b. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4c. Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)</td>
<td>☐ if yes, answer questions 5a-5b</td>
<td>☐ if no, go to question 6</td>
</tr>
<tr>
<td>5a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5b. Do you also have back problems affecting nerves or muscles?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
Please read the questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>6.</th>
<th>Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>6a</td>
<td>Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6b</td>
<td>Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6c</td>
<td>If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6d</td>
<td>Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7.</th>
<th>Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>7a</td>
<td>Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7b</td>
<td>Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7c</td>
<td>Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8.</th>
<th>Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>8a</td>
<td>Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>8b</td>
<td>Do you have any impairment in walking or mobility?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>8c</td>
<td>Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9.</th>
<th>Do you have any other medical condition not listed above or do you live with two chronic conditions?</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>9a</td>
<td>Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>9b</td>
<td>Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>9c</td>
<td>Do you currently live with two chronic conditions?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.
PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

› It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP) to help you develop a safe and effective physical activity plan to meet your health needs.
› You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
› As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
› If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

› You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal.

Delay becoming more active if:

› You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
› You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
› Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

› You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
› The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
› If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
› Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME ____________________________________________________ DATE _________________________________________

SIGNATURE _____________________________________WITNESS _________________________________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _________________________________________________________

For more information, please contact: Canadian Society for Exercise Physiology www.csep.ca

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

Appendix iv: IMT Group Instructions

Effects of inspiratory Muscle Training on Respiratory Muscle Mechanics and Haemodynamics in Healthy Adults

Strength Group

Inspiratory muscle training Instructions

You are a part of the respiratory muscle strength group. Our goal is to strengthen the muscles that help you breathe. You will be using the PowerBreathe K-3 system to train your breathing muscles.

Before you start:

Turn the PowerBreathe on and select train.

Make sure the counter below reads 30

Attach the mouthpiece and filter to the PowerBreathe system

Place the nose clips on your nose

Begin Training

Each breath: Slowly breathe out until you feel you are completely out of breath then breathe in as hard as you can!

Repeat this 30 times, that completes one session

Complete two sessions per day, one in the morning and one in the evening

Use the table on the other side of this page to help you track your training
### Training Schedule

<table>
<thead>
<tr>
<th>Session</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M E</td>
<td>M E</td>
<td>M E</td>
<td>M E</td>
<td>M E</td>
</tr>
<tr>
<td>Week 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Week 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Week 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Place a check in each box when you complete your 30 rep training session (M = Morning; E = Evening).*

Your Training **Start Date** is ____________

Your Training **End Date** is _________________

- Note: this is the time of your final visit to the CPEP laboratory.

Your weekly follow up visits are scheduled below:

<table>
<thead>
<tr>
<th>Week</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

If you have any questions please contact **Andrew Ramsook** – andrew.ramsook@hli.ubc.ca

Respiratory Muscles & IMT

Version 1 (March 19, 2014)
Appendix v: SC Group Instruction Sheet

Effects of inspiratory Muscle Training on Respiratory Muscle Mechanics and Haemodynamics in Healthy Adults

Endurance Group

Inspiratory muscle training Instructions
You are a part of the respiratory muscle endurance group. Our goal is make the respiratory muscles more resistant to tiring out. You will be using the PowerBreathe K-3 system to train your breathing muscles.

Before you start:

Turn the PowerBreathe on and select train.

Make sure the counter below reads 30

Attach the mouthpiece and filter to the PowerBreathe system

Place the nose clips on your nose

Begin Training

Each breath: Slowly breathe out until you feel you are completely out of breath then breathe in as hard as you can!

Repeat this 30 times, that completes one set.

Rest for 30 seconds (use this time to re-enter the training menu)

Complete one more set of training

Complete two sets per day at any time during the day

Use the table on the other side of this page to help you track your training
Training Schedule

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Set</strong></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Week 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 4</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Week 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Place a check in each box when you complete your 30 rep training session.*

Your Training **Start Date** is ___________.

Your Training **End Date** is _________________

- Note: this is the time of your final visit to the CPEP laboratory.

Your weekly follow up visits are scheduled below

<table>
<thead>
<tr>
<th>Week</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

If you have any questions please contact Andrew Ramsook – andrew.ramsook@hli.ubc.ca
Appendix vi: Participant Debrief

Effects of Inspiratory Muscle Training on Respiratory Muscle Mechanics and Haemodynamics in Healthy Adults

Research Methods Debrief

Dear ___________________________,

Thank you for participating in our study. We appreciate you taking the time to help us add to the knowledge of the field of exercise and health.

Our goals were to see how training muscles involved in breathing can improve exercise. This study had everyone randomly assigned to one of two groups. You were assigned to [insert either group1/group2]. We were unable to tell you the details of the exercise programs to remove the role of motivation in your results. Group 1 involved a strength-based training program. The strength program was designed to train your respiratory muscles and make them stronger to see how that affects how the body can respond to intense (maximal) exercise. This program has been used in previous studies and has been proven to improve respiratory muscle strength. Group 2 trained in such a way that the training would not have improved respiratory muscle strength. This formed what we call a sham group where you take part in a program that is meant to have no affect on the body. This group is extremely important to research as it allows us to figure out which changes are real and what are the results of you thinking you are going to improve. The table below shows the differences in training programs.

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus</td>
<td>Muscle Strength</td>
<td>Sham</td>
</tr>
<tr>
<td>Intensity</td>
<td>30 Repetition Maximum</td>
<td>10% of maximum inspiratory pressure (from visit 1)</td>
</tr>
<tr>
<td>Frequency</td>
<td>Twice daily</td>
<td>Once daily</td>
</tr>
<tr>
<td>Duration</td>
<td>Five Weeks</td>
<td></td>
</tr>
</tbody>
</table>

We again thank you for your participation. If you have any further questions feel free to contact Andrew Ramsook (andrew.ramsook@hli.ubc.ca).

Respiratory Muscles and IMT
Version 1 (May 9, 2014)
Appendix vii: Descriptors of Breathlessness

DESCRIPTORS OF BREATHLESSNESS

CIRCLE ALL APPLICABLE DESCRIPTORS OF YOUR "UNCOMFORTABLE" AWARENESS OF BREATHING:

1. My breath does not go in all the way
2. Breathing in requires effort
3. I feel that I am suffocating
4. I feel a need for more air
5. My breathing is heavy
6. I cannot take a deep breath in
7. My chest feels tight
8. My breathing requires more work
9. I feel a hunger for more air
10. I feel that my breathing is rapid
11. My breathing feels shallow
12. I feel that I am breathing more air
13. I cannot get enough air in
14. My breath does not go out all the way
15. Breathing out requires more effort

THE BEST 3 DESCRIPTORS (IN DESCENDING ORDER - best descriptor first):

1. ____________________
2. ____________________
3. ____________________

Reminder: Please Remove HR Monitor.
# Modified Borg Scale

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nothing at all</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Very, very weak</td>
<td>(just noticeable)</td>
</tr>
<tr>
<td>1</td>
<td>Very weak</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Weak</td>
<td>(light)</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Somewhat strong</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Strong</td>
<td>(heavy)</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very strong</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Maximal</td>
<td></td>
</tr>
</tbody>
</table>