Title: Functional training of the inspiratory muscles improves load carriage performance

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ABSTRACT

Inspiratory Muscle Training (IMT) whilst adopting body positions that mimic exercise (functional IMT; IMT_F) improves running performance above traditional IMT methods in unloaded exercise. We investigated the effect of IMT_F during load carriage tasks. Seventeen males completed 60 min walking at 6.5 $km \cdot h^{-1}$ followed by a 2.4 km load carriage time-trial (LC_{TT}) whilst wearing a 25 kg backpack. Trials were completed at baseline; post 4 weeks IMT (consisting of 30 breaths twice daily at 50% of maximum inspiratory pressure) and again following either 4 weeks IMT_F (comprising four inspiratory loaded core exercises) or maintenance IMT (IMT_{CON}). Baseline LC_{TT} was 15.93 ± 2.30 min and was reduced to 14.73 ± 2.40 min (mean reduction 1.19 ± 0.83 min, $P<0.01$) after IMT. Following phase two, LC_{TT} increased in IMT_F only (13.59 ± 2.33 min, $P<0.05$) and was unchanged in post-IMT_{CON}. Performance was increased following IMT_F, providing an additional ergogenic effect beyond IMT alone.

Practitioner Summary

We confirmed the ergogenic benefit of Inspiratory Muscle Training (IMT) upon load carriage performance. Furthermore, we demonstrate that functional IMT methods provide a greater performance benefit during exercise with thoracic loads.

Key Words:

Inspiratory muscle training, functional training, exercise performance, load carriage

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INTRODUCTION

Carrying heavy loads in a military-style backpack (25 kg) presents a unique challenge to the respiratory system via impeded ventilatory mechanics (Dominelli, Sheel, and Foster 2012). The placement of an external load in a backpack system that is worn upon the thorax imposes the lowest metabolic cost when compared with alternative load carriage methods such as double packs, satchels and hip belts (Knapik et al. 2012). The position on the thorax surrounds the respiratory pump, prompting a volume limiting action that inhibits ventilation (Shei et al. 2017). Sustained work in these conditions leads to the onset of inspiratory muscle fatigue and impaired load carriage performance, relative to an identical unloaded trial (Faghy and Brown 2014a). Accordingly, specific inspiratory muscle warm-up and training methods have been applied to unloaded (rowing and swimming) and load carriage tasks to attenuate the magnitude of inspiratory muscle fatigue and improve performance (Volianitis et al. 2001; Lomax, Grant, and Corbett 2011). However, inspiratory muscle warm-ups whereby the individual performs 2 x 30 sub-maximal (40% maximal inspiratory muscle pressure; P_{Imax}) inspiratory efforts prior to exercise in addition to a controlled whole body active warm-up was ineffective in eliciting an improvement in performance on a 2.4 km loaded time trial, despite transient increases in P_{Imax}, which is contradictory of unloaded performance tasks (Faghy and Brown 2017). However, six weeks of inspiratory muscle training (IMT), comprising 30 inspiratory efforts completed twice daily (50% P_{Imax}), increased baseline P_{Imax} and provided an ergogenic effect when exercising with a 25kg load compared with a double-blind placebo control (Faghy and Brown 2016). A finding that was recently confirmed by others (Shei et al. 2018), albeit with a lower load (10 kg). Despite the ergogenic effect, IMT has, to date, failed to attenuate inspiratory muscle fatigue, defined as a pre to post reduction in maximum inspiratory mouth pressure. Therefore, it is possible that the optimal ergogenic effect of IMT was not achieved. This could be related to the specificity of the training mode, which may fail to target the length-tension characteristics of this muscle group during load carriage exercise tasks (Brown and McConnell 2012). This is an important consideration for exercise with load carriage as respiratory muscle recruitment is greater and length-tension relationships are different when thoracic loads are carried due to the imposed thoracic restriction and the need to provide augmented spinal stability due to excessive anterior trunk displacement and lumbosacral forces (Goh, Thambyah, and Bose 1998; Heller, Challis, and Sharkey 2009; Hodges, Heijnen, and Gandevia 2001). In addition, the presence of the load compromises respiratory muscle mechanics and accelerates respiratory muscle fatigue which has been suggested to lead to the development of the respiratory muscle metaboreflex, a sympathetically-mediated reduction in limb blood flow that seeks to preserve diaphragmatic function (Harms et al. 1997), although this has yet to be determined with load carriage exercise. The unique challenge posed by load carriage activities alters respiratory muscle mechanics, which may mean that the previous IMT interventions may not load the respiratory muscles in a way that mirrors the demands of load carriage exercise.

Functional inspiratory muscle training (IMT_F), defined as performing IMT when adopting the body positions and movements that mimic the criterion performance, has demonstrated an ergogenic effect above that of traditional IMT for running exercise (Tong, McConnell, et al. 2014). This form of training provides a dual stimulus to both the ventilatory and core muscles which contribute to respiration and the control of posture during exercise tasks (Boussana et al. 2003; Tong and Fu 2006). Consequently, IMT_F may have a greater effect, relative to traditional IMT methods and improve load carriage performance by specifically targeting the dual role of the respiratory muscles (i.e. sustaining ventilation and spinal stability). Accordingly, the aims of this study were to i) confirm the ergogenic effect of traditional IMT upon load carriage time trial performance and ii) investigate the ergogenic effect of IMT_F

compared to traditional IMT. It was hypothesised that IMT_F would attenuate respiratory muscle fatigue and improve performance above that of traditional IMT.

Methods

PARTICIPANTS

Following ethics approval from the host university, 17 non-smoking healthy males with previous experience of load carriage through regular recreational load carriage activities were recruited (Table 1). There were two experimental phases in this study (see Figure 1 below). Participants were pooled for phase 1 (4 wks. IMT) and then randomly split into two groups (matched for P_{Imax}) for phase 2 of the study (4 wks. IMT_F or 4 wks. maintenance IMT hereon referred to as IMT_{CON}). With the exception of body mass and core endurance in IMT_{CON} there were no significant differences in physical characteristics between groups for phase 2 (see Table 1). Initially 20 participants were recruited to the study; however, three withdrew throughout the process for personal reasons.

**** TABLE 1 AROUND HERE ****

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PRELIMINARY ASSESSMENT

Prior to experimental trials, participants completed an incremental exercise test on a motorised treadmill (Desmo, Woodway, Germany) to determine $\dot{V}O_2$ peak, defined as the highest 30 s $\dot{V}O_2$ recorded during the test. Following a 5 min warm-up at 8 km·h^{-1} and 1% gradient, the gradient was subsequently increased to 4% and the speed increased by 1 km·h^{-1} at three-minute intervals until volitional exhaustion. Online breath-by-breath gas analysis (Cortex Biophysik, Metalyser II, Leipzig, Germany) was used to determine $\dot{V}O_2$, defined as the rate of oxygen consumption and subsequently $\dot{V}O_2$ peak. During the second preliminary trial, participants were fitted with a 25 kg military style backpack (Web Tex, 107, Bedford, UK). Measurements of all fastening straps were recorded to the nearest mm and replicated during subsequent experimental trials. The mass of the load was comprised of sandbags that were evenly distributed within the central compartment of the backpack and worn in accordance with the manufacturer's guidelines. After completing a sport-specific endurance plank test (SEPT, detailed below), participants completed a familiarisation protocol comprising of two separate elements. Firstly, 20 min constant load treadmill marching at 0% gradient and $6.5 km \cdot h^{-1}$, 15 min seated recovery and secondly a self-paced 2.4 km time-trial. During the final preliminary trial, participants were familiarised with the experimental trial excluding the measurements of all dependent variables (see below for full details). This approach has been shown to increase the learning effect and maximise between session reliability of dependent variables and load carriage performance (Faghy and Brown 2014b).

EXPERIMENTAL TRIALS

Experimental trials were completed on three occasions including at 'baseline' prior to phase one, post-phase one and post-phase two; the post-phase one trial was used as the reference trial for any post-phase two changes in dependent variables. Due to the length of time between experimental trials in phase one and two (i.e., 4 wks.), participants repeated the familiarisation trial one wk. prior to the post-phase one and post-phase two experimental trials. As shown in Figure 1 and in line with previous work from our laboratory (Faghy and Brown 2014a; Faghy and Brown 2016), the experimental trial comprised 60 min exercise at 0% gradient and 6.5 $km \cdot h^{-1}$ (hereon referred to as the load carriage trial: LC), which is consistent with the British Army Infantry Basic Combat Fitness Test where soldiers carry a 25 kg load at 15 $min \cdot mile^{-1}$ pace (6.4 $km \cdot h^{-1}$; Rayson, Holliman, and Belyavin 2000). Following 15 mins of seated recovery participants completed a self-paced 2.4 km time-trial (hereon referred to as LC_{TT}), a test used to determine the physical and physiological responses to acute changes in British Army infantry training programs (P. E. H. Brown et al. 2007; P. E. H. Brown et al. 2010). Throughout LC_{TT} the speed of the treadmill was manually adjusted by the participant in order to complete the distance in the quickest time possible; the time elapsed was blinded from participants. We have previously demonstrated that this protocol provides a reliable tool for assessing load carriage performance and physiological parameters before and after IMT (Faghy and Brown 2014b; Faghy and Brown 2016).

Participants completed the sport-specific endurance plank test (SEPT) prior to the experimental trial, which was conducted without the external load. The SEPT has been shown to be a valid and reliable assessment tool of core endurance described previously by Tong, Wu & Nie (2014). Briefly, participants maintained a continuous prone bridge position with maximum effort and correct form, contact points with the ground where hands/feet only. There was no rest between each transition: (1) hold the prone bridge position for 60 s, (2) lift the right arm off the ground and hold for 15 s, (3) return the right arm to the ground and lift the left arm for 15 s, (4) return the left arm to the ground and lift the right leg for 15 s, (5) return the right leg to the ground and lift the left leg for 15 s; (6) lift both the left leg and right arm from the ground and hold for 15 s, (7) return the left leg and right arm to the ground, and lift both the right leg and left arm off the ground for15 s; (8) return to the prone bridge position for 30 s. Each stage was repeated until the maintenance of the prone bridge failed. Participants were given two verbal warnings to maintain the prone bridge position and the time to the limit of tolerance that provided an index of global core muscle function was recorded. Following the completion of the SEPT, participants were given 10 minutes of seated recovery prior to completing preload carriage measurements.

Respiratory muscle strength and pulmonary function were measured whilst standing still and wearing the backpack on the treadmill at rest and immediately after the cessation of exercise. Measures of maximal inspiratory (P_{Imax}) and expiratory (P_{Emax}) mouth pressure was assessed using a hand-held mouth pressure meter (Micro R.P.M.; Micro Medical, Buckinghamshire, UK) and baseline pulmonary function was assessed using a handheld spirometer (MicroPlus; Micro Medical). The results were interpreted in accordance with published guidelines (American Thoracic Society and European Respiratory Society 2002). Heart rate (Polar, Kempele, Finland) was measured continuously throughout load carriage and averaged over the final 30 s of exercise. Capillary blood sampling was conducted pre and post LC and LC_{TT}. Samples were taken from the distal phalanx of the index finger and collected in 20 μl end-to-end capillary tubes which were placed into a 1 μl cuvette with a haemolysing solution to assess blood lactate ($[Lac^-]_B$; Biosen, EKF Diagnostics, Barleben, Denmark). Perceptual responses were measured using visual analogue scales at immediately pre-exercise, immediately post LC and post LC_{TT} and included discrete measures of whole-body perceived effort (6-20; Borg 1982), leg discomfort and breathing discomfort (measured on a scale of 0-10; Faghy and Brown 2014a; Verges et al. 2007).

TRAINING INTERVENTIONS: IMT – PHASE ONE

During phase one of the study, all participants were provided with an IMT device (POWERbreathe® classic series, HaB International, Warwickshire, UK) and completed a 4-wk IMT intervention consisting of thirty dynamic inspiratory efforts, at home, twice daily, against a pressure-threshold load of 50% P_{Imax}. This method has been shown to increase diaphragm and chest wall muscle strength (Brown, Johnson, and Sharpe 2014; HajGhanbari et al. 2013) and improve LC_{TT} performance (Faghy and Brown 2016); for a systematic review see Illi, Held, Frank, & Spengler, 2012). P_{Imax} was assessed bi-weekly throughout the interventions and used to re-calibrate the relative intensity of the training device (Faghy and Brown 2016).

TRAINING INTERVENTIONS: FUNCTIONAL IMT (IMT_F) – PHASE TWO

The IMT_F group performed functional IMT sessions three times per wk. for 4 wks. Each session comprised four inspiratory loaded core muscle training exercises repeated twice per session. One session per wk. was conducted in the laboratory to monitor progress and technique and the remaining two were conducted either at home or in the laboratory. Whole body exercises performed during IMT_F were specific to running and included raised alternating crunches, swiss ball crunches, prone bridge and finally dynamic bird dog, all of which have been used and described previously (McConnell, 2011; Tong and McConnell, et al., 2014). Participants were required to inhale forcefully through the device as they initiated the required body actions from the starting position and exhaled slowly when returning to the starting position. Session volume increased weekly from 12 repetitions per exercise in wk. 1 to 18 breaths in wk. 4 (an increase of 2 additional breaths per wk.) in line with recommendations from previous work (McConnell 2011; Tong, McConnell, et al. 2014). The device was set at 50% of P_{Imax} and adjusted weekly throughout the intervention, to calibrate the relative intensity of the training device (Johnson, Sharpe, and Brown 2007).

TRAINING INTERVENTIONS: TRADITIONAL IMT (IMT_{CON}) – PHASE TWO

The control group (IMT_{CON}), completed a maintenance IMT intervention which consisted of 30 inspiratory efforts at 50% P_{Imax}, twice daily 3 times per wk. for 4 wks. which has been shown previously to preserve IMT-induced improvements in P_{Imax} (Romer and McConnell 2004). P_{Imax} was assessed bi-weekly throughout the interventions and used to re-calibrate the relative intensity of the training device (Faghy and Brown 2016). In all aspects of the training intervention, adherence was monitored by the completion of a training diary.

STATISTICAL ANALYSIS

Normal distribution was confirmed using a Kolmogorov–Smirnov test. Within-group differences and interaction effects for dependent variables were assessed using a 3 (trial time point: pre-exercise, post-LC, post-LC_{TT}) x 3 (study time point: baseline vs. post phase 1 vs. post phase 2) ANOVA with Tukey’s post hoc analysis. All analysis was conducted using SPSS version 24 for Windows (Chicago, IL, USA). Between-group differences (IMT_F vs. IMT_{CON})

were assessed using independent samples T-Tests. A-priori α was set at 0.05 and all results are presented as mean ± SD. Effect sizes were calculated using Cohen's d ($d=(\bar{\boldsymbol{x}}_1-\bar{\boldsymbol{x}}_2)$/pooled σ).

RESULTS

TIME TRIAL PERFORMANCE

Baseline LC_{TT} was 15.93 ± 2.30 min and mean speed was 9.5 ± 1.5 km·h^{-1}. Post-phase 1, LC_{TT} improved by 1.19 ± 0.83 min (mean time 14.73 ± 2.40 min; P<0.01, effect size: d=0.56, Figure 2) and mean speed increased to 10.2 ± 1.47 km·h^{-1} (absolute increase 0.7 km·h^{-1}, 7.5 ± 6.6%, P<0.05, effect size: d=0.43). Post-phase 1 when the groups were randomly split, there was no difference in LC_{TT} time prior to the intervention (IMT_F, 14.11 ± 2.14 min and IMT_{CON} 14.75 ± 1.74 min; P>0.05). Relative to post-phase 1, Post-phase 2 LC_{TT} improved in IMT_F only (13.59 ± 2.33 min, absolute change 0.58 ± 0.65 min, 4.2 ± 4.4%, P<0.05, effect size: d=0.24) and was unchanged in the IMT_{CON} group (14.86 ± 2.83 min, P>0.05, effect size: d=0.12). There was a between-group difference between IMT_F and IMT_{CON} following phase two (absolute difference of 0.73 ± 0.85 mins, 9.3±3.6%, effect size d= 0.48, P<0.05, Figure 2). Post-phase two mean speed increased in IMT_F only (10.9 ± 1.9 km·h^{-1}, absolute increase: 0.5 km·h^{-1}, 4.5 ± 3.7%, P<0.05, effect size: d=0.27).

****FIGURE 2 HERE****

RESPIRATORY MUSCLE PRESSURES AND PULMONARY FUNCTION

Training compliance was above the set criteria (>85%) during phase 1 (94 ± 7%) and in both groups during phase 2 (IMT_F 94 ± 5% and IMT_{CON} 94 ± 9%). Resting P_{Imax} was reduced post LC (absolute reduction 16 ± 23 cmH_2O, 11 ± 14% P<0.05), with no further reduction post LC_{TT} (P>0.05). Post-phase 1 (i.e., after 4 wk. IMT) P_{Imax} was greater at rest (15 ± 5%,), post-LC (19 ± 13 %) and post-LC_{TT} (11 ± 12%, P<0.05). When the groups were split (post phase 1), there were no between-group differences in P_{Imax} (P>0.05). Within group, P_{Imax} was greater at each time point in IMT_F (P<0.05) and similar in IMT_{CON} (P>0.05). Baseline P_{Emax} was unchanged post-LC and post LC_{TT} during phase 1 and was not different between groups during phase 2 (Tables 2 and 3 P>0. 05). Pulmonary function values were not different between groups or at any time point (P>0.05). There were also no within trial changes in any experimental trial (P>0.05, see Tables 2-4).

SPORT-SPECIFIC ENDURANCE PLANK TEST (SEPT)

Baseline SEPT was 4.13 ± 1.24 min and post-phase 1 improved to 5.06 ± 1.65 min (absolute increase 0.58 ± 1.36 min P<0.05). Post-phase 1 there was a between-group difference (IMT_F 4.61 ± 1.45 min vs IMT_{CON} 5.73 ± 1.75 min, P<0.05). Post-phase 2, SEPT increased in IMT_F only (5.13 ± 1.86 min, absolute increase 0.94 ± 1.74 min P<0.05) and was unchanged in IMT_{CON} (5.44 ± 1.70, P>0.05; see Table 2).

PHYSIOLOGICAL AND PERCEPTUAL RESPONSES

Physiological and perceptual responses are shown in Tables 3 and 4. Responses in all variables were identical in all trials (P>0.05) and there were no within or between-group differences in perceptual responses at any time point.

**** TABLES 2,3 AND 4 AROUND HERE****

DISCUSSION

The key findings of this study were fourfold. First, 4 wks. IMT improved LC_{TT} performance confirming the findings of previous work from our group. Second, IMT_F further improved LC_{TT} performance. Third, maintenance IMT_{CON} maintained LC_{TT} performance with over 50% reduction in IMT volume and finally, neither IMT, IMT_F or IMT_{CON} attenuated respiratory muscle fatigue following load carriage exercise.

TIME-TRIAL PERFORMANCE

Time-trial performance improved by 7.5% following 4 wks. IMT, which is similar to our previous work (Faghy and Brown 2016). It is also similar to recent work by Shei *et al* (2018) who adopted a fixed paced, sub-maximal trial to the limit of tolerance with a 10kg load and observed a 9% improvement in time to exhaustion. To date, these studies provide the only studies demonstrating a change in load carriage performance following IMT. However, the current study extends previous knowledge demonstrating that performance can be further enhanced after a period of IMT_F by approximately 4%. To date, this mode of training has only been used with unloaded exercise demonstrating improvements in endurance running performance (Tong, McConnell, et al. 2014). In their study, recreational runners completed 4-wk IMT before completing either interval training plus IMT_F or just interval training. Following 6 wks. of concurrent interval training and IMT_F, performance on a 60 min treadmill test was improved in both groups, but to a greater extent in the IMT_F group (3.1%) compared with the control (1.5%). Improvements in IMT_F are attributed to increased respiratory muscle strength, which has a role in contributing to core stability, as this muscle group are essential for running performance (Tong, McConnell, et al. 2014). It is possible that the greater improvement in performance observed in the present study was due to a greater activation/adaptation of respiratory muscles during load carriage exercise, thus reducing the work of breathing and thereby releasing, in part, the primary respiratory muscle contribution and energy expenditure dedicated to core stability. It is possible that the post IMT response attenuated the respiratory muscle metaboreflex, a sympathetically-mediated reflex reduction in limb blood flow presumably in favour of the fatiguing respiratory muscles (Harms 2007). However, during load carriage tasks respiratory muscle fatigue occurs at a lower relative exercise intensity (~59% $\dot{V}O_2$ peak) compared to previous literature and it is therefore likely that energy requirements would be met via increased oxygen extraction as opposed to a re-distribution of limb blood flow; however, future study is warranted in a load carriage setting.

Another important finding of this work is that the ergogenic effect of IMT is preserved following a period of maintenance IMT where the training frequency is reduced by 57%. Previously, the protocol adopted in this study has demonstrated preserved inspiratory muscle strength following 9 and 18 wks. of maintenance IMT after a period of 9 wks. traditional IMT although performance was not measured in this work (Romer and McConnell 2003). Reduced training volume following periods of intense overload has long been linked with sustained performance outcomes (Spilsbury et al. 2015) and this study demonstrates for the first time that the ergogenic effect of IMT can also be maintained after initial conditioning. Whether this would be preserved after a maintenance phase or even after cessation of IMT remains to be determined especially since changes in P_{Imax} and performance are not correlated (Johnson et al., 2007) and the increase in P_{Imax} afforded by IMT is reduced following 9 wks. of detraining (Romer and McConnell 2003).

RESPIRATORY MUSCLE FUNCTION

P_{Imax} increased by 14% following phase one which is lower than previously observed from our group (31%, Faghy and Brown 2016), however this used a 6 wk. training intervention. Previous work has demonstrated the efficacy of a 4 wk. training intervention as Brown, Johnson, and Sharpe (2014) demonstrated a 19% increase in P_{Imax} using an identical approach to the one used here. A further consideration is the importance of baseline levels of P_{Imax} when considering the response to an IMT intervention. Brown et al. (2014) demonstrated that higher baseline P_{Imax} limits IMT-mediated improvements, as the opportunity for physiological adaptation is reduced. Notwithstanding this, the four wk. period was chosen to replicate the methodology of Tong et al. (2014) who observed a 21% increase in inspiratory muscle strength post 4 wk. IMT. P_{Imax} was unchanged following both $\mathrm{IMT_F}$ and $\mathrm{IMT_{CON}}$ interventions when compared to post IMT values. However, P_{Imax} was unchanged which is different from Tong et al. (2014) who observed an improvement of 3% following $\mathrm{IMT_F}$. This may be due to a reduction in the training volume and a constant inspiratory load may be responsible for the plateau in P_{Imax}. Training intensity here was adjusted weekly to maintain relative training stimuli throughout $\mathrm{IMT_F}$ and training volume increased weekly which may explain why P_{Imax} was unchanged post $\mathrm{IMT_{F.}}$

Neither IMT nor $\mathrm{IMT_F}$ attenuated the level of respiratory muscle fatigue observed throughout the study. We hypothesised that targeting the non-respiratory roles of the primary and accessory ventilatory muscles with the use of actions that challenge stability via deliberate core perturbations might protect against the volume limitation of the thorax during load carriage activities. However, this was ineffective despite the increased performance on the SEPT. This could be partly explained by the subjective measure of the assessment of P_{Imax}, which, despite extensive familiarisation, is a volitional measure. Additionally, this could also be due to the lung volumes targeted during IMT sessions; individual breaths are initiated from residual volume with participants seeking to maximise tidal volume during all efforts (McConnell 2011). Therefore, the lung volumes during IMT may not reflect the reduced operational lung volumes that are seen when the load is being worn, therefore targeting an inappropriate component of the length-tension curve of the respiratory muscles. The exercises undertaken during IMT_F were selected due to their specificity for running (Tong et al, 2012), and also because of the possibility that they may reduce operational lung volumes. Although reductions in end-inspiratory lung volume alter the length-tension relationship of the respiratory musculature and mimic the imposed volume limitation on the thoracic cavity during load carriage activities (Brown & McConnell, 2012), more work is needed to fully understand this. The exercises primarily reduced end-expiratory lung volume rather than end-inspiratory lung volume, which is constrained by the presence of a thoracic load. Consequently, the training stimuli may be targeting and strengthening the inspiratory muscles throughout an operational range, which may not be utilised during exercise with load carriage. Importantly, previous work has identified that fatigue of the expiratory muscles is not an influencing factor in determining operational lung volumes despite reduced end-expiratory time and increased peak gastric and oesophageal pressures and it may be more appropriate to assess influences that inhibit flow (Taylor, How, and Romer 2013). In relation to this study, IMT_F sessions were designed to challenge both breathing and core stability concurrently but across an entire range of movement where limited flow would only occur at the termination of each exercise. Therefore, it might be possible the selected exercises adopted might not adequately account for the shift in the boundaries of their length-tension curve (Romer & McConnell, 2004) as it is also noted for example that the parasternal intercostals optimal length-tension curve is at a greater lung volume (Verges, Notter, and Spengler 2006). The resulting adaption could, therefore, be insufficient in deterring respiratory muscle fatigue. Future research should seek to conduct IMT and IMT_F under conditions similar to those imposed by the presence of the load essentially by wearing a heavy backpack throughout training sessions.

A further consideration is the activation of the diaphragm during IMT sessions. Recent evidence suggests that the use of targeted IMT, achieved via audible cues during IMT sessions increases transdiaphragmatic pressure (Pdi) and reduces the electromyographic activity of the accessory muscles (Ramsook et al. 2016). These findings are developed from previous work demonstrating increased surface electromyography amplitude of the diaphragm and intercostals following two sets of 30 inspiratory efforts at a load equivalent to 40% of an individual's P_{Imax} (Hawkes, Nowicky, and McConnell 2007). To date, the work here has only been conducted over the course of a single IMT session and the benefits over the course of a chronic intervention (4-6 weeks) remains unknown. IMT has previously shown an increase in Pdi (Brown, Johnson, and Sharpe 2014) and it would be interesting to determine the extent to which exercise performance is affected, especially considering that during hard exercise the chest wall muscles and accessory muscle recruitment is elevated relative to the diaphragm (Johnson et al. 1993; Aliverti 2008) demonstrating a need to target both the obligatory and accessory respiratory muscles. Although the use of targeted IMT was not considered in the current study, it could have important considerations for IMT interventions and its combination with an $\mathrm{IMT_F}$ intervention warrants further explorations.

CORE MUSCLE FUNCTION

Performance on the SEPT was improved following phase one and again following phase 2 in $\mathrm{IMT_F}$ and was unchanged in $\mathrm{IMT_{CON}}$. Improved performance is attributed to increased P_{Imax}, core endurance and the coordination between core muscle activation and breathing activities which are targeted during $\mathrm{IMT_F}$ (Tong, McConnell, et al. 2014). These activities require the utilisation of similar muscle groups which are tasked with both thoracic excursions to assist with ventilation and trunk stabilisation during exercise (Hodges et al. 2005; Janssens et al. 2010; Tong and Fu 2006). Importantly, reduced stabilisation of the torso and fatigue of the abdominal complex has been identified as a limiting factor to both running and cycling performance (McDaniel, Subudhi, and Martin 2005; Tong, Wu, and Nie 2014). Fatigue of the muscles comprising the abdominal complex prior to endurance running exercise is associated with a 31% and 39% reduction in both SEPT and time at 85% $\dot{V}O_2$ peak, respectively (Tong, Wu, et al. 2014). Mechanistically, this could be the result of the diaphragm's dual role in powering ventilation and providing stability of the trunk during exercise tasks due to the insertion of the diaphragm on the thoracic (T12) and lumbar (L1 and L2) regions of the spine (Hodges et al. 2005). The authors acknowledge a between-group difference in core muscle endurance once the groups were split (post phase one) however this did not translate to a difference in performance. We suggest the exercises conducted as part IMT_F is not solely related to increased performance however; this may be caused by the altered interaction of the diaphragm and the muscles that comprise the abdominal cavity. Further investigation is required to determine the contribution to both ventilatory tasks and stabilisation of the abdominal cavity during load carriage tasks and how this affects performance.

CONCLUSION

We have previously demonstrated that inspiratory muscle training techniques improve exercise performance with thoracic load carriage. Here the improvement in exercise performance is enhanced by incorporating IMT_F, providing an additional ergogenic effect to 2.4 km time-trial performance that is pre-loaded with 60 min sub-maximal exercise. We suggest that the performance enhancement is the result of improved coordination between the core and respiratory muscle groups that are tasked heavily via load carriage and IMT_F, allowing the respiratory muscles to increase their non-respiratory contribution.

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Figure Captions:

Figure 1- Schematic detailing each phase of the study and the experimental load carriage (LC) protocol. Upward facing arrows depict the time point in which respiratory muscle pressure and lung volumes were assessed. The downward facing arrows depict the time point when physiological and perceptual responses were assessed. Inspiratory muscle training (IMT), Maintenance IMT (IMT_{con}), functional Inspiratory Muscle Training (IMT_F).

Figure 2 - Absolute time for LC_{TT} performance, values are presented as mean ± SD. Solid lines refer to pooled data, open circle markers refer to IMT_{Con} and open square markers refer to $IMT_{F.}$ A different from pre-intervention: B, different to post 4 wks. IMT in IMT_F (P<0.05).