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The effect of exercise training with an additional inspiratory load on inspiratory muscle fatigue and time-trial performance

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ABSTRACT

The purpose was to determine the effect of moderate-intensity exercise training (ET) on inspiratory muscle fatigue (IMF) and if an additional inspiratory load during ET (ET+IL) would further improve inspiratory muscle strength, IMF, and time-trial performance. 15 subjects were randomly divided to ET ($n = 8$) and ET+IL groups ($n = 7$). All subjects completed six weeks of exercise training three days/week at ~70%$\dot{V}O_{2peak}$ for 30 min. The ET+IL group breathed through an inspiratory muscle trainer (15% P_{Imax}) during exercise. 5-mile, and 30-min time-trials were performed pre-training, weeks three and six. Inspiratory muscle strength increased ($p < 0.05$) for both groups to a similar ($p > 0.05$) extent. ET and ET+IL groups improved ($p < 0.05$) 5-mile time-trial performance (~10% and ~18%) and the ET+IL group was significantly faster than ET at week 6. ET and ET+IL groups experienced less ($p < 0.05$) IMF compared to pre-training following the 5-mile time-trial. In conclusion, these data suggest ET leads to less IMF, ET+IL improves inspiratory muscle strength and IMF, but not different than ET alone.

1. Introduction

Endurance training leads to no appreciable training adaptations in the pulmonary system except within the inspiratory musculature (Dempsey, 1986). Cross-sectional investigations suggest that endurance-trained individuals exhibit greater inspiratory muscle endurance compared to sedentary individuals (Eastwood et al., 2001; Martin and Chen, 1982; Martin and Stager, 1981); however, similar inspiratory muscle strength (Eastwood et al., 2001; Callegaro et al., 2011; Cordain et al., 1987; Coast et al., 1990). Data from longitudinal studies show that high-intensity endurance training leads to improvements in inspiratory muscle strength and endurance (Leith and Bradley, 1976; Robinson and Kjeldgaard, 1982; Dunham and Harms, 2012; Clanton et al., 1987; Mickleborough et al., 2008). Furthermore, endurance-trained subjects develop less exercise-induced inspiratory muscle fatigue (IMF) compared to inactive subjects (Coast et al., 1990). In contrast, moderate-intensity exercise training has generally been considered to be an insufficient stimulus to improve inspiratory muscle strength and endurance (McConnell, 2011). However, we have recently shown that four weeks of moderate-intensity exercise training led to moderate increases (~25%) in inspiratory muscle strength (Dunham and Harms, 2012).

Previous studies have specifically trained the inspiratory muscles (IMT) at a high inspiratory load (~50–65% of maximal inspiratory pressure (P_{Imax})) resulting in muscular adaptations. For example, 4–11 weeks of specific IMT leads to increased diaphragm thickness (Downey et al., 2007) and strength (Downey et al., 2007; Romer et al., 2002a; Romer and McConnell Jones, 2002b; Volianitis et al., 2001; Witt et al., 2007), less exercise-induced IMF (Downey et al., 2007; Romer and McConnell Jones, 2002b; Verges et al., 2007; Volianitis et al., 2001), attenuated inspiratory muscle metaboreflex (Witt et al., 2007), and improved exercise performance (Romer et al., 2002a; Romer and McConnell Jones, 2002b; Volianitis et al., 2001). Interestingly, the combination of high-intensity exercise training and specific IMT leads to similar changes in inspiratory muscle strength and endurance as high-intensity exercise training alone (Clanton et al., 1987; Mickleborough et al., 2008). Because high-intensity exercise training leads to greater increases in inspiratory muscle strength compared to moderate-intensity exercise training (Dunham and Harms, 2012), it is likely an additional inspiratory muscle stimulus with moderate-intensity exercise training would lead to greater increases in inspiratory muscle strength. Recently, six weeks of moderate-intensity cycling training with a breathing resistive mask improved gas exchange threshold and

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respiratory muscle endurance compared to cycling training alone (Kido et al., 2013). However, it is not known if exercise-induced IMF and exercise performance were improved following the combined exercise training with the additional inspiratory load. Studies previously investigating specific IMT have used an inspiratory load of 50–65%P_{Imax}; however, it is likely this inspiratory load would lead to hypoventilation, hypoxemia, and dyspnea during the exercise training.

Therefore, the purpose of this study was first to determine the effect of moderate-intensity exercise training (ET) on the development of exercise-induced IMF during time-trials. A second purpose was to determine the influence of an additional inspiratory load during moderate-intensity exercise training (ET+IL) on inspiratory muscle strength, IMF, and time-trial performance. We hypothesized that (1) ET will lead to less exercise-induced IMF and (2) ET+IL will lead to greater improvements in inspiratory muscle strength and time-trial performance and less exercise-induced IMF compared to ET.

2. Methods

Eighteen active, healthy subjects (12 men, 6 women) were recruited to participate in this study. Health and normal pulmonary function were determined by self-report from a medical health questionnaire and standard pulmonary function testing. All subjects were non-smokers, free from chronic and/or acute illness/injury, and were at various fitness levels. One subject in the ET group and two subjects in the ET+IL group did not complete the training program and were not included in the analysis. Informed consent was obtained prior to participation in the study which was approved by the Institutional Review Board of Human Subjects at Kansas State University, Manhattan, KS and conformed to the Declaration of Helsinki.

2.1. Study design

Subjects were randomly divided into an ET (n = 8) and ET+IL group (n = 7). The ET and ET+IL groups cycled 3 times a week for 30 min at ∼70% peak workload for six weeks. In addition, the ET+IL group breathed through an inspiratory threshold muscle trainer while cycling set at 15%P_{Imax}. At pre-training, week 3, and week 6, pulmonary function, peak aerobic capacity, and exercise performance (via 5-mile and 30-min time-trials) were measured. IMF, dyspnea, and rating of perceived exertion were measured pre-training and at weeks 3 and 6 for each time-trial.

2.2. Peak aerobic capacity ($\dot{V}O_{2peak}$)

All subjects performed incremental exercise tests on an electronically braked cycle ergometer (Corival 400, Lode B.V, Gronigan, Holland) to determine $\dot{V}O_{2peak}$ at pre-training and weeks 3 and 6 of training. For each test, subjects completed a warm-up (5–10 min) at 100 W for men and 50 W for women. The resistance was increased 30 W for men and 25 W for women every two min until volitional fatigue. At baseline and during exercise, breath-by-breath metabolic and ventilatory analyses were recorded using an automated metabolic cart (SensorMedics 229 Metabolic Cart, SensorMedics Corp., Yorba Linda, CA). Heart rate (HR) was recorded using four-lead ECG interfaced with the computer. Arterial oxygen saturation (SpO_2) was estimated using a pulse oximeter (Datex-Ohmeda, 3900P, Madison, WI) attached at the earlobe. Rates of perceived exertion (RPE) and dyspnea (DYS) ratings were taken at each stage throughout the test (Borg Scale (1–10)).

2.3. Pulmonary function tests

Pulmonary function tests were performed according to American Thoracic Society/European Respiratory Society guidelines (Miller et al., 2005). Total lung capacity was measured via nitrogen washout technique (SensorMedics 229 Metabolic Cart, SensorMedics Corp., Yorba Linda, CA. USA). Lung diffusion capacity for carbon monoxide (D_{LCO}) was determined intrabreath at rest via the single breath exhalation technique (SensorMedics 229 Metabolic Cart, SensorMedics Corp., Yorba Linda, CA. USA) as previously described (Smith et al., 2015). D_{LCO} was corrected for [Hb] using the equation: $D_{LCOadj} = D_{LCO} \times ((10.22 + [Hb])/(1.7[Hb]))$ (Crapo et al., 1995). Maximum flow-volume loops were assessed giving measures of forced expiratory volume in one second (FEV_1). P_{Imax} measurements were performed pre-training and each week of training to assess inspiratory muscle strength. P_{Imax} was also measured pre- and post-exercise performance tests to determine the degree of IMF as previously done (Downey et al., 2007; Kurti et al., 2015; Smith et al., 2014) with the three closest measurements used for analysis. P_{Imax} tests were performed from residual volume and maximal mouth expiratory pressures (P_{Emax}) from total lung capacity.

2.4. Exercise performance tests

Two exercise performance tests on a cycle ergometer (Monarck 818E) were completed during pre-training and weeks 3 and 6 of training. Performance tests consisted of an all-out cycle 5-mile and 30-min time-trial. These tests were chosen to assess the effects of ET and ET+IL on IMF and other variables (e.g., DYS and RPE) on a shorter (10–15 min) high intensity time-trial and also a longer endurance test. Resistance on the cycle ergometer for each subject was set at ∼3% of his/her body weight to add a slight amount of resistance while cycling to prevent excessively high pedal revolutions. The time-trial began after a 30 s warm-up. Subjects were blinded to their time in the 5-mile time-trial and to their distance on the 30-min time-trial, but were given feedback about their distance and time, respectively at consistent intervals. At week 3 and 6, subjects were given incentives (lottery tickets) to better their performance. HR and SpO_2 were monitored continuously throughout the tests. DYS and RPE (Borg scale (1–10)) were evaluated at each mile of the 5-mile time-trial and every five min of the 30-min time-trial. To determine the reliability of the 5-mile and 30-min time-trials, we had four subjects not associated with this study perform four trials of each test on separate days over a three week period. These tests showed good reproducibility as the coefficients of variation (CV) between trials were 4.6% for the 5-mile time-trial and 3.7% for the 30-min time-trial.

2.5. Exercise training

Subjects were randomized to either the ET or ET+IL group. The ET and ET+IL groups cycled three times per week for 30 min at ∼70% of peak workload at 70 rpm for 6 weeks. During the exercise training, the ET+IL group also breathing through an inspiratory muscle trainer (Threshold IMT, Respironics, Cedar Grove, NJ) while cycling set at 15% of the subjects PI_{max}. Resistance of the inspiratory trainer was adjusted each week to maintain 15% of P_{Imax} throughout the training program. Previous studies investigating specific IMT have used a 15%P_{Imax} load as the sham because it leads to negligible changes in inspiratory muscle strength (Romer et al., 2002a; Tong et al., 2008). In the current study, 15%P_{Imax} was used because a higher inspiratory load (50–65%P_{Imax}) would likely lead to hypoventilation and hypoxemia during the exercise training. Second in contrast to studies specifically training the inspiratory muscles, the modest inspiratory load of 15%P_{Imax} would be in addi-