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ORIGINAL ARTICLE

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The effects of different inspiratory muscle training intensities on exercising heart rate and perceived exertion

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Abstract This study investigated the relationship between the intensity of an inspiratory muscle training programme and its effect on respiratory muscle strength, exercising heart rate, and ratings of perceived exertion. A total of 66 subjects were randomly assigned to one of three groups. One group trained at 100% of maximum inspiratory pressure (MIP) for 6 weeks (MAX, $n=22$). A second group performed 6 weeks of inspiratory muscle training at 80% of MIP (SUB, $n=21$) and a third control group received no inspiratory training (CON, $n=23$). Both the MAX and SUB training groups improved MIP relative to the control group [32 (19) cmH_2O, $P=0.01$; 37 (25) cmH_2O, $P=0.001$, respectively]. A significant decrease in heart rate [−6 (9) beats min^{-1}, $P=0.02$] and rating of perceived exertion [−0.5 (1.4), $P=0.04$] was observed for the MAX group only. It is concluded that 6 weeks of both MAX and SUB training were sufficient to improve inspiratory muscle strength. However, exercising heart rate and perceived exertion decreased with MAX training only.

Keywords Exercise · Resistive loading · Rating of perceived exertion · Respiratory · Training intensity

Introduction

Respiratory muscle training (RMT) studies usually employ one of two modes of training: (1) voluntary isocapnic hyperpnoea (VIH) to specifically improve respiratory muscle endurance; or (2) inspiratory resistive loading (IRL) to improve respiratory muscle strength (Sheel 2002). IRL training typically consists of subjects repeatedly inspiring against a load, 3–5 times per week. With this method of training, increases in inspiratory strength, as measured by maximal inspiratory pressure (MIP) have repeatedly been found (Hanel and Secher 1991; Inbar et al. 2000; Leith and Bradley 1976; Romer et al. 2002a, b, c; Suzuki et al. 1993; Williams et al. 2002). However, only some of these studies that demonstrated an increase in inspiratory strength also found evidence of an exercise or performance benefit (Romer et al. 2002a, b, c; Volianitis et al. 2001) whereas others did not (Hanel and Secher 1991; Williams et al. 2002). Similarly, VIH training has been shown to significantly increase breathing endurance (Boutellier and Piwko 1992; Boutellier et al. 1992; Fairbarn et al. 1991; Kohl et al. 1997; Leith and Bradley 1976; Markov et al. 2001; Morgan et al. 1987; Spengler et al. 1999; Stuessi et al. 2001). But only some of these studies have found a concomitant increase in breathing endurance and exercise performance (Boutellier and Piwko 1992; Boutellier et al. 1992; Markov et al. 2001; Spengler et al. 1999; Stuessi et al. 2001).

One reason why some studies have shown increases in respiratory muscle function, but no change in exercise responses may be related to the intensity of the RMT programme. Sheel (2002) suggested that studies utilising the highest percentage of MIP also report the greatest improvement in MIP. However, no studies have compared RMT protocols at high intensities, most typical of such strength training regimes, on changes in MIP and exercising responses, i.e. heart rate and ratings of perceived exertion. We hypothesised that higher training intensities will result in a greater training stimulus and result in more marked changes in MIP and exercise responses. Therefore, the aim of this study was to compare the effects of 6 weeks IRL at two relatively high intensities on changes in MIP and exercise responses with a control group who perform no IRL.

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Methods

Subjects

Sixty-six apparently healthy subjects, consisting of 40 males and 26 females, with a mean (SD) age 21.8 (3.9) years, height 1.73

Table 1 Anthropometrical data for maximum (*MAX*) sub-maximum (*SUB*) and control (*CON*) training groups. Values are means (SD)

Parameter	MAX ($n=22$)	SUB ($n=21$)	CON ($n=23$)
Sex (♂/♀)	16/6	12/9	12/11
Age (years)	21.9 (3.3)	21.3 (1.8)	21.8 (5.1)
Height (m)	1.74 (0.10)	1.70 (0.10)	1.71 (0.10)
Body mass (kg)	76.1 (11.4)	70.0 (12.4)	74.1 (12.2)

(0.10) m, body mass 74.9 (12.0) kg were assigned randomly to one of two IRL training groups or a control group (Table 1). Written informed consent was obtained from all subjects before commencing the experiment, which had local ethical committee approval. Subjects were instructed to maintain both their usual diet and training regime (physical activity pattern) during the training period, and to abstain from strenuous physical activity the day before the exercise test.

Procedure

Lung function spirometry, including MIP, and maximum expiratory pressure (MEP), were assessed before and after a 6-week inspiratory training or control period. In addition, changes in exercising heart rate (HR) and Borg's (1974) rating of perceived exertion (RPE) were measured at the end of a 5-min, constant load cycling bout. The work rate for this exercise was set at 2 W (kg body mass)$^{-1}$ for males, and 1.5 W (kg body mass)$^{-1}$ for females.

Lung function

Forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC) and peak expiratory flow (PEF) were determined by spirometry using a computerised spirometer (Spirosense Spirometry System, Burdick, Milton, Wis.). The best of three measurements were used for subsequent analysis as recommended by Quanjer et al. (1993).

Mouth pressures were measured with a portable hand-held mouth pressure meter (Micro Medical, Rochester, Kent, UK). Subjects were encouraged to make maximum inspiratory and expiratory efforts at or near residual volume and total lung capacity respectively. The maximum of three manoeuvres was recorded as recommended by Green et al. (2002).

Respiratory training

All training was conducted three times per week for 6 weeks. The maximum group (MAX) consisted of 22 subjects who trained by reproducing 100% MIP ten times with 20 s recovery between each effort. The sub-maximum group (SUB) consisted of 21 subjects who completed a sub-maximal training protocol of ten "through range" inspirations, from residual volume to total lung capacity, at 80% of MIP. Subjects were allowed 20 s recovery between each of the ten attempts. The control group (CON) consisted of 23 subjects who did not complete any respiratory training between pre- and post-testing. All inspiratory muscle training was conducted using the RT2 training device (DeVilbiss Sunrise Medical, Wollaston, UK), which is flow-resistive in nature with subjects having to breathe through a 2-mm leak, present to prevent glottal pressure. The measured resistance was approximately 270 $cmH_2O\ l^{-1}\ s^{-1}$ as determined in a pilot study. The pressure generated at the mouth is recorded by computer and displayed in real time. Subjects perform three maximal inspirations from residual volume to total lung capacity and the user selects the highest of the three recorded. Depending on the group, the computer then re-draws an on-screen template at 100% (MAX group) or 80% (SUB group) which the subject must reproduce at the end of each 20-s rest period. In this way it is possible to ensure that the subjects are training at the prescribed intensity. The maximal template is re-assessed at each IRL session.

Statistics

Shapiro-Wilks tests were applied to data from each dependent variable and confirmed distribution normality. A one-way analysis of variance (ANOVA) was used to test the differences in the training-induced changes between training and control groups (post- and pre-test scores). A Tukey post hoc test was used to locate any significant differences between groups. Pearson's product moment correlation coefficient was used to establish whether changes in MIP data were related to the HR and RPE changes. An alpha of less than 0.05 was accepted as statistically significant in all tests. All data are presented as means and 1 SD.

Results

Lung function

There was no difference in basal measures for age, height or body mass for the three groups (Table 1). Respiratory data including lung function as assessed by FEV_1, FVC, FEV_1/FVC%, and PEF did not change differently for the MAX, SUB, and CON groups (Table 2). However, the increase in MIP was significantly greater for the MAX [32 (19) cmH_2O] ($P=0.011$) and SUB [37 (25) cmH_2O] ($P=0.001$) training groups when compared with the CON [12 (21) cmH_2O] (Fig. 1). The change in MEP was not different between any of the groups (Table 2).

Exercise responses

The change in MAX exercising HR [6 (9) beats min^{-1}] was significantly different from CON [2 (11) beats min^{-1}]

Table 2 Changes in respiratory data from pre- to post-training for MAX, SUB, and CON training groups. Values are means (SD). *MEP* Maximum expiratory pressure, *FEV_1* forced expiratory volume in 1 s, *FVC* forced vital capacity, *PEF* peak expiratory flow

Parameters	MAX ($n=22$)		SUB ($n=21$)		CON ($n=23$)	
	Pre	Post	Pre	Post	Pre	Post
MEP (cmH_2O)	108 (25)	110 (29)	96 (28)	100 (32)	97 (22)	97 (24)
FEV_1 (l)	3.8 (0.6)	3.7 (0.7)	3.8 (0.6)	3.7 (0.8)	3.7 (0.7)	3.5 (0.7)
FVC (l)	4.6 (0.7)	4.4 (0.8)	4.4 (1.0)	4.3 (1.0)	4.4 (0.9)	4.2 (0.8)
FEV_1/FVC%	83 (6)	84 (6)	87 (6)	86 (7)	84 (6)	83 (7)
PEF ($l\ s^{-1}$)	8.0 (1.6)	7.5 (1.4)	7.5 (1.8)	7.6 (1.6)	7.9 (1.6)	7.7 (1.8)

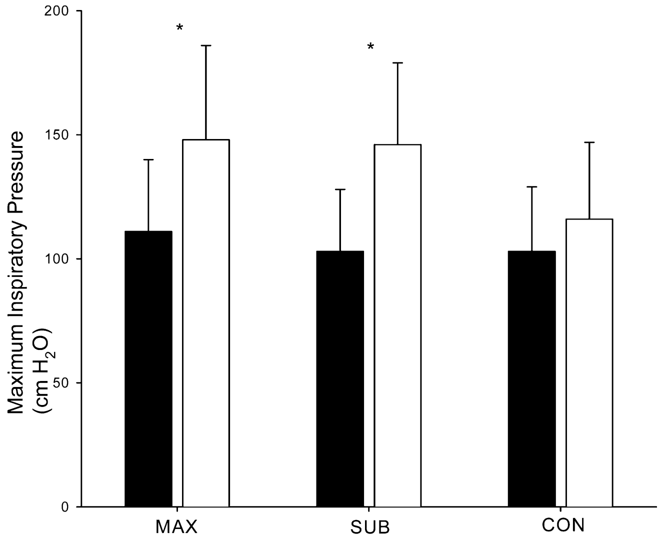

Fig. 1 Effects of 6 weeks of maximal (*MAX*), submaximal (*SUB*), and control (*CON*) on maximum inspiratory pressure. Values are means and SD.*Change significantly different from CON ($P < 0.05$). *Filled bars* Pre-training, *open bars* post-training

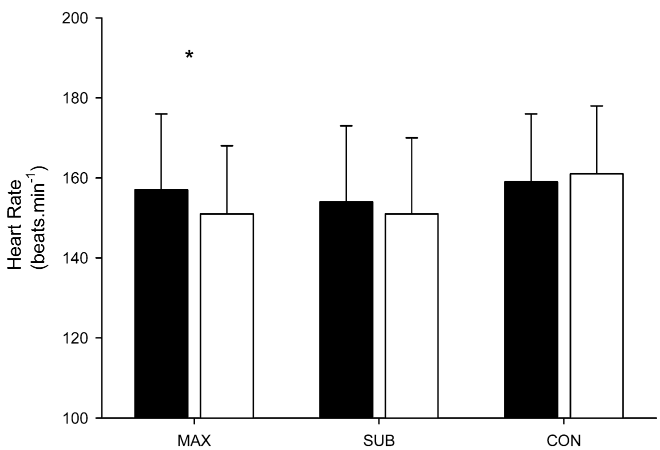

Fig. 2 Effects of 6 weeks of MAX, SUB, and CON on heart rate. Values are means and SD. *Change significantly different from control ($P < 0.05$). *Filled bars* Pre-training, *open bars* post-training

($P = 0.02$). However, the change in SUB exercising HR [3 (9) beats min^{-1}] was not different from either group (Fig. 2). The reduction in RPE for the MAX group [0.5 (1.4)] was significantly different ($P = 0.04$) from both the SUB and CON group [0.4 (1.5) and 0.6 (1.5) respectively] (Fig. 3). Reductions in HR and RPE were not significantly correlated regardless of group ($P > 0.05$, $r = 0.47$).

Discussion

The main findings of this study were that MIP increased significantly following 6 weeks of training for both the MAX and SUB training groups. However, exercising HR and RPE were significantly lower for the MAX group only. Changes in expired volumes and associated flow rates were unchanged for all three groups. Nevertheless, MIP an indicator of voluntary inspiratory muscle strength, showed a 29% and a 38% improvement in the MAX and SUB training groups respectively. The magnitudes of these increases are in agreement with previous studies (Clanton et al. 1985; Inbar et al. 2000; Romer et al. 2002a, b, c; Volianitis et al. 2001; Williams et al. 2002). The 12% change observed in the control group, who performed no respiratory training, was not statistically significant, but does reflect the caution that should be exercised when relying on MIP as an indicator of inspiratory muscle strength.

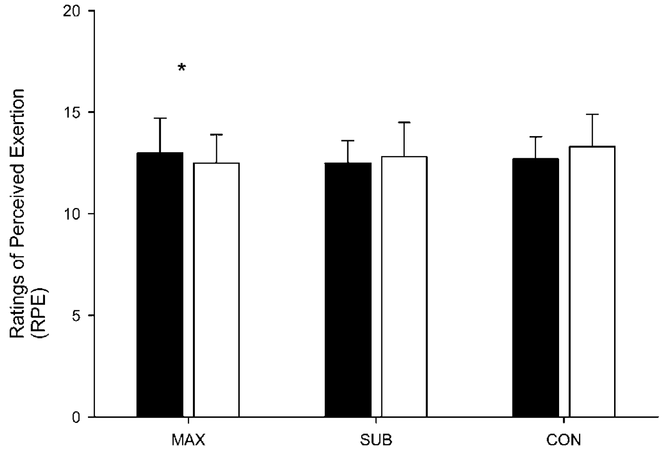

Fig. 3 Effects of 6 weeks of MAX, SUB, and CON on ratings of perceived exertion. Values are means and SD.*Change significantly different from control ($P < 0.05$). *Filled bars* Pre-training, *open bars* post-training

MIP is a simple way to gauge inspiratory muscle strength (Green et al. 2002); however, as discussed previously, an improvement in exercise performance is not always associated with an increase in this measure. As performance was not measured in the present study, the effects of the observed increases in MIP cannot be ascertained. The observed reduction in HR and RPE for the MAX group suggests a performance benefit may accompany this training however. McConnell et al. (1997) demonstrated that exercise-induced fatigue (measured as a reduction in MIP) was greatest in subjects with the lowest inspiratory muscle strength. Therefore, an improvement in MIP through an inspiratory muscle training protocol may improve performance by attenuating exercise-induced respiratory muscle fatigue. Fatigue of the respiratory muscles has been demonstrated following both short-term exercise to volitional fatigue (Coast et al. 1990; Johnson et al. 1993) and prolonged sub-maximal exercise such as marathon running (Loke et al. 1982). Furthermore, two recent studies have demonstrated a decrease in respiratory muscle fatigue following RMT (Romer et al. 2002c; Volianitis et al. 2001). After RMT, these authors also found an improvement in cycling and rowing performance respectively. However, out of the aforementioned studies only Johnson et al. (1993) really demonstrated diaphragmatic fatigue (they used phrenic nerve stimulation) whilst the remaining studies all assessed respiratory muscle fatigue as a reduction in MIP post-exercise. The significance of a change in this measure is reduced when it is considered that our own control group demonstrated a test–retest variation of 12%.

Both the MAX and SUB groups completed a total of 18 inspiratory muscle training sessions at 100% and 80% of MIP respectively. Both of these training interventions resulted in significant improvements in MIP, which did not differ between training groups. Clearly the difference in training intensity was not sufficient to alter the magnitude of the induced changes in inspiratory muscle strength. Whether these represent optimal training loads remains to be determined, as lower training intensities previously used to successfully improve MIP were not included in the present study (Volianitis et al. 2001). The significant increase in MIP of approximately 30%, despite the relatively short 6-week IRL training programme, suggests that inspiratory training in the region of 80–100% MIP is very effective. Volianitis et al. (2001) found a 10-week IRL programme resulted in a 45% improvement in MIP, whereas Sonetti et al. (2001) reported only an 8% increase following a 5-week training programme. However, Sonetti et al. (2001) employed a mixed VIH/IRL training programme, which Romer et al. (2002a) have suggested may not be as effective. This study also demonstrated that significant changes in MIP and exercising HR could be brought about with relatively short IRL sessions lasting around 10–15 min. This contrasts with previous studies where IRL sessions commonly last around 30 min (Chatham et al. 1999).

That the largest increase in MIP was not associated with the changes in HR and perceived exertion is an unexpected finding of the present study. However, we suggest that this finding may represent a separate effect of the respiratory training stimulated by the higher training intensity. In other words, a lower HR is not a primary function of a higher MIP. This may also help explain why very few other studies of respiratory muscle training have observed a reduction in exercising HR. Clearly further studies are required here to clarify this situation.

The finding that MEP was not changed for any of the groups probably demonstrates the specificity of the effects of inspiratory training on expiratory lung function. The finding that FEV_1 and PEF were unchanged may also be explained in the same manner, whilst FVC is generally held to be largely dictated by an individual's stature and not influenced by training. Consequently, any observed increase in these parameters would most likely have been due to familiarisation, and suggests this was not a significant factor in the present study.

Although, both the MAX and SUB training groups increased MIP, only the MAX group experienced a significant decrease in exercising HR. Swanson (1998) also found HR was lower following a 6-week VIH training intervention; however, no other study investigating VIH training has corroborated these findings. Harms et al. (1997) have shown that reducing the cost of breathing (by 50%) leads to an increase in blood flow to exercising skeletal muscle (by 5–7%). However, at present, we are not aware of any published studies reporting the effects of redistribution of blood flow following RMT. Indeed, it is highly unlikely that an RMT programme will reduce the cost of breathing to the extent that a ventilator does and hence, the concomitant increase in exercising skeletal muscle will be correspondingly small and potentially difficult to detect. An increase in stroke volume following a respiratory training intervention would explain the HR observations. However, Markov et al. (2001) have demonstrated that VIH does not appear to alter stroke volume. Consequently, the mechanism behind the observed decrease in exercising HR for the MAX group remains to be determined. It is tempting to suggest that the mechanisms behind the observed improvements after an IRL intervention are different to that following VIH. Indeed O'Kroy and Coast (1993) demonstrated that VIH training improves both flow and resistive tests while IRL appears to affect only strength and resistive measurements so the possibility does exist. Therefore, we suggest that the mechanisms behind improvements following VIH and IRL interventions deserve individual investigation in their own right.

The RPE was significantly decreased in the MAX group only. This decrease in RPE may be related to the same factors associated with the decrease in HR, and/or to an altered perception of breathing effort. Perceived exertion has previously been demonstrated to correspond to HR and blood lactate response (Borg et al. 1987). However, no significant correlation was found between changes in HR and RPE in the present study ($r = 0.47$). A reduction in RPE has been reported previously following IRL (Kellerman et al. 2000; Volianitis et al. 2001). Consequently, the precise mechanism by which RMT lowers RPE remains to be determined, but we speculate that the improvement in the physiological conditioning that IRL brings about (suggested by an increase in MIP) may result in perceived reduction in the cost of breathing.

Although variations in the menstrual cycle could have affected measures of HR and perceived exertion, the design of the present study makes it extremely unlikely that these variations have resulted in a consistent effect, e.g. so as to give rise to a significantly different change. Instead, we suggest that these variations were more likely to randomly change HR and perceived exertion, thereby being balanced in their influence before and after training when considered across the whole study.

In the present study, subjects in the SUB group were required to inspire from residual volume through to total lung capacity, whereas those in the MAX group simply repeatedly reproduced 100% MIP. The reason for this was that subjects attempting to inspire at 100% MIP fell short of the through-volume manoeuvre, though lung volume training has previously been suggested to be superior to other methods of IRL (Chatham et al. 1999). This suggestion was made following the observation that IRL performed at different lung volumes exhibited the greatest effect within the lung volume in which the training was prescribed (Tzelepis et al. 1994). The present study confirms that inspiring from residual volume to total lung capacity is not necessary to bring about significant adaptations in the respiratory muscles provided the intensity is high enough to compensate. Moreover, only subjects in the MAX group, who did not inspire through volume, experienced a significant decrease in exercising HR and RPE. These findings also indicate that pressure-threshold devices, which close when the target pressure can no longer be maintained (Romer et al. 2002a, b, c; Volianitis et al. 2001), are therefore likely to be as effective in increasing MIP.

Conclusion

This study has demonstrated that 6 weeks of inspiratory muscle training is sufficient to induce a significant increase in MIP in both MAX and SUB training groups. However, only the MAX training resulted in a significant decrease in HR and RPE during exercise.

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