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Inspiratory muscle warm-up and inspiratory muscle training: Separate and combined effects on intermittent running to exhaustion

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Abstract

In the present study, we examined the independent and combined effects of an inspiratory muscle warm-up and inspiratory muscle training on intermittent running to exhaustion. Twelve males were recruited to undertake four experimental trials. Two trials (Trials 1 and 2) preceded either a 4-week training period of 1×30 breaths twice daily at 50% (experimental group) or 15% (control group) maximal inspiratory mouth pressure (PImax). A further two trials (Trials 3 and 4) were performed after the 4 weeks. Trials 2 and 4 were preceded by a warm-up: 2×30 breaths at 40% PImax. Pre-training PImax and distance covered increased ($P < 0.05$) similarly between groups after the warm-up ($\sim$11% and $\sim$5–7% PImax and distance covered, respectively). After training, PImax increased by 20 ± 6.1% ($P < 0.01$; d = 3.6) and 26.7 ± 6.3% ($P < 0.01$; d = 3.1) when training and warm-up were combined in the experimental group. Distance covered increased after training in the experimental group by 12 ± 4.9% ($P < 0.01$; d = 3.6) and 14.9 ± 4.5% ($P < 0.01$; d = 2.3) when training and warm-up interventions were combined. In conclusion, inspiratory muscle training and inspiratory muscle warm-up can both increase running distance independently, but the greatest increase is observed when they are combined.

Keywords: *Inspiratory muscle warm-up, inspiratory muscle training, intermittent running*

Introduction

Pulmonary musculature requires up to 15% of maximal oxygen uptake (Aaron, Seow, Johnson, & Dempsey, 1992) and approximately 16% of cardiac output (Harms et al., 1998) during maximal exercise. Studies have also shown that both short-duration, high-intensity (Lomax & McConnell, 2003; Volianitis, McConnell, Koutedakis, & Jones, 1999; Volianitis et al., 2001b) and prolonged exercise (Chevrolet, Tschopp, Blanc, Rochat, & Jundoi, 1993; Romer, McConnell, & Jones, 2002a; Ross, Middleton, Shave, George, & McConnell, 2008) induce inspiratory muscle fatigue in trained athletes and that the time course of skeletal muscle fatigue can be increased by as much as 40% in the presence of inspiratory muscle fatigue (McConnell & Lomax, 2006). Given such observations, it is not surprising that procedures to counter pulmonary muscle limitations and enhance exercise performance have been sought.

Two such procedures are an inspiratory muscle warm-up and inspiratory muscle training. A frequently adopted mode of inspiratory muscle training is pressure-threshold training (for a review, see McConnell & Romer, 2004). After such training the magnitude of inspiratory muscle fatigue experienced during exercise is lower when exercise duration is similar (Downey et al., 2007), the same absolute exercise intensity (Volianitis et al., 2001b) or inspiratory muscle challenge (McConnell & Lomax, 2006) is used, or when distance is fixed such as during a time trial (Romer, McConnell, & Jones, 2002c). Other beneficial adaptations also occur such as an increase in exercise time during both constant-intensity exercise (Edwards & Cooke, 2004; McConnell & Lomax, 2006) and shuttle running to exhaustion (Tong et al., 2008). In addition, when exercise intensity (McConnell & Sharpe, 2005; Romer, McConnell, & Jones, 2002b) and volitional hyperpnoea demands (Brown, Sharpe, & Johnson, 2008) are fixed, blood lactate is reduced after inspiratory muscle training. There is also evidence that the inspiratory muscle metaboreflex is reduced when absolute exercise intensity is fixed (McConnell & Lomax, 2006) or breathing-task intensity and duration are identical (Witt, Guenette, Rupert, McKenzie, & Sheel, 2007) before and after

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inspiratory muscle training. Furthermore, the unpleasant sensation of breathing (dyspnoea) and/or whole-body perceptual responses is ameliorated at similar time points or for sub-maximal (Downey et al., 2007; Romer et al., 2002a, 2002b; Volianitis et al., 2001b) and possibly maximal (Downey et al., 2007) exercise intensities after such training.

Similar observations have been made after an inspiratory muscle warm-up, albeit with smaller effects. For example, baseline inspiratory muscle strength, as measured by maximal inspiratory mouth pressure (PImax), increases (Lomax & McConnell, 2009; Ross, Nowicky, & McConnell, 2007; Volianitis, McConnell, Koutedakis, & Jones, 2001a), blood lactate is lower at equivalent time points (Lin et al., 2007), negative perceptual changes are reduced (Lin et al., 2007; Tong & Fu, 2006; Volianitis et al., 2001a), and exercise performance is improved (Cruickshank, Peyrebrune, & Caine, 2007; Lin et al., 2007; Tong & Fu, 2006). It is therefore evident that for performance, both inspiratory muscle training and inspiratory warm-up are beneficial, even if the mechanisms responsible for such adaptations differ.

To date, studies investigating the impact of inspiratory muscle training and inspiratory muscle warm-up on exercise performance have focused on one or the other. No studies have directly compared the performance effects of inspiratory muscle training with those of an inspiratory muscle warm-up. It is reasonable to propose that a combination of the two would have an additive effect and enhance performance to a greater extent than that of either one alone. However, data to support this are lacking. Specifically, we hypothesized that an inspiratory muscle warm-up combined with inspiratory muscle training would improve performance (as measured by distance covered in an intermittent running test to exhaustion) the most, followed by inspiratory muscle training alone and lastly an inspiratory muscle warm-up alone. We anticipated that the least distance covered would occur in the absence of both interventions.

Methods

Participants

After receiving a full explanation of the test requirements and risks, 12 healthy county-standard and semi-professional male football players provided written informed consent and participated. All participants were free of cardiopulmonary disease and completed a medical screening questionnaire before testing began. The age, body mass, and stature (mean $\pm$ *s*) of the participants were as follows: 24.6 ± 1.3 years, 75.2 ± 5.9 kg, and 179.0 ± 6.2 cm, respectively. The study was approved by the Biosciences Research Committee at the University of Portsmouth.

Procedures

Preliminary testing, habituation, and measurements. Each participant undertook at least one pulmonary habituation session and a Yo-Yo intermittent recovery test (Yo-Yo test). Reliability of PImax measurements was deemed present when three technically proficient manoeuvres were within 5% or 5 cmH_2O of one another (Lomax & McConnell, 2009; Volianitis et al., 1999). Each manoeuvre was measured from residual volume using a hand-held mouth pressure meter (RPM, Micro Medical, Rochester, UK) attached to a flanged rubber mouthpiece, with the nose occluded. In addition, maximal expiratory mouth pressure (PEmax) (RPM, Micro Medical, Rochester, UK), forced vital capacity (FVC), forced expired volume in one second (FEV_1), and peak expiratory flow rate (PEFR) were assessed (MicroLab, Micro Medical, Rochester, UK) from total lung capacity and with the nose occluded for demographic purposes only (Table I). A 60-s rest separated repeated PImax, PEmax, FVC, FEV_1, and PEFR measurements. As with PImax, the highest of three satisfactory PEmax, FVC, FEV_1, and PEFR measurements within 5% were reported (see McConnell, 2007). Both the pressure meter and spirometer were calibrated in accordance with the manufacture's instructions before testing and the instruments were verified immediately after testing.

The initial Yo-Yo test served as preparation for the four subsequent experimental Yo-Yo tests (trials). The Yo-Yo intermittent recovery test (level 1) has been described elsewhere (Krustrup et al., 2003). Briefly, the test involves completing a series of 20-m shuttle runs at progressively increasing speed until volitional exhaustion. Consequently, the total distance covered during the initial Yo-Yo test was used solely as the reliability trial for comparison with

Table I. Baseline pulmonary function data for the control and experimental groups (mean $\pm$ *s*).

Parameter	Control group	Experimental group
FEV_1 (L)	4.83 ± 0.26	4.69 ± 0.25
FVC (L)	5.65 ± 0.05	5.69 ± 0.09
FEV_1/FVC (%)	83 ± 5	84 ± 2
PImax (cmH_2O)	123 ± 8	$134 \pm 6^{\star}$
PEmax (cmH_2O)	167 ± 5	172 ± 6
PEFR ($L \cdot min^{-1}$)	628 ± 18	649 ± 24

Note: FEV_1 = forced expired volume in one second, FVC = forced vital capacity, PImax = maximal inspiratory mouth pressure, PEmax = maximal expiratory mouth pressure, PEFR = peak expiratory flow rate.
⋆Significantly different to control group ($P < 0.05$).

Trial 1 (the control trial). A coefficient of variation (CV) $\leq$5% was deemed acceptable. During this habituation session, participants were accustomed to the ratings of perceived exertion (RPE) and dyspnoea scales (Borg 0–10 and CR-10 scales, respectively).

Experimental trials. Participants undertook four trials on separate occasions. Trials 1 and 2 were completed before a 4-week period of either sham ($n = 6$: control group) or real ($n = 6$: experimental group) inspiratory muscle training and Trials 3 and 4, in a counterbalanced order, were completed after the intervention. Only in Trials 2 and 4 was an inspiratory muscle warm-up administered before the Yo-Yo tests (Tong & Fu, 2006). A minimum of 24 h separated Trials 1 and 2, and Trials 3 and 4. The first trial after inspiratory muscle training (i.e. 3 or 4) occurred within 5 days of completing the training intervention.

Inspiratory muscle warm-up and inspiratory muscle training. The inspiratory muscle warm-up consisted of two sets of 30 breaths at 40% PImax (Powerlung, Sports, USA) with a 60-s rest between sets. A single PImax was recorded during the recovery period and the resistance on the trainer adjusted if required (Lomax & McConnell, 2009). Inspiratory muscle training consisted of either one set of 30 breaths at 30-repetition maximum ($\sim$50–60% PImax) twice daily, 7 days a week (experimental group) or one set of 30 breaths at $\sim$15% PImax twice daily, 7 days a week (control group) (based on Lomax & McConnell, 2009; Tong et al., 2008). Each week participants in the experimental group increased the resistance on the respiratory muscle trainer (Powerlung, Sport, USA) by increasing the tension on the trainer to a point where the last five breaths of the 30 felt progressively harder.

The inspiratory muscle warm-up and inspiratory muscle training were undertaken while seated with each breath initiated from residual volume with the nose occluded. The training device provided a threshold resistance during inspiration only, as the device was removed during expiration to ensure that no expiratory resistance was encountered (Witt et al., 2007). We chose not to incorporate a placebo inspiratory muscle warm-up, as it has been shown previously that two sets of 30 forced breaths through an inspiratory muscle trainer without the imposition of an inspiratory challenge increases PImax (Ross et al., 2007).

Protocol

Participants performed a standardized warm-up that comprised 5 min of self-paced jogging in the sports hall to be used for the trials. This was followed by 10 min of stretching; these procedures were identical for all trials. After the whole-body warm-up participants undertook either the Yo-Yo test (Trials 1 and 3) or an inspiratory muscle warm-up followed by the Yo-Yo test (Trials 2 and 4). Where an inspiratory muscle warm-up was administered, the Yo-Yo test began within 3 min of completing the warm-up. Between each fourth exercise bout in the Yo-Yo test, 10 s of active recovery (2×5 m of jogging) was permitted and RPE and dyspnoea were measured. Each participant's total number of completed repetitions was recorded and converted to distance covered in metres.

Statistical analysis

Since the baseline PImax data varied among participants (Table I), PImax data were normalized by expressing them as a percentage change from Trial 1 baseline PImax. As there was similar variability in running distance (m) between participants, the same approach was taken for distance-covered data. As the total distance covered during the Yo-Yo tests differed between trials, comparisons of RPE and dyspnoea among trials and groups were made at the mid-point and end-point of each test.

As parametric data assumptions were met (Shapiro-Wilks test, $P > 0.05$), mixed-design (trial $\times$ time) factorial analysis of variance (ANOVA) was used to compare PImax, RPE, and dyspnoea between groups. One-way repeated-measures ANOVA was used to compare distances covered. Where appropriate, *post-hoc* analyses for PImax, RPE, and dyspnoea via one-way repeated-measure ANOVAs per condition per trial were used to assess within-trial differences. Mann-Whitney *U*-tests were used to compare groups per time point per trial. Where significant differences were identified, effect sizes were calculated using Cohen's *d* (the pooled standard deviation was used). Accordingly, an effect size of 0.2 was deemed small, 0.5 medium, and 0.8 or above large (Cohen, 1988). The coefficient of determination was also calculated where appropriate. Pearson's correlation coefficient was used to assess the relationship (expressed as percentage change from Trial 1) between PImax and distance covered, dyspnoea and distance covered, and RPE and distance covered.

An alpha of 0.05 was set *a priori* for statistical significance. All statistical analyses were conducted using SPSS for Windows version 16.0 (SPSS Inc., Chicago Ill, USA), and data are expressed as means $\pm$ standard deviations (*s*).

Results

Inspiratory muscle strength

The percentage change in PImax differed among trials and between groups ($P < 0.01$). Compared with Trial 1 (see Table I for baseline absolute data), the inspiratory muscle warm-up increased PImax by a similar extent in the control (10.5 ± 3.3%, $P = 0.008$) and experimental (10.8 ± 3.2%, $P = 0.006$) groups before inspiratory muscle training (Trial 2, $P = 1.000$): pooled absolute PImax data revealed a d of 1.3. When the inspiratory muscle warm-up and training were combined (Trial 4), the percentage improvement (from Trial 1) in the experimental group (26.7 ± 6.3%, $P = 0.002$) was greater ($P < 0.001$) than that observed in the control group (9.7 ± 4.5%, $P = 0.048$) with a d of 3.1. Trial 4 produced the greatest increase in PImax of all trials ($P < 0.01$) (Figure 1). When the effect of inspiratory muscle training alone is considered (Trial 3), PImax increased in the experimental group (20 ± 6.1%, $P = 0.013$) but did not differ from Trial 1 in the control group (2.3 ± 3.0%, $P = 0.467$) and produced a d of 3.6. Thus, PImax increased only after the inspiratory muscle warm-up in the control group (Trials 2 and 4), but increased in response to the inspiratory muscle warm-up and training (Trials 2, 3, and 4) in the experimental group (Figure 1).

Intermittent running to exhaustion

In both the control and experimental groups, running distance was the lowest in the absence of an inspiratory muscle warm-up and inspiratory muscle training (Trial 1, $P < 0.05$). Furthermore, running distance increased by a similar magnitude in the control (7.2 ± 5.4%, $P = 0.040$) and experimental (5.3 ± 2.9%, $P = 0.042$) groups after an inspiratory muscle warm-up before inspiratory muscle training (Trial 2, $P = 0.522$). Pooled absolute distance covered data revealed a d of 0.48. When the impact of group alone was considered, there was no difference between Trials 2 and 3 in the control group ($P = 1.000$), meaning that distance increased (~6%) after sham inspiratory muscle training. Similarly, when the two inspiratory muscle warm-up trials were compared for before and after sham training (Trials 2 and 4), distance increased by an additional 6%, although this failed to reach statistical significance ($P = 0.247$, $d = 0.95$) (Figure 2).

In the experimental group, absolute running distance increased by an additional 18% from Trials 1 to 3, and a further 24% from Trials 2 to 4. However, when expressed as the percentage improvement above that for the control group, the experimental group ran 12.0 ± 4.9% further than the control group in the absence of an inspiratory muscle warm-up (Trial 3, $P = 0.002$; $d = 3.6$) and 14.9 ± 4.5% further than the control group when the inspiratory muscle warm-up and training were combined (Trial 4, $P = 0.005$; $d = 2.3$). When all four trials were compared in the experimental group, running distance was greatest when the inspiratory muscle warm-up and training were combined (Trial 4, $P < 0.05$), followed by inspiratory muscle training alone (Trial 3, $P < 0.05$) and lastly inspiratory muscle warm-up alone (Trial 2, $P < 0.05$) (Figure 2). In addition, there was a positive correlation between distance covered and PImax (data pooled from Trials 2, 3, and 4), whether distance was expressed as the absolute percentage change from Trial 1 ($r = 0.780$, $P < 0.001$) (Figure 3) or as the percentage change above that of the control group ($r = 0.738$, $P < 0.001$).

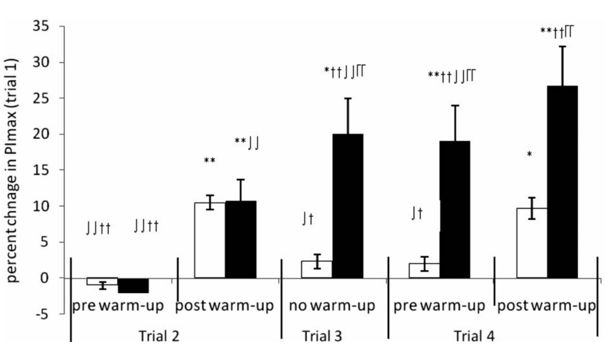

Figure 1. The percentage change in PImax as measured from Trial 1 in Trials 2, 3, and 4 (mean ± s). Open and closed bars represent control and experimental groups, respectively. *$P < 0.05$, **$P < 0.01$ different to Trial 1; †$P < 0.05$, ††$P < 0.01$ different to Trial 2 after inspiratory muscle warm-up; ⌋$P < 0.05$, ⌋⌋$P < 0.01$ different to Trial 4 after inspiratory muscle warm-up; ⌈⌈$P < 0.01$ different to the control group.

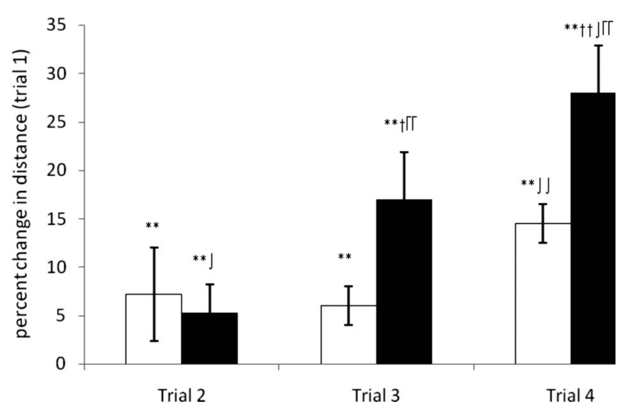

Figure 2. The percentage change in running distance as measured from Trial 1 in Trials 2, 3, and 4 (mean ± s). Open and closed bars represent control and experimental groups, respectively. **$P < 0.05$ different to Trial 1; †$P < 0.05$, ††$P < 0.01$ different to Trial 2; ⌋$P < 0.05$, ⌋⌋$P < 0.01$ different to Trial 3; ⌈⌈$P < 0.01$ different to the control group.

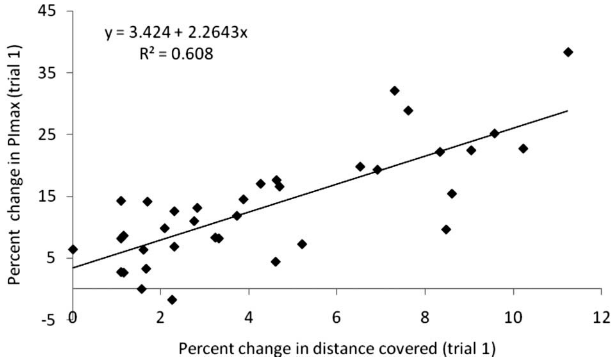

Figure 3. The relationship between the percentage change in PImax and the percentage change in running distance as measured from Trial 1. Data are pooled from Trials 2, 3, and 4 and represent control and experimental groups percentage change.

Perceptual responses

There were no differences among trials or groups for RPE ($P > 0.05$), but RPE did increase progressively ($P < 0.001$) from baseline (range: 0–2) to mid-test (range: 5.7–6.7) through to end-test (range: 9.0–10). There were no differences among trials for dyspnoea ($P > 0.05$), which increased progressively ($P < 0.001$) from baseline (range: 0–2) to mid-test (range: 4.7–6.5) through to end-test (range: 9.3–10). However, after inspiratory muscle training only (Trial 3), dyspnoea was lower in the experimental group (4.8 $\pm$ 0.8) than the control group (6.0 $\pm$ 0.6, $P = 0.010$; $d = 1.7$). There was no relationship between RPE and absolute distance covered (% change from Trial 1) (mid-point: $r = -0.154$, $P = 0.369$; end RPE did not differ at all) or between dyspnoea and absolute distance covered (% change from Trial 1) (mid-point: $r = 0.126$, $P = 0.463$; end: $r = -0.131$, $P = 0.446$). There were similar findings when distance covered was expressed as the percentage increase above that of the control group (RPE: mid-point, $r = 0.121$, $P = 0.483$; end RPE did not differ; dyspnoea: mid-point, $r = 0.105$, $P = 0.542$; end, $r = 0.252$, $P = 0.205$).

Discussion

Inspiratory muscle strength

It has been shown that motor unit recruitment and inspiratory muscle coordination are improved by an inspiratory-muscle warm-up (Hawkes, Nowickey, & McConnell, 2007; Ross et al., 2007). In contrast, structural adaptations to pulmonary musculature, such as myosin heavy chain adaptations (Gea et al., 2000), changes in the proportion of type I and type II muscle fibres (Ramirez-Sarmiento et al., 2002), and diaphragm muscle thickness (Downey et al., 2007) have been shown to occur in response to inspiratory muscle training. Given that structural adaptations (e.g. hypertrophy) require a minimum of 12 training sessions to establish (Staron et al., 1991), it is unlikely that such changes arise from a one-off session of loaded breathing (i.e. an inspiratory-muscle warm-up). Thus, the predominant mechanism(s) responsible for increasing PImax after such a warm-up ($\sim$11%) and inspiratory muscle training ($\sim$20%) (Figure 1) cannot be identical.

Notably, the increase in PImax when inspiratory muscle training and warm-up interventions were combined was less than if the individual effects had been summated. The two interventions must therefore use to some extent the same mechanism(s) to increase inspiratory muscle force output. Based on the data in Figure 1, we suggest that this leads to a "dampening" of PImax in response to an inspiratory muscle warm-up, which could be the result of shared neuromuscular alterations after an inspiratory muscle warm-up and inspiratory muscle training. For example, it is known that neural adaptations such as increased discharge rate and/or motor unit recruitment are responsible for the initial increase in strength after a strength-training programme (Kamen & Knight, 2004; Ploutz, Tesch, Biro, & Dudley, 1994; Sale, 1992). However, motor unit firing rate can decline in response to a reduction in co-activation of antagonists after just one week of maximal prolonged isometric strength training. This adaptation, which is thought to reflect improved muscle synergy or skill (Carolan & Cafarelli, 1992), has also been proposed as a means of increasing PImax after an inspiratory muscle warm-up (Hawkes et al., 2007).

If enhanced synergy was present after inspiratory muscle training in the current study, this could explain the lower than anticipated increase in PImax when the two interventions were combined (Trial 4). In this situation, neural alterations that arise from an inspiratory muscle warm-up would probably be reduced or overshadowed by the response to inspiratory muscle training. As no studies have compared neuromuscular adaptations/responses to combined inspiratory muscle training and warm-up, this remains speculation and requires further study.

Inspiratory muscle strength and running performance

Previous studies have shown that an inspiratory muscle warm-up (Tong & Fu, 2006) and inspiratory muscle training (Tong et al., 2008) can extend intermittent running to exhaustion in trained individuals by $\sim$19% and $\sim$16% respectively, and increase distance covered during a badminton footwork test by $\sim$7–8% (Lin et al., 2007). Our findings build on those of Tong and Fu (2006) and Tong et al. (2008) by directly comparing the separate and combined effects of an inspiratory muscle warm-up and inspiratory muscle training.

It is important to note, however, that running distance in the control group increased by a further 6 ± 2% from Trial 1 to Trial 3 ($P = 0.007$, $d = 0.85$) and by 6 ± 4% from Trial 2 to Trial 4 ($P = 0.247$, $d = 0.95$) (see Figure 2). As it was not possible to ascertain whether or not there was similar bias in the experimental group, we expressed this group's post-inspiratory muscle training distance data as the percentage increase above that in the control group. Importantly, running distance was still greater in the experimental group, being ~12% longer after inspiratory muscle training only (Trial 3, $P = 0.003$) and ~15% greater when inspiratory muscle training and warm-up were combined (Trial 4, $P = 0.002$). There was a large effect size (≥2.3) in both trials. This suggests that the interventions were primarily responsible for the increase in distance rather than a learning effect.

Furthermore, the coefficient of determination between the change in baseline PImax and change in absolute distance covered was 61% (Figure 3). A sizeable portion of the variability in distance covered could be attributed to the baseline strength of the inspiratory muscles. When the distance covered was adjusted to reflect the percentage improvement above that of the control group, a sizeable portion remained (54%). Thus, our data are consistent with those of McConnell and colleagues (McConnell, Caine, & Sharpe, 1997) and indicate that the baseline strength of the inspiratory muscles is an important factor in determining intermittent running to exhaustion.

Perceptual responses

The increase in whole-body perceived exertion and dyspnoea throughout each trial is not a new finding. Tong and colleagues (Tong, Fu, Quach, & Lu, 2004) reported that up to 60% of the variance in exercise to exhaustion during repeated intermittent cycle ergometry to exhaustion could be accounted for by dyspnoea. However, the exact impact of an inspiratory muscle warm-up and inspiratory muscle training on this relationship is hard to determine, since studies have reported coefficients of determination of between 22 and 85% for dyspnoea and exercise performance (Tong & Fu, 2006; Tong et al., 2008; Volianitis et al., 2001a).

Perceptual responses are generally reduced during similar sub-maximal exercise intensities after inspiratory muscle training, although not at the end of exercise (Romer et al., 2002a, 2002b; Volianitis et al., 2001b). In contrast, it has been shown that if distance covered or speed is increased after an inspiratory muscle warm-up, dyspnoea (Lin et al., 2007; Tong & Fu, 2006; Volianitis et al., 2001a) and RPE (Cruickshank et al., 2007; Tong & Fu, 2006) do not differ at the point of exhaustion. Our observations are similar to these. As distance covered increased in response to inspiratory muscle training and warm-up (Figure 2), similar RPE and dyspnoea values were observed at similar points among trials. This is in line with the notion that the rate of increase in whole-body perceptual effort can predict time to exhaustion (Crewe, Tucker, & Noakes, 2008). Notably, dyspnoea was lower in the experimental group at the mid-point of Trial 3, suggesting that only after this point did exercise intensity increase to a point that abolished the reduction in dyspnoea induced by inspiratory muscle training. As the same was not observed in Trial 4, an inspiratory muscle warm-up could have provided some protection against such change at this time point.

In conclusion, both an inspiratory muscle warm-up and inspiratory muscle training increased distance covered during an intermittent running test to exhaustion. Although the effect of inspiratory muscle training alone was greater than that of an independent inspiratory muscle warm-up, the combination of interventions elicited the greatest improvement in running distance, with the baseline strength of the inspiratory muscles accounting for 61% of the variance observed in distance covered. However, the combined interventions did not result in a summative increase in inspiratory muscle strength. Part of the increase in PImax after an inspiratory muscle warm-up and inspiratory muscle training can therefore be attributed to the same mechanism, which is probably neural in origin. How much of the shared increase in PImax is accounted for by this mechanism remains to be determined.

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