Title:

Whole body active warm up and inspiratory muscle warm up do not improve running performance when carrying thoracic loads.

Authors:

Mark A. Faghy[1], Peter I. Brown[2]

Address of correspondence:

Dr Mark Faghy, Sport, Outdoor and Exercise Sciences, Exercise and Health Sciences,
Kedleston Road, Derby, DE22 1GB, E: Email: M.Faghy@derby.ac.uk

Affiliation:

[1] College of Life and Natural Sciences, University of Derby, UK

[2] English Institute of Sport, Loughborough High Performance Centre, UK

ABSTRACT

Whole body active warm ups (AWU) and inspiratory muscle warm up (IMW) prior to exercise improves performance on some endurance exercise tasks. This study investigated the effects of AWU with and without IMW upon 2.4 km running time-trial performance while carrying a 25 kg backpack, a common task and backpack load in physically demanding occupations. Participants (n = 9) performed five 2.4 km running time-trials with a 25 kg thoracic load preceded in random order by 1) IMW comprising 2 x 30 inspiratory efforts against a pressure-threshold load of 40 % maximal inspiratory pressure ($P_{\mathrm{I}max}$), 2) 10 min unloaded running (AWU) at lactate turnpoint (10.33 ± 1.58 km·h^{-1}), 3) placebo IMW (PLA) comprising five min breathing using a sham device, 4) AWU+IMW and 5) AWU+PLA. Pooled baseline $P_{\mathrm{I}max}$ was similar between trials and increased by 7% and 6% following IMW and AWU+IMW ($P<0.05$). Relative to baseline, pooled $P_{\mathrm{I}max}$ was reduced by 9% after the time-trial, which was not different between trials ($P>0.05$). Time-trial performance was not different between any trials. Whole body AWU and IMW performed alone or combination have no ergogenic effect upon high intensity, short duration performance when carrying a 25 kg load in a backpack.

KEY WORDS

Inspiratory muscle warm-up, load carriage, exercise performance, respiratory system

INTRODUCTION

Whole body active warm-ups (AWU) are an essential element in the preparation for performance and as a result have received considerable attention from the literature, collectively demonstrating an ergogenic effect upon a variety of sports performance (Jones et al. 2003, Carter et al. 2005, Bailey et al. 2009). Warm-up activities are typically whole body and target large muscle groups to increase core muscle temperature and accelerate oxygen kinetics (for a comprehensive review see (Bishop 2003a, 2003b). Thoracic load carriage exercise is defined as locomotion while bearing a mass upon the torso (i.e. a backpack; Knapik et al. 2012) yet despite being commonplace in physically demanding occupations (e.g. deployed military and emergency services) and recreational groups no research has investigated the ergogenic effect of AWU upon load carriage performance.

In addition, AWU may pose little focus upon preparing the respiratory muscles (Tong and Fu 2006, Johnson et al. 2014). This is surprising since they contribute extensively to exercise tolerance and performance through a number of central and peripheral mechanisms (Dempsey et al. 2006, Marcora 2009) and maximum inspiratory pressure (P_{Imax}) is significantly reduced following load carriage exercise (Faghy & Brown, 2014a). However, performing specific inspiratory muscle warm-up (IMW) increases peripheral excitability of the diaphragm and intercostal muscles thus increasing inspiratory muscle force (Hawkes et al. 2007, Ross et al. 2007). When combined with AWU, this has been shown to have an ergogenic effect demonstrated by increased time (>7%) to the limit of tolerance in intermittent running (Tong and Fu 2006, Lin et al. 2007, Lomax et al. 2011) and distance covered (1.1%) during a 6 min all out rowing time trial (Volianitis et al. 2001). The increased P_{Imax}, prior to exercise reduces the relative work of the inspiratory muscles during exercise (Lomax et al. 2011, Johnson et al. 2014) and may attenuate dyspnoea, blood lactate accumulation and inspiratory muscle fatigue (Volianitis et al. 2001, Lin et al. 2007, Lomax et al. 2011). However, no studies have investigated the effects of IMW upon load carriage performance which is surprising since carrying a thoracic load modifies breathing mechanics via an inspiratory volume limitation (Dominelli et al. 2012), reducing respiratory muscle efficiency and accelerating respiratory muscle fatigue (~59% $\dot{V}O_{2peak}$, Faghy & Brown, 2014b) and impairs load carriage performance (Faghy and Brown 2014a).

Accordingly, the aim of this study was to examine the effects of AWU with and without the addition of IMW upon a running 2.4 km load carriage (25 kg) time-trial performance (a specific performance model used within British Army infantry training programs). It was hypothesised that time-trial performance would be improved and attenuate reductions in inspiratory muscle pressure, perceptual and metabolic responses attenuated following an AWU, and that this effect would be magnified with IMW.

METHODS

Following ethics approval from the host University, nine healthy, non-smoking and physically active males (Table 1), familiar with load carriage through regular recreational load carriage activities, participated in this study. All participants were fully briefed on experimental procedures and informed consent was obtained. Participants did not engage in strenuous exercise on the day preceding and the day of an exercise test. Each participant completed a 24 h diet record prior to their first exercise trial, which was then repeated prior to all subsequent trials. Participants abstained from alcohol and caffeine in the 24h prior to testing and arrived at the laboratory 2h post-prandial.

**** TABLE ONE NEAR HERE****

PRELIMINARY TRIALS

Participants attended the laboratory twice, on separate occasions during preliminary trials. First an assessment of body composition was conducted using bioelectrical impedance analysis (Bodystat 1500, Isle of Man, UK; for details see Brown et al., 2013). Following this and during the same session, participants completed an incremental running exercise test on a motorised treadmill (Desmo, Woodway, Germany) without a backpack to determine lactate threshold and lactate turnpoint. Following a 5 min warm-up at 8 $km \cdot h^{-1}$ and 1% gradient, the gradient was subsequently increased to 4% and the speed increased by 1 $km \cdot h^{-1}$ at three minute intervals (Beneke et al. 2011). At the end of each stage participants dismounted the treadmill belt (<30s) and blood lactate concentration $[lac^{-}]_{B}$ was measured from arterialised-venous fingertip blood samples (Biosen, EKF Diagnostics, Barleben, Denmark). Lactate threshold and lactate turnpoint were identified through real-time visual inspection of each individual $[lac^{-}]_{B}$-velocity curve. Lactate threshold was defined as the first deflection in blood lactate concentration from baseline (mean increase from rest 0.87 ± 0.37 $mmol \cdot l^{-1}$), and lactate turnpoint was defined as the second observable and sustained deflection (4.58 ± 0.87 $\text{mmol}\cdot\text{l}^{-1}$) in blood lactate beyond the lactate threshold (Eston and Reilly 2009).

During the second preliminary visit, participants were familiarised with all testing equipment and protocols to be used during experimental trials. A hand-held mouth pressure meter (Micro R.P.M., Micro Medical, Buckinghamshire, UK) was used to assess maximal inspiratory (P_{Imax}) and expiratory (P_{Emax}) mouth pressures. Participants then completed baseline pulmonary function tests using a handheld device (MicroPlus, Micro Medical, Buckinghamshire, UK). Between session reliability of baseline P_{Imax} (log ratio limits of agreement) was: mean bias = 0.97, standard error 0.37, confidence interval (CI) 0.10 to 1.83; random error ratio =1.08 [standard error 0.64], CI lower LoA -0.57 to 2.43, CI upper LoA -0.46 to 2.54. Parameters were performed and interpreted in accordance with published guidelines (American Thoracic Society and European Respiratory Society 2002, McConnell 2007).

Participants were fitted and familiarised with the 25 kg backpack (Web Tex, Bedford, UK). Participants individually adjusted all straps, measurements here were recorded to the nearest mm and replicated for each experimental trial.

TIME TRIAL TESTS AND WARM UP CONDITIONS

Participants completed five 2.4 km experimental load carriage time-trials (LC_{TT}) each separated by a minimum of 7 days; trials were randomised using a Latin square to minimise any order effects. The experimental design and within session timings are illustrated in Figure 1. All warm up conditions were completed without the addition of the backpack, preceded the time trial and comprised: 1) inspiratory muscle warm (IMW) up of 2 × 30 dynamic inspiratory efforts using a pressure threshold-loading device (POWERbreathe® classic, HaB International, Warwickshire, UK). The intensity here was 40% of baseline P_{Imax} consistent with previous literature (Hawkes et al. 2007, Ross et al. 2007, Lomax et al. 2011). 2) Running only warm up

(AWU) comprising 10 min unloaded exercise and following the this there was 5 min of standing rest prior to LC_{TT}. The speed of the treadmill was equal to the velocity in which lactate turn point was observed (V_{LTP}), determined during preliminary testing sessions (pooled mean 10.33 ± 1.58 $km \cdot h^{-1}$). This intensity was used in accordance with best practice guidelines for whole body warm-up (Bishop 2003a, 2003b). 3) Placebo IMW (PLA) comprising relaxed spontaneous breathing for five min through a pressure threshold-loading device. The resistance spring was removed here and replaced with loosely packed aquarium gravel as described previously, which through pilot work had minimal effect upon P_{Imax} (Faghy and Brown, 2015, 2016; Johnson et al. 2007, Sonetti, et al. 2001). This technique is advantageous over alternative methods using minimal inspiratory resistances (i.e. 10-15% of baseline P_{Imax}) which result in inspiratory muscle activation (Ross et al., 2007). 4) combining AWU+IMW, where the AWU preceded IMW and finally 5) combining AWU+PLA.

**** FIGURE 1 NEAR HERE****

Dependent variables were measured at baseline (defined as standing still on the treadmill while wearing the backpack), post-warm up condition (defined as standing still on the treadmill immediately following the warm up protocol) and post LC_{TT} (for respiratory muscle and pulmonary function, this was defined as standing still on the treadmill immediately after the cessation of the time trial, for the physiological variables, this was defined as the mean value of the final 30s of the time trial). P_{Imax}, P_{Emax} and pulmonary function was measured at baseline following the warm up and immediately post LC_{TT} in each trial. Heart rate (Polar T31, Polar, Kempele, Finland), expired respiratory gases (Cortex Biophysik, Metalyser II, Leipzig, Germany), $[lac^{-}]_B$ and perceptual responses (RPE, $RPE_{breathing}$ RPE_{Legs}) were measured prior to the warm-up, post warm up and post $LC_{TT.}$ During the time-trial, participants were able to view distance completed and running speed but not time elapsed. Running speed was manually adjusted by the participant during the time trial. The only instruction given to the participant during the experimental trials was to complete the time-trial in the shortest time possible (Hajoglou et al. 2005). Time-trial performance was similar to our previous work (Faghy and Brown 2014b, 2015) and the approach used aligns with recommendations for laboratory based assessment of load carriage performance (Rayson et al. 2000). The specific time-trial distance and mass carried were selected to reflect realistic occupational requirements and based upon the British Army infantry training program assessment tests (Brown et al., 2007; Brown et al., 2010; The British Army, 2014). This protocol demonstrates a very high between day reliability (log ratio limits of agreement [LoA]; bias =1.02 [standard error 0.37], Confidence interval [CI] 0.18 to 1.86; random error ratio =1.11 [standard error 0.65], CI lower LoA -0.49 to 2.43, CI upper LoA -0.33 to 2.59). At the cessation of the time trial test, participants were instructed to stand still on the treadmill to perform post-LC_{TT} measures of respiratory muscle strength and pulmonary function.

STATISTICAL ANALYSIS

All data are presented as mean ± SD. A one-way repeated measures ANOVA was used to assess differences between variables at baseline between trials. A two-way repeated measures ANOVA was used to examine differences between conditions with Tukey's post hoc analysis to identify differences at individual time points. For all analyses a priori α was set at 0.05. Effect size was calculated using Cohen's *d* (where: $d=(\bar{x}^1-\bar{x}^2)/\text{pooled } \sigma$) and judgements of the magnitude of the effect were based on the 'minimal worthwhile effect' as described in previous literature (Hopkins 2000). All statistical analysis was performed using SPSS for Windows (SPSS, Chicago, IL, USA).

RESULTS

Time-Trial Performance

Time trial performance was not different between trials (IMW 14.32 ± 1.34 min, AWU 14.40 ± 2.28 min, PLA 14.77 ± 1.92 min, AWU+IMW 14.14 ± 1.74 min, AWU+PLA 14.68 ± 2.15, P>0.05) with a range of small effect sizes for each trial relative to AWU (0.04 to 0.18).

Respiratory Muscle Pressure and Pulmonary Function

Baseline values of P_{Imax} and P_{Emax} were similar between all trials (Table 2, P>0.05). Following IMW there was a 7% increase in P_{Imax} (pre: 122 ± 25 cmH$_2$O vs post 136 ± 28 cmH$_2$O, P<0.05) and a 6% increase from baseline post AWU+IMW (pre: 119 ± 26 cmH$_2$O vs post: 133 ± 27 cmH$_2$O, P<0.05). Following AWU+PLA, PLA and AWU, P_{Imax} was unchanged relative to baseline (P>0.05). Following LC$_{\mathrm{TT}}$ P_{Imax} was reduced in all experimental trials (pooled data: -9%, P<0.05) which was similar between trials (Table 3). Reductions in P_{Imax} were within normal limits (Faghy and Brown, 2014a, 2015) and were similar for each participant between trials (P<0.05, Figure 2). P_{Emax} was unchanged from baseline in all trials (P>0.05; Table 2 and 3). Values of pulmonary function are shown in Table 1 and were similar between trials at baseline, and post LC$_{\mathrm{TT}}$ in all trials (P>0.05).

****FIGURE TWO NEAR HERE****

Physiological and Perceptual Responses

Mean physiological and perceptual responses at baseline and following LC$_{\mathrm{TT}}$ across all trials are presented in Tables 2 and 3 respectively. All baseline values were similar between trials (P>0.05) and increased following AWU+IMW, AWU and AWU+PLA (P<0.05) but remained similar following IMU and PLA (P>0.05). Post LC$_{\mathrm{TT}}$ all physiological and perceptual responses were increased relative to baseline and post warm-up in all trials (Table 2 and 3, $P<0.05$). However, there were no within or between trial differences or interaction effects in any physiological or perceptual measure immediately following LC_{TT} (Table 3, $P>0.05$).

**** TABLE 2 NEAR HERE****

**** TABLE 3 NEAR HERE****

DISCUSSION

The main findings of this study were threefold. Firstly, AWU did not enhance LC_{TT} performance. Secondly, an increase in P_{Imax} following IMW had no effect upon LC_{TT} performance when performed with or without AWU. Thirdly, there were no between trial differences in P_{Imax}, physiological and/or perceptual variables during the time trial (P>0.05). Accordingly, it is unlikely that the active warm up and/or the inspiratory muscle warm up used in this study performed alone or in combination would provide an ergogenic benefit to personnel operating in physically demanding occupations while carrying a 25 kg backpack and performing short duration (<15 min) high intensity exercise.

To our knowledge, we are the first to report that performance was unchanged following an AWU when exercising with load carriage. This is surprising since AWU consistently improves running and cycling performance during exercise of a similar intensity and duration as the present study including 7 min all out cycling (Burnley et al. 2005) and 800 m running time-trial performance (Ingham et al. 2013). Why AWU failed to improve load carriage performance is therefore interesting especially since load carriage performance can be improved through a variety of whole body (Knapik, 1997) and inspiratory muscle training interventions (Faghy and Brown, 2015). Accordingly, the lack of effect upon performance is likely the design of the AWU. Since this was the first study to investigate the effects of AWU upon load carriage performance, we designed our protocol in line with best practice whereby the warm-up intensity should be designed according to the physical demands of the criterion task (Bishop, 2003b). However, future study should design an AWU that provides an upper body strength and whole body endurance warm-up stimulus as this would utilise the muscle groups, energy systems, and related components of fitness that are fundamental to load carriage performance (Knapik et al. 2012).

We are the first to investigate the effects of acute IMW, alone or in combination with AWU upon time-trial performance while carrying a heavy thoracic load. Accordingly, the results can only be compared with unloaded exercise studies that have employed a similar inspiratory muscle warm-up protocol. Tong and Fu (2006) observed an increase in time to the limit of tolerance (20%) during an open ended intermittent running performance test when IMW identical to that used here was combined with AWU. Data that was replicated by Lomax et al. (2011). Similar positive improvements were also reported from the same group when an identical pre-exercise warm-up routine preceded a badminton footwork performance test (8% improvement; (Lin et al. 2007). In exercise modes where normal breathing mechanics are altered such as cycling and rowing, albeit to a lesser extent to load carriage (Boussana et al. 2003) results are equivocal. Distance covered and mean power output during a 6 min all out rowing simulation test was improved (3%) when a specific rowing AWU was complemented by IMW (Volianitis et al. 2001). In contrast Johnson et al. (2014) observed similar increases in P_{Imax} to others (Volianitis et al. 2001, Tong and Fu 2006, Lin et al. 2007, Lomax et al. 2011) yet the addition of IMW to a 15 min cycling AWU did not improve 10 km cycling time-trial performance (Johnson et al. 2014). Consequently, the effects of combined IMW and AWU upon exercise performance remains unclear.

The ergogenic effects of IMW are attributed to greater pre-exercise P_{Imax} (Volianitis et al. 2001, Tong and Fu 2006, Lin et al. 2007, Lomax et al. 2011) via greater excitability and synchrony of inspiratory muscle motor units (Hawkes et al. 2007, Ross et al. 2007). The increase in strength allows the inspiratory muscles to operate at a lower relative intensity during exercise, however, that performance was not improved in this study following AWU with and without IMW suggest that some other mechanism(s) are regulating performance during load carriage exercise, independent of increases in P_{Imax} and the cascade of potential physiological changes that may occur. This notion is consistent with previous work whereby inspiratory muscle training (IMT) increased P_{Imax} (>30%) and subsequently 2.4 km $\mathrm{LC}_{\mathrm{TT}}$ performance (Faghy and Brown 2015, 2016) yet failed to attenuate reductions in P_{Imax}. Therefore, transient increases in P_{Imax} per se following IMW are clearly not sufficient in all exercise modes, to affect load carriage performance and affect the ensuing respiratory muscle fatigue. To gain an improvement in load carriage performance structural changes of the inspiratory muscles and systemic physiological changes appear to be required.

The difference in findings of current work relative to previous studies demonstrating an ergogenic effect of IMW may be explained by the research design. There are clear differences in the performance tasks used, with observed improvements documented in open ended fixed intensity (Tong and Fu 2006, Lin et al. 2007, Lomax et al. 2011) and also fixed duration all out (6 min) exercise tasks (Volianitis et al. 2001). Although the ventilatory demands and sensitivity of these exercise modes may be similar (Amann et al. 2008), it is difficult to compare studies objectively. In addition, differences in performance outcome may be explained by the design of the warm-up protocol (Johnson et al. 2014). In the present study, warm up intensities were prescribed relative to the velocity of the lactate turnpoint and similarly Johnson et al., (2014) prescribed a warm up intensity relative to each participants' gas exchange threshold which align with best practice recommendations for short duration (<20 min) intense exercise (Bishop 2003b, Burnley et al. 2005) providing a sufficient stimulus for whole body exercise tasks. However Tong and Fu (2006) and Lin *et al* (2007) instructed participants to adopt a self-selected exercise intensity for the AWU prior to the performance task. It has been noted that this approach is sub-optimal (Ingham et al. 2013) and most likely provides a stimulus to the locomotor and respiratory muscles that is insufficient (Burnley et al. 2005, Johnson et al. 2014) and hence potentially greater opportunity for performance improvement through IMW. In addition, the duration between the end of the AWU and performance in previous studies was greater than 10 min (5 min in the present study) (Tong and Fu 2006, Lin et al. 2007, Lomax et al. 2011). This extended period is known to be detrimental to performance primarily by attenuating the gains in intramuscular temperature and oxidative priming (Mohr et al. 2004, Edholm et al. 2015). Accordingly, there is great disparity in the design and outcomes of research investigating the role of combined AWU and IMW upon performance. Although we are the first to investigate this in an occupational performance setting, further research should design an AWU, which aligns more closely with the demands of the performance test and at an intensity, which reflects best practice guidelines.

CONCLUSION

IMW increased P_{Imax} however; this provided no ergogenic effect to load carriage time-trial performance when performed alone or in addition to a whole-body active warm-up. Accordingly, the benefit of acute inspiratory muscle loading and active warm up prior to a short duration high intensity effort in occupational tasks reflective of this research is questionable. Future studies should target inspiratory, locomotor and antagonist muscle groups that support load carriage activities to optimise their priming to deliver an ergogenic effect to load carriage performance.

INTEGRITY OF RESEARCH AND REPORTING

Acknowledgments:

None.

Ethical Standards:

All experimental procedures and methods of assessment used in this study were ethically approved by the host university's ethics committee and conform to the laws of the United Kingdom.

Conflicts of interest:

No conflicts of interest for each of the authors.

REFERENCES

Amann, M., Hopkins, W.G., and Marcora, S.M. 2008. Similar sensitivity of time to exhaustion and time-trial time to changes in endurance. Med. Sci. Sports Exerc. **40**(3): 574–578. doi:10.1249/MSS.0b013e31815e728f.

American Thoracic Society, and European Respiratory Society. 2002. ATS/ERS Statement on Respiratory Muscle Testing. Am. J. Respir. Crit. Care Med. **166**(4): 518–624. doi:10.1164/rccm.166.4.518.

Bailey, S.J., Vanhatalo, A., Wilkerson, D.P., DiMenna, F.J., and Jones, A.M. 2009. Optimizing the “priming” effect: influence of prior exercise intensity and recovery duration on O2 uptake kinetics and severe-intensity exercise tolerance. J. Appl. Physiol. **107**(6): 1743–1756.

Beneke, R., Leithäuser, R.M., and Ochentel, O. 2011. Blood Lactate Diagnostics in Exercise Testing and Training. Int. J. Sports Physiol. Perform. **6**(1): 8–24. doi:10.1123/ijspp.6.1.8.

Bishop, D. 2003a. Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. Sports Med. Auckl. NZ **33**(6): 439–454.

Bishop, D. 2003b. Warm up II: performance changes following active warm up and how to structure the warm up. Sports Med. **33**(7): 483–498. [accessed 25 February 2015].

Boussana, A., Galy, O., Hue, O., Matecki, S., Varray, A., Ramonatxo, M.,et al. 2003. The effects of prior cycling and a successive run on respiratory muscle performance in triathletes. Int. J. Sports Med. **24**(1): 63–70. doi:10.1055/s-2003-37201.

Brown, P.E., Fallowfield, J.L., Blacker, S.D., Izard, R.M., Wilkinson, D.M., and Bilzon, J.L. 2007. Does Loaded Marching Economy Explain Some of the Variance in Loaded Marching Performance? Med. Sci. Sports Exerc. **39**(Supplement): 154.

Brown, P.E.H., Fallowfield, J.L., Blacker, S.D., Wilkinson, D.M., Izard, R.M., and Bilzon, J.L.J. 2010. Physical and Physiological Responses to a Modified British Army Infantry Physical Training Programme: 1118. Med. Sci. Sports Exerc. **42**: 166. doi:10.1249/01.MSS.0000384933.80108.dd.

Brown, P.I., Venables, H.K., Liu, H., de-Witt, J.T., Brown, M.R., and Faghy, M.A. 2013. Ventilatory muscle strength, diaphragm thickness and pulmonary function in world-class powerlifters. Eur. J. Appl. Physiol. **113**(11): 2849–2855. doi:10.1007/s00421-013-2726-4.

Burnley, M., Doust, J.H., and Jones, A.M. 2005. Effects of prior warm-up regime on severe-intensity cycling performance. Med. Sci. Sports Exerc. **37**(5): 838–845. [accessed 6 January 2016].

Carter, H., Grice, Y., Dekerle, J., Brickley, G., Hammond, A.J.P., and Pringle, J.S.M. 2005. Effect of prior exercise above and below critical power on exercise to exhaustion. Med. Sci. Sports Exerc. **37**(5): 775–781.

Dempsey, J.A., Romer, L., Rodman, J., Miller, J., and Smith, C. 2006. Consequences of exercise-induced respiratory muscle work. Respir. Physiol. Neurobiol. **151**(2): 242–250.

Dominelli, P.B., Sheel, A.W., and Foster, G.E. 2012. Effect of carrying a weighted backpack on lung mechanics during treadmill walking in healthy men. Eur. J. Appl. Physiol. **112**(6): 2001–2012. [accessed 16 May 2013].

Edholm, P., Krustrup, P., and Randers, M.B. 2015. Half-time re-warm up increases performance capacity in male elite soccer players. Scand. J. Med. Sci. Sports **25**(1): e40–e49. doi:10.1111/sms.12236.

Eston, R.G., and Reilly, T. 2009. Kinanthropometry and Exercise Physiology Laboratory Manual: Anthropometry. Taylor & Francis. Available from https://books.google.co.uk/books?hl=en&lr=&id=w3n38eUwRqIC&oi=fnd&pg=PP1&dq

=kinanthropometry+and+exercise+physiology&ots=kfjziO_2hR&sig=cF9SkgzmCfuKuPjHjGeBiVQgK54 [accessed 18 March 2015].

Faghy, M.A., and Brown, P.I. 2014a. Thoracic load carriage-induced respiratory muscle fatigue. Eur. J. Appl. Physiol. **114**(5): 1085–1093. doi:10.1007/s00421-014-2839-4.

Faghy, M.A., and Brown, P.I. 2014b. Preloaded time trial to assess load carriage performance. J. Strength Cond. Res. Natl. Strength Cond. Assoc. **28**(12): 3354–3362.

Faghy, M.A., and Brown, P.I. 2015. Training the inspiratory muscles improves running performance when carrying a 25 kg thoracic load in a backpack. Eur. J. Sport Sci.16(5): 585-594. 1–10. doi:10.1080/17461391.2015.1071878.

Faghy, M.A., and Brown, P.I. 2016. Functional Inspiratory Muscle Training (IMT_F) Improves Load Carriage Performance Greater than Traditional IMT Techniques. Boston, USA.

Hajoglou A, Foster C, De Koning JJ, Lucia A, Kernozek TW, Porcari J,P. 2005. Effect of warm-up on cycle time trial performance. Med Sci Sports Exerc 37:1608–1614

Hawkes, E.Z., Nowicky, A.V., and McConnell, A.K. 2007. Diaphragm and intercostal surface EMG and muscle performance after acute inspiratory muscle loading. Respir. Physiol. Neurobiol. **155**(3): 213–219. [accessed 8 June 2013].

Hopkins, W.G. 2000. Measures of reliability in sports medicine and science. Sports Med. **30**(1): 1–15. [accessed 21 August 2014].

Ingham, S.A., Fudge, B.W., Pringle, J.S., and Jones, A.M. 2013. Improvement of 800-m running performance with prior high-intensity exercise. Int J Sports Physiol Perform **8**(1): 77–83. [accessed 11 March 2015].

Johnson, M., Gregson, I.R., Mills, D.E., Gonzalez, J.T., and Sharpe, G.R. 2014. Inspiratory muscle warm-up does not improve cycling time-trial performance. Eur. J. Appl. Physiol. **114**(9): 1821–1830. doi:10.1007/s00421-014-2914-x.

Johnson, M., Sharpe, G. R., & Brown, P. I. 2007. Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. *European Journal of Applied Physiology*, *101*(6), 761–770.

Jones, A.M., Koppo, K., and Burnley, M. 2003. Effects of prior exercise on metabolic and gas exchange responses to exercise. Sports Med. Auckl. NZ **33**(13): 949–971.

Knapik, J. 1997. The influence of physical fitness training on the manual material handling capability of women. Appl Ergon. **28**(5-6):339-45.

Knapik, J., Harman, E.A., Steelman, R.A., and Graham, B.S. 2012. A systematic review of the effects of physical training on load carriage performance. J. Strength Cond. Res. **26**(2): 585–597.

Lin, H., Tong, T.K., Huang, C., Nie, J., Lu, K., and Quach, B. 2007. Specific inspiratory muscle warm-up enhances badminton footwork performance. Appl. Physiol. Nutr. Metab. **32**(6): 1082–1088. [accessed 11 December 2013].

Lomax, M., Grant, I., and Corbett, J. 2011. Inspiratory muscle warm-up and inspiratory muscle training: separate and combined effects on intermittent running to exhaustion. J. Sports Sci. **29**(6): 563–569. [accessed 11 December 2013].

Marcora, S. 2009. Perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart, and lungs. J. Appl. Physiol. **106**(6): 2060–2062. [accessed 9 January 2014].

McConnell, A.K. 2007. Lung and respiratory muscle function. *In* Sport and Exercise Physiology Testing Guidelines, the British Association of Sport and Exercise Sciences Guide. *Edited by* E.M. Winter, A.M. Jones, and R.C.R. Davison. Routledge, Oxford. pp. 63–76.

Mohr, M., Krustrup, P., Nybo, L., Nielsen, J.J., and Bangsbo, J. 2004. Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time. Scand. J. Med. Sci. Sports **14**(3): 156–162. doi:10.1111/j.1600-0838.2004.00349.x.

Rayson, M., Holliman, D., and Belyavin, A. 2000. Development of physical selection procedures for the British Army. Phase 2: relationship between physical performance tests and criterion tasks. Ergonomics **43**(1): 73–105.

Ross, E.Z., Nowicky, A.V., and McConnell, A.K. 2007. Influence of acute inspiratory loading upon diaphragm motor-evoked potentials in healthy humans. J. Appl. Physiol. Bethesda Md 1985 **102**(5): 1883–1890. doi:10.1152/japplphysiol.00694.2006.

Sonetti, D, A., Wetter, T, J., Pegelow,D, F., Dempsey, J, A., 2001. Effects of respiratory muscle training versus placebo on endurance exercise performance. Respiration Physiology 127(2):185-199.

The British Army, land-mediacomms-webcontent@land mod uk. 2014, March 6. The British Army - Homepage. Available from http://www.army.mod.uk/ [accessed 7 March 2014].

Tong, T.K., and Fu, F.H. 2006. Effect of specific inspiratory muscle warm-up on intense intermittent run to exhaustion. Eur. J. Appl. Physiol. **97**(6): 673–680. [accessed 11 December 2013].

Volianitis, S., McConnell, A.K., Koutedakis, Y., and Jones, D.A. 2001. Specific respiratory warm-up improves rowing performance and exertional dyspnea. Med. Sci. Sports Exerc. **33**(7): 1189–1193. [accessed 11 December 2013].

TABLES

Table 1 Descriptive characteristics of the participants (Mean ± SD; *n*=9).

Age (years)	26.4 ± 9.1
Body Mass (kg)	74.3 ± 10.8
Height (m)	1.7 ± 0.4
Body Fat (%)	21.3 ± 7.7
BIA Lean body mass (kg)	55.7 ± 4.9
BIA Fat mass (kg)	15.7 ± 7.2
V_{LT} (km·h^{-1})	8.1 ± 1.1
V_{LTP} (km·h^{-1})	10.3 ± 1.6
FEV_1 (L)	3.97 ± 0.31
FVC (L)	4.69 ± 0.43
FEV_1/ FVC (%)	82 ± 6
PEF (L·min^{-1})	534 ± 69

BIA bioelectrical impedance, V_{LT} Velocity at lactate threshold, V_{LTP} Velocity at lactate turn point, FEV_1 forced expired volume in one second, FVC forced vital capacity, FEV_1/ FVC forced expiratory volume in one second / forced vital capacity, PEF peak expiratory flow.

Table 2 Respiratory muscle pressure, physiological and perceptual responses at baseline and following each warm up condition.

		Post Warm up				
	Pooled Baseline	**IMW**	**PLA**	**AWU**	**AWU+IMW**	**AWU+PLA**
P_{Imax} (cmH$_2$O)	120 ± 23	136 ± 24^{*BCE}	118 ± 25	119 ± 18	133 ± 25^{*BCE}	121 ± 25
P_{Emax} (cmH$_2$O)	103 ± 26	102 ± 33	106 ± 32	105 ± 18	103 ± 26	108 ± 23
HR (beats·min^{-1})	82 ± 13	86 ± 15	84 ± 18	109 ± 23^{*CE}	107 ± 19^{*BCE}	105 ± 14^{*AC}
[Lac^{-}]$_{\text{B}}$ (mmol·l^{-1})	1.1 ± 0.4	1.3 ± 0.3	1.0 ± 0.3	2.2 ± 0.7^{*AC}	2.1 ± 0.8^{*AC}	2.0 ± 0.8^{*AC}
$\dot{V}_E$ (L·min^{-1})	23.3 ± 11.1	20.3 ± 6.9	19.6 ± 6.3	70.2 ± 17.8^{*AC}	76.5 ± 9.3^{*AC}	77.5 ± 9.3^{*AC}
f_{R} (breaths·min^{-1})	24 ± 9	24 ± 6	19 ± 6	43 ± 13^{*AC}	48 ± 10^{*AC}	47 ± 11^{*AC}
$\dot{V}O_2$ (L·min^{-1})	0.72 ± 0.31	0.68 ± 0.28	0.62 ± 0.24	2.30 ± 0.42^{*AC}	2.53 ± 0.31^{*AC}	2.51 ± 0.41^{*AC}
$\dot{V}CO_2$ (L·min^{-1})	0.68 ± 0.33	0.59 ± 0.23	0.59 ± 0.23	2.40 ± 0.51^{*AC}	2.57 ± 0.27^{*AC}	2.70 ± 0.3^{*AC}
RER	0.88 ± 0.07	0.86 ± 0.08	0.90 ± 0.09	1.01 ± 0.06^{*A}	1.00 ± 0.04^{*AC}	1.02 ± 0.04^{*AC}
RPE (AU)	6 ± 1	6 ± 1	6 ± 0	8 ± 1	7 ± 2	7 ± 1
RPE$_{\text{legs}}$ (AU)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1 ± 1
RPE$_{\text{breathing}}$(AU)	0 ± 0	0 ± 0	0 ± 0	1 ± 0	1 ± 1	0 ± 0

Values presented as mean ± SD. Maximal inspiratory pressure ($P_{I\text{max}}$), Maximal expiratory pressure (P_{Emax}), Heart rate (HR), Blood lactate concentration ([Lac^{-}]$_{\text{B}}$), minute ventilation ($\dot{\text{V}}_{\text{E}}$), breathing frequency ($f_{\text{R}}$), oxygen consumption ($\dot{\text{V}}\text{O}_2$), carbon dioxide production ($\dot{\text{V}}\text{CO}_2$), Respiratory exchange ratio (RER), Rating of Perceived Exertion (RPE), RPE for legs (RPE$_{\text{legs}}$), RPE for breathing (RPE$_{\text{breathing}}$), Arbitrary units (AU). *Different from baseline, ^{A} Different from IMW, ^{B} Different from ACT, ^{C} Different from PLA, ^{D} Different from AWU+IMW, ^{E} Different from ACT+PLA.

Table 3 Post-time trial respiratory muscle pressure, physiological and perceptual responses.

	IMW	**PLA**	**AWU**	**AWU+IMW**	**AWU+PLA**
P_{Imax} (cmH$_2$O)	106 ± 20 ^{AB}	105 ± 20 ^{AB}	100 ± 18 ^{AB}	106 ± 16	104 ± 16 ^{AB}
P_{Emax} (cmH$_2$O)	95 ± 29	99 ± 32	99 ± 18	100 ± 20	98 ± 15
HR (beats·min^{-1})	191 ± 16 ^{AB}	191 ± 15 ^{AB}	194 ± 14 ^{AB}	194 ± 17 ^{AB}	195 ± 13 ^{AB}
[Lac^{-}]$_{\mathrm{B}}$ (mmol·l^{-1})	7.3 ± 2.3 ^{AB}	6.8 ± 2.8 ^{AB}	7.5 ± 1.7 ^{AB}	7.1 ± 1.3 ^{AB}	7.0 ± 1.7 ^{AB}
$\dot{V}_E$ (L·min^{-1})	121.0 ± 20.6 ^{AB}	118.1 ± 13.7 ^{AB}	116.9 ± 18.9 ^{AB}	112.5 ± 17.0 ^{AB}	115.6 ± 18.2 ^{AB}
f_{R} (breaths·min^{-1})	62 ± 14 ^{AB}	59 ± 9 ^{A}	60 ± 13 ^{AB}	62 ± 14 ^{A}	62 ± 14 ^{A}
$\dot{V}O_2$ (L·min^{-1})	3.27 ± 0.55 ^{AB}	3.27 ± 0.42 ^{AB}	3.09 ± 0.37 ^{AB}	3.08 ± 0.49 ^{AB}	3.22 ± 0.46 ^{AB}
$\dot{V}CO_2$ (L·min^{-1})	3.67 ± 0.60 ^{AB}	3.64 ± 0.43 ^{AB}	3.40 ± 0.52 ^{AB}	3.37 ± 0.47 ^{AB}	3.47 ± 0.55 ^{AB}
RER	1.13 ± 0.06 ^{AB}	1.14 ± 0.07 ^{AB}	1.12 ± 0.06 ^{AB}	1.12 ± 0.05 ^{AB}	1.10 ± 0.04 ^{AB}
RPE (AU)	17 ± 2 ^{AB}	16 ± 2 ^{AB}	16 ± 1 ^{AB}	16 ± 2 ^{AB}	17 ± 2 ^{AB}
RPE$_{\mathrm{legs}}$ (AU)	7 ± 2 ^{AB}	7 ± 2 ^{AB}	6 ± 2 ^{AB}	7 ± 2 ^{AB}	6 ± 2 ^{AB}
RPE$_{\mathrm{breathing}}$(AU)	7 ± 2 ^{AB}	7 ± 2 ^{AB}	7 ± 2 ^{AB}	7 ± 2 ^{AB}	6 ± 2 ^{AB}

Values presented as mean ± SD. For abbreviations see Table 2. ^{A} different from baseline, ^{B} different from post warm up,

FIGURE CAPTIONS

Figure 1 Schematic of each warm-up procedure and the components of each warm up; V_{LTP} velocity at lactate turnpoint, AWU active warm up, IMW Inspiratory muscle warm-up and PLA placebo inspiratory muscle warm-up.

Figure 2 Relative change in inspiratory muscle pressure (P_{Imax}) from baseline following 2.4 km time-trial during each experimental trial. Solid horizontal line represents group mean response. Individual responses across conditions is represented by a different symbol per participant (between conditions, the same symbol is used to reflect the same participant). For trial abbreviations, see methodology.