Hindawi Publishing Corporation
Journal of Obesity
Volume 2012, Article ID 918202, 6 pages
doi:10.1155/2012/918202

Clinical Study

Four Weeks of Inspiratory Muscle Training Improves Self-Paced Walking Performance in Overweight and Obese Adults: A Randomised Controlled Trial

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Received 20 February 2012; Revised 26 April 2012; Accepted 10 May 2012

Academic Editor: Jack A. Yanovski

Objective. To examine whether a programme of inspiratory muscle training (IMT) improves accumulative distance of self-paced walking in overweight and obese adults. *Methods.* A total of 15 overweight and obese adults were randomized into experimental (EXP: $n = 8$) and placebo (PLA: $n = 7$) groups. Lung function, inspiratory muscle performance, 6-minute walking test, and predicted $\dot{V}O_2$ max were assessed prior to and following the 4-week IMT intervention. Both groups performed 30 inspiratory breaths, twice daily using a proprietary inspiratory resistance device set to 55% of baseline maximal effort (EXP), or performing the same inspiratory training procedure at the minimum resistive setting (PLA). *Results.* Lung function was unchanged in both groups after-training; however inspiratory muscle strength was significantly improved in EXP (19 ± 25.2 cm H_2O gain; $P < 0.01$) but did not significantly change in PLA. Additionally, the posttraining distance covered in the 6-minute walking test was significantly extended for EXP (62.5 ± 37.7 m gain; $P < 0.01$), but not for PLA. A positive association was observed between the change (%) of performance gain in the 6-minute walking test and body mass index ($r = 0.736$; $P < 0.05$) for EXP. *Conclusion.* The present study suggests that IMT provides a practical, minimally intrusive intervention to significantly augment both inspiratory muscle performance and walking distance covered by overweight and obese adults in a clinically relevant 6-minute walk test. This indicates that IMT may provide a useful priming (preparatory) strategy prior to entry in a physical training programme for overweight and obese adults.

1. Introduction

Obesity is a serious health concern which increases the risk of all-cause mortality across all populations [1]. To address this issue, many exercise-based interventions have been developed which aim to reduce excess body weight and improve health outcomes for obese individuals [2]. However, the effectiveness of exercise interventions is often limited by factors including premature sensations of fatigue among overweight and obese individuals [3] which could diminish the motivational drive to commence (or continue) a physical training programme. As obesity leads to an increase in respiratory demands [4–6], it is possible that an intervention such as inspiratory muscle training (IMT) might improve respiratory compliance, exercise tolerance, and the benefits of exercise training in this population group.

The work of breathing is primarily undertaken on inspiration whereby the chest and lungs expand to accommodate an increased volume of air, while expiration is largely passive [7]. Consequently, a training programme specifically designed to enhance the performance of inspiratory muscles among overweight and obese individuals might lessen subconscious inhibition of exercise performance [3], reduce respiratory muscle fatigue [5], and promote greater performance in response to exercise challenges [8, 9]. In support of this perspective, a recent study of hospitalized obese adults demonstrated an aggressive two-month intervention of supervised respiratory (inspiratory and expiratory) muscle training coupled with diet and physical training significantly improved both respiratory muscle endurance (∼52% gain) and the distance covered in a 6-minute walking test (∼11% gain) [8]. While the results of that experiment strongly suggest respiratory muscle training may be of value to obese individuals, its findings are not directly applicable to nonhospitalised individuals due to the multidimensional nature of the intervention and the supervisory requirements of such an intense protocol. A less aggressive, but potentially equally effective strategy, is via inspiratory muscle training (IMT) using a portable inspiratory-resistance training device [9].

The IMT strategy proposed in this study is minimally intrusive, does not require supervision, and directly targets inspiratory effort which account for up to 80% of the work of breathing [7]. This strategy has been shown to improve inspiratory muscle strength and physical performances across a range of individuals in as little as four weeks [9, 10]. This intervention has not, to our knowledge, been investigated as a strategy to augment physical performances in overweight or obese individuals, although other recent studies of supervised respiratory muscle training appear to support the development of this technique as a useful strategy to augment resistance to respiratory fatigue [11], promote performance gain, and potential weight loss [12]. Performance gain in response to IMT could support this technique as an important priming (preparatory) strategy for overweight and obese individuals prior to prospective entry in a physical training programme.

As obese individuals are well known to experience shortness of breath to a greater extent than healthy normal subjects [5], it is therefore likely that a programme of IMT training will be particularly meaningful for obese individuals. The aim of this study is therefore to investigate whether a 4-week intervention of IMT will improve inspiratory muscle strength and functional performance as assessed by the 6-minute walk test [13].

2. Methods

2.1. Participants. Fifteen adults (male and female) volunteered for this study, provided written informed consent prior to participation, and were randomly allocated to either experimental (EXP: $n = 8$) or placebo (PLA: $n = 7$) group as matched parallel pairs based on body mass index (BMI) and history of smoking. Inclusion criteria were (i) BMI $>$ 27 kg/m^2, (ii) being free of respiratory or cardiovascular diseases. The physical characteristics of the two groups are shown in Table 1. Ethical clearance for this study was provided by the Research and Ethics committee of James Cook University.

Table 1: Participants' characteristics.

	EXP ($m = 4, f = 4$)	PLA ($m = 3, f = 4$)
Age (years)	49 ± 8.6	55 ± 11.0
Height (cm)	173.4 ± 9.3	165.9 ± 10.8
Mass (kg)	112.7 ± 36.9	90.5 ± 16.6
BMI (kg/m^2)	34.5 ± 8.4	32.8 ± 4.8
Systolic blood pressure (mm Hg)	135.9 ± 15.1	135.7 ± 12.7
Diastolic blood pressure (mm Hg)	87.8 ± 13.5	88.7 ± 20.7

Mean ± SD. There were no statistically significant differences between the physical characteristics of EXP and PLA groups.

2.2. Study Overview. All individuals in EXP and PLA completed baseline physical assessments of height, mass, blood pressure, standard spirometry (FVC, FEV_1), inspiratory muscle performance (MIP), estimation of maximal aerobic power ($\dot{V}O_2$ max), and 6-minute walk test performance. Following baseline measurements, all individuals were familiarized with a proprietary portable inspiratory-resistance training device (POWERBreathe, Gaiam, UK) to be used over the duration of the intervention period. The device was preset to either 55% of their individualized maximal inspiratory effort (EXP) or to the minimum device setting equivalent to approximately 10% of maximal inspiratory effort (PLA) [9, 14]. Both groups thereafter performed 2×30 daily inspiratory efforts using the IMT device [15, 16]. Immediately following the 4-week intervention, the same battery of assessments as used at baseline was repeated. Adherence and compliance to the training protocol were checked twice weekly. No participants reported experiencing any issues or difficulties with the intervention.

2.3. Study Procedures

2.3.1. Lung Function and Inspiratory Muscle Performance. Baseline spirometry included measurements of forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) using a portable hand-held device (Microlab-Spirometry SN M20364, USA). Participants were seated and wearing noseclips. After inspiration to total lung capacity, FEV_1 and FVC were measured.

Maximal static inspiratory mouth pressure (MIP) was measured at residual volume following a slow and complete expiration using a portable hand-held mouth pressure meter (POWERBreathe KH1 INSPIRATORY METER, Gaiam, UK). The best of three maximal efforts were analysed for spirometry and MIP measures. All procedures were performed in accordance with methodologies previously reported [9, 14].

2.3.2. Functional Exercise Capacity. The 6-minute walk test is a performance-based measure assessing voluntary effort in response to an exercise stimulus and provides an effective measure of functional capacity in untrained, sedentary adults [13]. Participants were instructed to "*walk as far as you can in six minutes without running or jogging*" [17] on a motorized laboratory treadmill (TrackMaster, TMX 55, Australia) in accordance with previously validated techniques for this test [18] and were reminded at regular intervals to increase or decrease the treadmill belt speed according to their individual needs. Participants were able to view time elapsed

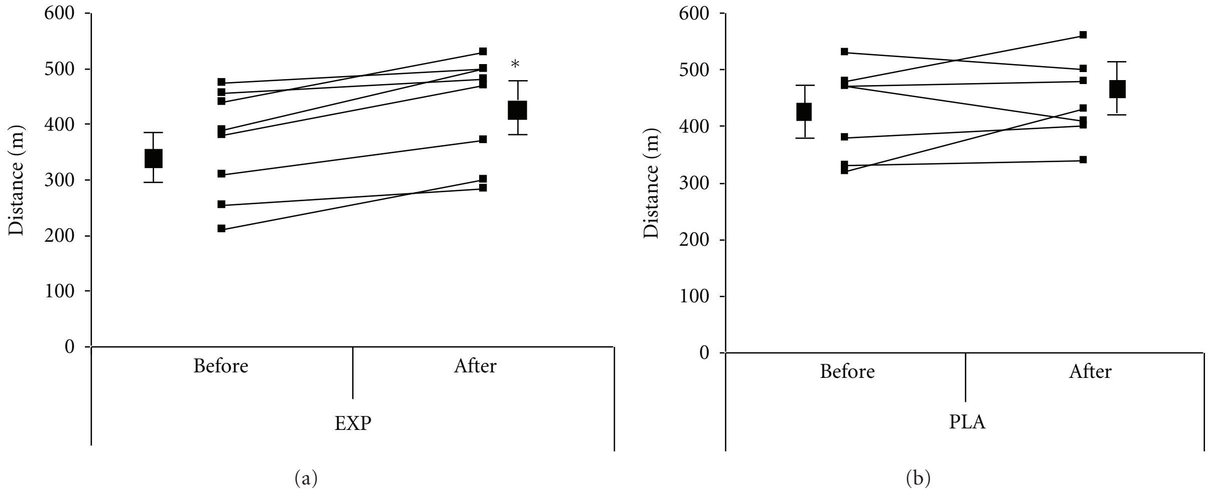

FIGURE 1: Distance covered (metres) in response to the 6-minute walk test for both experimental (EXP; $n = 8$) and placebo (PLA; $n = 7$) groups. * = significant difference between baseline and posttraining distance covered ($P < 0.01$). Means ± SD and individual (before and after training) results are displayed.

on the treadmill visual display, but velocity and distance covered were obscured from vision. Participants therefore paced the 6-minute bout in the knowledge of exercise duration and their individual capabilities. Distance covered (m) and heart rates were recorded at the conclusion of the 6-minute period [19, 20].

Maximal aerobic power ($\dot{V}O_2$ max) was estimated from a validated heart-rate-derived algorithm utilizing a submaximal single stage 4-minute walking test [21]. Participants were required to complete a brisk but comfortable constant walking pace ranging from 3.5 to 5 km/h for 4-minutes on a treadmill.

Participants were required to wear a chest strap transmitter (Polar, T31 Coded Transmitter, Australia) for the measurement of heart rate during exercise testing.

2.4. Psychological Measures. The modified Borg Scale (CR10) [22] was used to measure ratings of perceived exertion RPE in response to exercise as an index of fatigue perception.

2.5. Statistical Analyses. The statistical software package SPSS (version 18.0, SPSS, Chicago, IL,USA) was used for all statistical analysis. Pre-and posttraining results and group interactions were statistically compared using two-way repeated measures analyses of variance (group × time) (ANOVA) and post hoc Tukey tests of honestly significant difference were used where differences were indicated. The relationships between data sets were examined using Pearson Product Moment Correlations. Probability values of <0.05 were considered significant and all tests were two sided. All results are expressed as means (SD) unless otherwise stated. Sample size analysis was based on an anticipated mean improvement (SD) in the 6-minute walk test of those in the EXP of 54(35) metres versus 1(7) metres in the PLA group [8]. Based on a statistical power (1-beta) of 90% and alpha of 0.05 a sample size of six was required in both the EXP and PLA groups. Sample sizes were also in accordance with previous work utilizing this intervention technique [9, 14–16].

3. Results

There was no between-group difference for distance covered either at baseline or posttraining, but group × time ANOVA interaction indicated a meaningful effect ($P \leq 0.05$). Consequently, post hoc within-group comparisons for time (pre- to posttraining) indicated EXP significantly improved distance covered (m) in response to the 6-minute walk test from baseline to posttraining (62.5 ± 37.7 m gain; $P < 0.01$). However, PLA did not significantly extend distance covered across the 4-week intervention period (14.3 ± 58.9 m gain; NS) (Figure 1).

The prediction of $\dot{V}O_2$ max from submaximal heart rates did not identify significant differences between EXP and PLA at either baseline or posttraining (Table 2).

Additionally, assessment of standard spirometry variables (FVC and FEV_1) also did not identify differences between groups at either baseline or posttraining (Table 2).

For MIP, a group × time ANOVA interaction indicated a meaningful effect ($P < 0.05$) and subsequent post hoc evaluation revealed MIP improved significantly over the 4-week training period for EXP (19.4 ± 25.2 cm H_2O gain; $P < 0.01$) but was not significantly changed for PLA (9.9 ± 7.2 cm H_2O gain; NS) (Figure 2). There were no between group differences.

Mean heart rates in response to the 6-minute walk test were unchanged for EXP (121.3 ± 16.1 and 119.5 ± 16.4 b/min) and PLA (114.1 ± 15.3 and 114.9 ± 11.6 b/min) from pre- to posttraining.

Postexercise RPE evaluations did not change significantly from baseline to posttraining in either EXP (2.63 ± 0.7 to 2.56 ± 0.9) or PLA (2.71 ± 1.8 to 3.43 ± 1.8).

Table 2: Lung function and estimated maximal aerobic power variables prior to and following the 4-week intervention period.

	EXP		PLA	
	Pre ($n = 8$)	Post ($n = 8$)	Pre ($n = 7$)	Post ($n = 7$)
FVC (l)	3.3 ± 0.9	3.0 ± 0.8	2.8 ± 0.8	2.7 ± 0.7
FEV_1 (l)	2.8 ± 0.6	2.7 ± 0.7	2.5 ± 0.5	2.5 ± 0.5
$\dot{V}O_2$ max (mL/kg/min)	41.7 ± 11.1	41.6 ± 10.7	42.3 ± 11.6	42.4 ± 11.6

Mean ± SD.

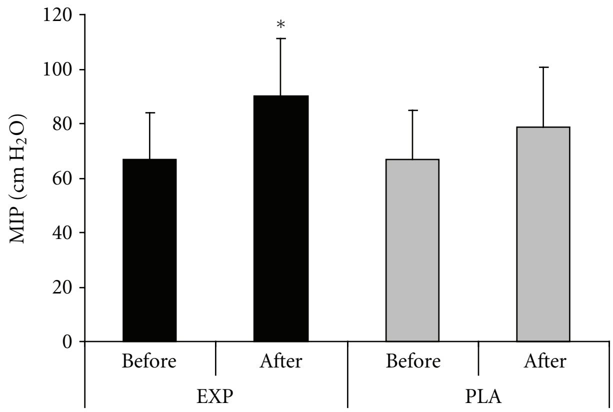

Figure 2: Maximal inspiratory mouth pressure (MIP) measure before and after the 4-week intervention period for both experimental (EXP) and placebo (PLA) groups. * = significant difference between baseline (before) and posttraining (after) distance covered ($P < 0.01$).

Bivariate analysis identified several significant correlations between participant factors and intervention response which were specific to EXP. The % change of distance covered in the 6-minute walk test (pre- to post-training) was significantly associated with baseline BMI ($r = 0.736$; $P < 0.05$) (Figure 3(a)). The % change from pre- to posttraining 6-minute walking distance was also correlated with % change in MIP ($r = 0.746$; $P < 0.05$) (Figure 3(b)). There were no meaningful associations identified in PLA.

4. Discussion

This study demonstrated that 4 weeks of inspiratory muscle training (IMT) significantly improved the physical performance of obese and overweight subjects as assessed by the 6-minute walk test. As this effect was not evident for PLA, it suggests IMT is a meaningful intervention with which to augment physical performance outcomes for overweight and obese individuals. The results of our study support and exceed those of Villiot-Danger et al. [8] from hospitalized obese individuals (∼11% gain in walking distance) but were achieved with a considerably less aggressive intervention which could be undertaken at home and without supervision. It is possible the statistically significant 62.5 m gain (18.8% gain) in walking distance observed in our study was achieved as a consequence of directly targeting inspiratory muscles for the intervention rather than generalized respiratory muscle training.

The walking distance covered during the 6-minute walk test was subject to self-regulation in so far as participants were able to continually adjust the treadmill velocity according to their individual requirements [18]. Accrued distance was obscured from participants' view on the digital treadmill display unit to ensure pacing was not performed in accordance with simply attempting to better the baseline effort [23, 24]. Consequently, performances by both EXP and PLA occurred in the knowledge of only time elapsed (which was displayed) and participants transient perceptions of attainable work outputs across a 6-minute period.

Although a significant improvement in 6-minute walking performance following IMT was observed, the mechanisms by which IMT evokes performance improvements remain unclear. Several putative mechanisms have been proposed to explain performance-enhancing effects of IMT [25] and these include a delay in respiratory muscle fatigue [26, 27], a redistribution of blood flow from respiratory to locomotor muscles [25] and a decrease in the perceptions of respiratory and limb discomfort during exercise to fatigue [27, 28]. As changes within the respiratory muscles underlie interactions between the brain and working locomotor muscles [23] it seems likely that IMT-induced improvements to inspiratory muscle functionality would positively influence this feedback mechanism. This could therefore desensitize subconscious recruitment patterns of skeletal muscle as a consequence of reduced sensations of breathlessness during the 6-minute walk test. As the instruction for performing this test was for individuals to walk as far as they could without running or jogging, they were not requested to perform at a preset RPE. Posttest evaluations of perceived exertion were not different between groups or test occasions but this is to be expected where individuals pace themselves according to physical sensations. For example, numerous studies have demonstrated pacing is based on the anticipated level of physical discomfort the individual is prepared to endure in the defined task [24]. As such, participants would be expected to experience the same level of tolerable physical discomfort during the 6-minute walk test at both baseline and posttraining; the difference, being that greater distance was achieved posttraining for the same level of physical discomfort when compared to baseline.

Despite training-induced improvements to inspiratory muscle performance across the 4-week period, MIP for EXP remained beneath levels reported for healthy subjects [10] suggesting that continuation of IMT beyond a 4-week period could be meaningful to this population. There are very limited data in this topic area and it remains unclear as to the extent of improvement likely in individuals where

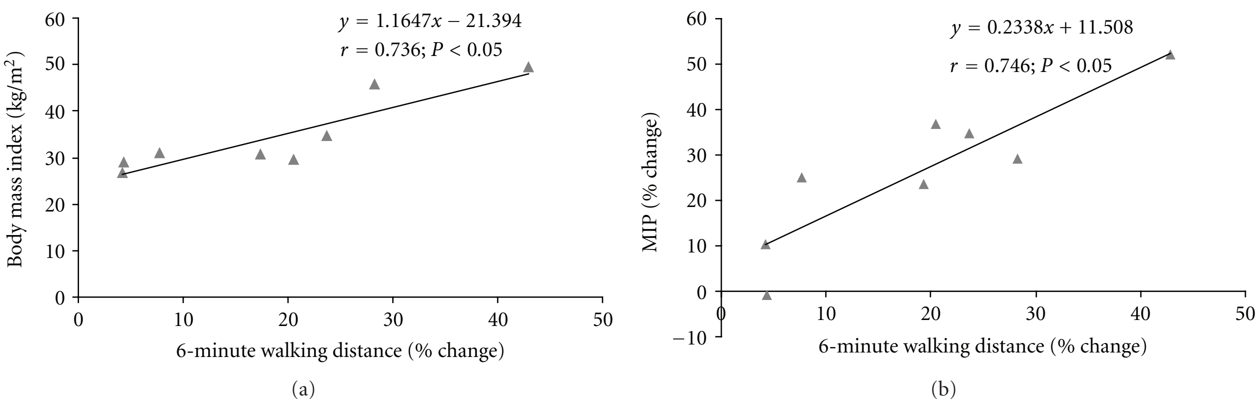

Figure 3: Associations between (a) body mass index and % change in 6-minute walking distance from pre- to posttraining and (b) between the (%) changes of maximal inspiratory mouth pressure and 6-minute walking distance from pre- to posttraining.

inspiratory muscle performance remains suboptimal. Previous studies (e.g., [9]) have also indicated that concurrent IMT and physical conditioning enhances training outcomes. Therefore, further studies may elucidate whether extending IMT prior to physical training and also concurrent (IMT and physical) training strategies improve performance outcomes for overweight and obese individuals.

Standard spirometry measures FVC and FEV_1 were unchanged in this study which is consistent with previous observations [10]. As the intervention in this study focused on inspiratory muscle training this effect is largely to be expected and demonstrates specificity of the inspiratory pressure threshold technique.

There were several interesting associations between data sets observed in this study. First, the (%) change from baseline to posttraining in distance covered for the 6-minute walk test was positively related to BMI for EXP ($r = 0.736$; $P < 0.05$). This suggests individuals of higher BMI could gain the most from an IMT intervention as greater adiposity of the chest wall increases respiratory resistance which contributes to exercise-induced dyspnea [29]. As a positive association was observed between the change in 6-minute walking performance and change in MIP ($r = 0.746$; $P < 0.05$) it could be expected that IMT, to some extent, alleviates this effect. However, correlation analysis of such small subject numbers should be treated with caution as, alternatively, it is equally likely that greater adiposity is simply indicative of greater physical inactivity. This would probably act to evoke a greater detraining effect of the respiratory system and a wider study is required to confirm this observation.

Despite the significant benefits associated with IMT the small sample size means these findings should be interpreted with caution. Further substantiation from larger confirmatory studies and demonstration of whether the changes seen here are sustainable will be required before IMT can be advocated as a component of exercise training in this setting.

In summary, this study indicates that IMT may provide a practical, inexpensive, and minimally intrusive intervention to augment both inspiratory muscle strength and walking distance among overweight and obese adults. The beneficial effects of this treatment were similar to those previously reported from vigorous, supervised training among hospitalised obese patients [8]. Our findings indicate similar effects could be expected without the need for hospitalisation and indicate that IMT via an inspiratory resistance device can easily be performed in the home environment. IMT therefore appears a useful strategy to enhance walking performance in overweight and obese individuals which may prove a meaningful priming intervention with which to stimulate performance adaptations and future engagement with physical activity.

Conflict of Interests

None of the authors had any conflict of interests regarding any aspect of this work.

Acknowledgments

The authors would like to thank Megan Mackenzie and Stephanie Tahn for their valuable contributions to data collection in this project.

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