ERJ Express. Published on May 15, 2007 as doi: 10.1183/09031936.00095406

COMPARISON OF INCREMENTAL AND CONSTANT LOAD TESTS OF INSPIRATORY MUSCLE ENDURANCE IN COPD

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Short title: inspiratory muscle endurance in COPD

Key words: assessment, endurance, lung disease, respiratory muscles

Supported by the NHMRC (Australia) Grant Number: 212016

ABSTRACT

Aim: To determine the relative value of incremental and constant load tests in detecting changes in inspiratory muscle endurance following high-intensity inspiratory muscle training (H-IMT) in chronic obstructive pulmonary disease (COPD).

Methods: 16 subjects (11 males, FEV_1 37.4±12.5%) underwent H-IMT. 17 subjects (11 males, FEV_1 36.5±11.5%) underwent sham inspiratory muscle training (S-IMT). Training took place 3 times a week for 8 weeks. Baseline and post-training measurements were obtained of maximum threshold pressure sustained during an incremental load test (Pthmax) and time breathing against a constant load (Tlim). Breathing pattern was unconstrained.

Results: H-IMT increased Pthmax and Tlim relative to baseline and to any change seen following S-IMT. The effect size for Pthmax was greater than for Tlim. Post-training tests were accompanied by changes in breathing pattern, including decreased duty cycle, which may have served to decrease inspiratory work and thereby contribute to the increase in Pthmax and Tlim in both groups.

Conclusions: When assessing inspiratory muscle function in COPD using tests in which the pattern of breathing is unconstrained, we recommend incremental load tests be used in preference to constant load tests. However, to attribute changes in these tests to improvements in inspiratory muscle endurance, breathing pattern should be controlled.

INTRODUCTION

Inspiratory muscle function is most often described in terms of the maximum force generating capacity (i.e. strength) and the capacity to maintain a specific muscular task over time (i.e. endurance) (1). The measurement of maximum inspiratory pressure (PImax) is widely accepted and commonly used as a simple assessment of global inspiratory muscle strength (1, 2). However the physiological relevance of PImax is unclear given that maximal inspiratory pressures are rarely generated during activities of daily living in either healthy individuals or those with respiratory disease. As the inspiratory muscles are required to perform submaximal contractions throughout life, it is possible that assessment of their endurance may be of greater functional relevance than measurements of their strength. In contrast to the measurement of PImax, no such generally accepted method exists for the measurement of global inspiratory muscle endurance (1, 3) although both the maximum threshold pressure sustained during an incremental load test (Pthmax) and the time to exhaustion while inspiring against a constant submaximal load (Tlim) are commonly used for this purpose (2, 4, 5).

Following inspiratory muscle training (IMT) many studies have reported improvements in the performance of incremental or constant load tests of inspiratory muscle endurance relative to baseline values (6-15). However, reports of such improvements are less common when changes are compared with those observed in a control group (9, 11-13). This disparity suggests that these tests may have limited specificity for the detection of training responses to IMT programs.

In a recent analysis of the effect of an 8-week program of high-intensity IMT on inspiratory muscle function we demonstrated a 56% increase in endurance as assessed by incremental loading (Pthmax) (16). In the present study we have extended this analysis to compare this measure of endurance with assessment of endurance by a constant load test. The purpose of doing so was to determine: a) their value in detecting changes in muscle performance relative to baseline values; and b) the capacity of each to discriminate between a treatment and control group. The results of such analyses could be helpful in determining which type of test is of greater value in investigating respiratory muscle endurance and response to training in clinical and research settings.

METHODS

Subjects

The subjects recruited for this study have been described in detail elsewhere (16). Briefly, subjects were recruited who had a forced expiratory volume in one second (FEV_1) of between 15% and 70% of the predicted normal value (17), a medical diagnosis of COPD and a smoking history in excess of 10 pack-years. Exclusion criteria were the use of long-term oxygen therapy, tapering doses of corticosteroids or methylxanthines, a history of lung surgery or spontaneous pneumothorax, and any co-morbid condition thought to adversely affect test performance.

Study design

A prospective double-blind randomised controlled trial was undertaken to compare the effects of high intensity, interval-based IMT (H-IMT) with sham IMT (S-IMT). All subjects entered a two-week "screening and familiarisation" phase, during which time all baseline measurements were collected. To account for any improvements due to familiarisation with the tests (18) both incremental and constant load tests of inspiratory muscle endurance were performed on four separate occasions (> 24 hours apart) prior to commencing training. Subjects were then randomised to receive eight weeks of H-IMT or S-IMT. On completion of the training period measurements were repeated. Specific details of the measurements of resting lung function, inspiratory muscle strength, exercise capacity, dyspnea and health-related quality of life and on the changes in these measurements following H-IMT and S-IMT have been described previously (16). Approval for the study was obtained from the Human Research Ethics Committees of Sir Charles Gairdner Hospital and Curtin University of Technology and written informed consent was obtained from each subject prior to participation.

Measurements

<u>Inspiratory muscle endurance</u>

Inspiratory muscle endurance was assessed using an incremental load test (4) and a constant load test (5). Details of the assessment procedures have been described elsewhere (16). Briefly, subjects were seated, wore a nose clip and received standardised instructions and encouragement to facilitate maximal performance. Both tests were performed using a modified threshold loading valve (19, 20) and measurements of inspiratory mouth pressure (differential pressure transducer, Honeywell, Morristown, NJ, USA), inspiratory flow and tidal volume (Fleisch no. 2 pneumotachograph and differential pressure transducer, Validyne Engineering, Northridge, CA, USA) were continuously recorded on an electronic strip chart recording system (PowerLab/16s, ADIinstruments Pty Ltd, Castle Hill, Australia). Subjects were permitted to choose their own breathing pattern throughout both tests. Inspiratory time was defined as the time period extending from the commencement of an increase in inspiratory pressure to the end of inspiratory flow (21). Expiratory time was defined as the remainder of the total respiratory cycle time (21). The pressure-time index (PTI) was calculated as the product of inspiratory duty cycle and the proportion of PImax generated with each inspiratory effort (1, 22, 23).

Incremental load test

The incremental load test required subjects to breathe against inspiratory threshold loads that were increased each minute by 10% of baseline PImax until voluntary task failure. Inspiratory muscle endurance was defined as the Pthmax sustained for a minimum of 30 seconds (18). The highest Pthmax achieved during the "screening and familiarisation" phase was recorded as the baseline measure. The load increments were kept identical between baseline and post-training tests. Breathing pattern variables were averaged over the final 20-second epoch of the maximum load achieved (Pthmax) during the baseline and post-training tests. Any breaths affected by artifact (e.g. swallowing) were excluded from the analyses.

Constant load test

The constant load test was performed at least 15 minutes after completion of the incremental load test. Subjects were required to breathe against a submaximal threshold load until task failure, with inspiratory muscle endurance defined as the time able to breathe against the load (Tlim). An inspiratory load was selected such that Tlim was between 5 and 10 minutes (24). Determination of this load was undertaken during the "screening and familiarisation" phase by increasing inspiratory loads if Tlim exceeded 15 minutes and reducing them if Tlim was less than one minute. Once determined this load was used during all pre- and post-training assessments. While the absolute magnitude of the load varied between individuals, it was equivalent to approximately 80% of baseline Pthmax in all subjects, being of similar magnitude to that used by Ramirez-Sarmiento et al (14) in a similar group of subjects. The longest Tlim achieved against this load during the "screening and familiarisation" phase was selected as the baseline value. In the event that a subject sustained inspiratory efforts against the constant load for 15 minutes on any test occasion, the investigator terminated the test and recorded the Tlim as 15 minutes. Breathing pattern variables were averaged over the final minute of each of the baseline and post-training tests. Any breaths affected by artifact (e.g. swallowing) were excluded from these analyses.

Inspiratory muscle training

Training was supervised and took place three times a week for eight weeks. We applied a novel interval-based H-IMT program using a modified threshold training device (Threshold IMT, Respironics, Cedar Grove, NJ, USA) which comprised seven cycles of two minutes loaded breathing followed by a one minute rest (25). To familiarize subjects with the handheld training device, a low inspiratory load (45% of the pre-training PImax) was applied during the first training session. The load was increased so that following the third session, subjects were generating inspiratory pressures equivalent to approximately 60% of the pre-training PImax with each breath. Subjects were permitted to choose their own breathing pattern. The load was further increased over the 8-week period with the aim of titrating to a level where subjects were just able to complete the final 2-min interval. Subjects allocated to receive S-IMT underwent training at a load equivalent to 10% of the previously determined PImax which was unchanged throughout the training program. Further details of the H-IMT and S-IMT programs have been described elsewhere (16).

Data management and statistical analyses

Statistical analyses were performed using SPSS® (Statistical Package for Social Sciences, version 11.0 for Windows) and Analyse-it for Microsoft Excel (version 1.6). An α (p) value less than 0.05 was considered significant. All data are expressed as mean ± SD unless otherwise stated.

Analyses

Baseline measurements were compared between groups using unpaired t-tests (continuous variables) or χ^2 tests (categorical variables). Data that deviated significantly from the normal distribution were transformed. Differences between and within groups were analysed using independent and paired t-tests, respectively.

Cohen's *d* effect sizes were calculated by dividing the difference in the magnitude of change in each measure between the groups by the pooled standard deviation of the mean change in each group. The capacity of each measure to discriminate individuals who had participated in H-IMT or S-IMT was evaluated in terms of their sensitivity and specificity, presented together as Receiver Operating Characteristic (ROC) curves. The area under the curve for each ROC plot and the associated 95% confidence interval were compared to assess the ability of each measure to discriminate between individuals in the H-IMT and S-IMT groups, and therefore the effect of training.

RESULTS

Subjects

16 subjects (FEV_1 of 37.4 ± 12.5% predicted, age of 69.4 ± 7.2 years, 11 males) completed the H-IMT program and 17 subjects (FEV_1 36.5 ± 11.5% predicted, age of 66.6 ± 9.8 years, 11 males) completed the S-IMT program. Further details on subject characteristics are described elsewhere (16). Prior to initiating training, no significant differences were observed in any measure of resting lung function, inspiratory muscle strength or endurance, exercise capacity, dyspnea or health-related quality of life between the H-IMT and S-IMT groups (16).

Effects of H-IMT and S-IMT on measures of inspiratory muscle strength

PImax increased by 29% (from 67.2 ± 16.5 to 80.7 ± 17.8 cmH_2O; $p < 0.001$) following H-IMT and by 8% (from 66.5 ± 19.0 to 71.7 ± 18.7 cmH_2O; $p < 0.05$) following S-IMT (16). The magnitude of the increase in PImax was greater following H-IMT than the increase seen following S-IMT ($p = 0.002$) (16).

Effects of H-IMT and S-IMT on measures of inspiratory muscle endurance

Following H-IMT, Pthmax increased by 56% (21.6 ± 10.8 cmH_2O; $p < 0.001$) (Figure 1a) and Tlim increased by 162% (511 ± 198 sec; $p < 0.001$) (Figure 2a). Sixteen subjects (100%) achieved a Pthmax greater than their baseline result, 15 subjects (94%) achieved a Tlim greater than their baseline result and 12 subjects (75%) achieved a Tlim of 15 minutes.

Following S-IMT, Pthmax was unchanged (Figure 1a) and Tlim increased by 70% (237 ± 343 sec; $p < 0.02$) (Figure 2a). Six subjects (35%) achieved a Pthmax greater than their baseline result, 11 subjects (65%) achieved a Tlim greater than their baseline result and 8 subjects (47%) achieved a Tlim of 15 minutes.

Receiver Operating Characteristic (ROC) curves were used to determine the capacity of Pthmax and Tlim to discriminate individuals who participated in H-IMT or S-IMT. The cut-off value with an optimal combination of sensitivity and specificity to distinguish the two groups was a 5.6% increase in Pthmax (sensitivity of 100% and specificity of 70.6%) and a 44.3% increase in Tlim (sensitivity of 94% and a specificity of 65%). The area under the ROC curve for the percentage change in Pthmax (0.87) (Figure 1b) exceeded the area under the ROC curve for the percentage change in Tlim (0.67) (Figure 2b) ($p < 0.05$).

The increases in Pthmax and Tlim following H-IMT were greater than any change observed in the S-IMT group ($p < 0.05$) (Figures 1a and 2a). The magnitude of change in each measure of inspiratory muscle function following H-IMT and S-IMT are shown in Figure 3. Also displayed in Figure 3 are the 95% confidence intervals associated with each change and the effect sizes for the difference in the magnitude of change in each measure between the groups.

Effects of H-IMT and S-IMT on breathing pattern during loaded breathing tests

Incremental load test

While minute ventilation at Pthmax was similar following H-IMT and S-IMT, differences in breathing pattern were observed in both groups at Pthmax during the post-training test (Table 1). Specifically, relative to the baseline test, during the post-training incremental loading test subjects breathed with a decreased inspiratory duty cycle, primarily as a consequence of increased expiratory time. Mean and peak inspiratory flow increased only in the H-IMT group. PTI was unchanged by training in either group.

Constant load test

Minute ventilation at Tlim during the constant load test was lower following S-IMT and unchanged following H-IMT (Table 2). In general the changes in breathing pattern observed during the incremental test were also noted during the constant load test. Specifically, inspiratory duty cycle decreased, primarily as a consequence of an increase in expiratory time. As seen in the incremental load test, mean and peak inspiratory flow increased following H-IMT but not S-IMT. The changes in breathing pattern resulted in a reduction in PTI following H-IMT and S-IMT.

H-IMT vs. S-IMT

While breathing pattern during the loaded breathing tests changed in both groups with training, comparison of the magnitude of change between the two groups revealed that during the incremental and constant load tests the increase in mean and peak inspiratory flow and the decrease inspiratory duty cycle were significantly greater following H-IMT than S-IMT ($p < 0.05$). During the constant load test, the decrease in PTI following H-IMT was greater than any seen following S-IMT ($p = 0.001$).

DISCUSSION

This is the first study to compare the magnitude and specificity of change in measures of inspiratory muscle endurance assessed using an incremental and constant load test following a program of H-IMT and S-IMT. Relative to any change seen following S-IMT, H-IMT was associated with significant increases in Pthmax and Tlim. Thus, both the incremental and constant load tests were able to discriminate between individuals who had participated in H-IMT from those who underwent S-IMT. It was notable, however, that the specificity and effect sizes for the magnitude of change in Pthmax were substantially greater than for Tlim, suggesting that incremental load tests may more accurately discriminate a true training response.

Inspiratory muscle training

The magnitude of any physiological training response appears to be related to the magnitude of the training load (6, 10, 26). For this reason the subjects in this study underwent high-intensity, interval-based, inspiratory muscle training (H-IMT). Such a program includes frequent rest periods, permitting relief of dyspnea and local muscle fatigue and thereby allowing greater loads to be achieved than would be possible with a continuous-based training protocol (16). We adopted such a protocol in order to optimise any potential improvement in inspiratory muscle endurance.

The magnitude of the increase in Pthmax and Tlim was greater than reported in most previous studies of IMT in COPD (7, 9, 12, 14, 15). This most likely reflects the characteristics of the H-IMT program as high-intensity, interval-based, fully supervised whole-body exercise training performed over brief periods has been demonstrated to induce substantial increases in the endurance capacity of healthy subjects (27). Indeed, the recent demonstration in COPD subjects of an increase in the proportion of Type I fibers in the external intercostal muscles in response to a five week, interval-based IMT program performed at intensities considerably less than achieved in the current study (40 – 50% of PImax) (14) reflects the rapidity of structural adaptations likely to occur with such programs.

In contrast, S-IMT was performed at 10% of the baseline PImax and was unchanged over the training period. This load was chosen to facilitate blinding of the subjects (28) without improving inspiratory muscle function (9). By maximizing the training load in one group (H-IMT) and selecting a load incapable of inducing physiological change in the other (S-IMT), the likelihood of inducing a detectable difference in inspiratory muscle function between groups following the training period was optimised.

Incremental load test vs. constant load test

The eight-week program of H-IMT resulted in significant increases in Pthmax and Tlim relative to measures obtained at baseline and to any change seen in the S-IMT group. These findings demonstrate that, with the sample size used in the present study (n = 33), both the incremental and constant load tests were able to discriminate between individuals who had participated in H-IMT from those who underwent S-IMT.

The 95% confidence intervals and effect sizes for difference in magnitude of change in Pthmax and Tlim were calculated in order to quantify and compare the capacity of the incremental and constant load tests to discriminate between the H-IMT and S-IMT groups. The effect size for Pthmax (0.68) is considered medium to large and the effect size for Tlim (0.44) is considered small to medium (29). The large variability in the magnitude of change observed in Tlim following S-IMT (see Figure 3) is likely to have contributed to the smaller effect size. This finding is consistent with that of an earlier study which demonstrated greater variability in the performance of a constant load test compared with an incremental load test when both were performed on multiple occasions (30).

The capacity of each measure to discriminate between individuals who had participated in H-IMT from those who underwent S-IMT was also evaluated in terms of their sensitivity and specificity. These analyses showed that the change in measures obtained from both the incremental and constant load tests were equally sensitive in correctly identifying individuals who had undergone H-IMT. However Tlim was less specific in its capacity to distinguish individuals who had undergone H-IMT than Pthmax. This finding was reflected in the significantly greater area under the ROC curve for the change in Pthmax than the change in Tlim. It is likely that the large number of subjects achieving a Tlim of 15 minutes contributed to the reduced specificity and smaller area under the ROC for the constant load test. An alternative constant load test protocol designed to limit the number of subjects able achieve a Tlim of 15 minutes may have reduced the difference in the areas under the ROC curves between these two tests.

Limitations

A potential limitation in applying the constant load test to determine inspiratory muscle endurance was the requirement to terminate the test at 15 minutes. By manipulating the inspiratory load, task failure (Tlim) was able to be elicited in less than 15 minutes in all subjects during the baseline test. However, following training, application of the same inspiratory load resulted in the test being terminated at 15 minutes in 75% and 47% of subjects in the H-IMT and S-IMT groups, respectively. Thus, adjusting the load to elicit task failure within 5 to 10 minutes in the baseline constant load test resulted in failure to obtain a finite post-training measurement of endurance in a large number of subjects. While increasing the initial load may have reduced the number of subjects who achieved 15 minutes during the post-training test, doing so may well have decreased the initial Tlim in many individuals to less than 5 minutes, reducing its value as an endurance measure (19). Conversely, had subjects been permitted to continue past 15 minutes, the magnitude of change in Tlim between the two groups may have increased. However a test of 20 or 30 minutes in duration, or longer, is likely to be of limited practical use in the clinical setting.

Another potential limitation of the study was the capacity of the subjects to adopt their own breathing pattern during the incremental and constant load tests. It is possible that the observed increases in Pthmax and Tlim reflect not only improved inspiratory muscle function, but also any training-related changes in breathing pattern. Indeed, previous studies have demonstrated that performance during assessments of inspiratory muscle endurance is influenced not only by the inspiratory load imposed (31) but also by the breathing pattern adopted (22, 32).

It was notable that, following training, the H-IMT group increased mean and peak inspiratory flows during both the incremental and constant loading tests whereas the S-IMT group did not. Such a strategy is an efficient way to deal with inspiratory threshold loads, where once the threshold pressure is exceeded flow changes independently of pressure (20, 33). While these changes reflect greater muscle power output with increased velocity of muscle shortening during the inspiratory phase of the respiratory cycle (10, 34), the accompanying decrease in inspiratory duty cycle (and respiratory frequency) resulted in a decrease in the breath-by-breath load on the inspiratory muscles (*i.e.*, PTI) in the case of the constant loading test, with no change in the case of the incremental loading test. These changes and their effects on inspiratory muscle work are consistent with a study by Hart et al (5) who showed an inverse linear relationship between inspiratory duty cycle and time to exhaustion while breathing against a constant inspiratory load. Hence, while an eight-week program of H-IMT increased inspiratory muscle strength, power and velocity of shortening, the changes in breathing pattern adopted during the constant and incremental load tests served to minimize the overall load on the inspiratory muscles. Thus an improvement in Pthmax and Tlim may not necessarily represent an improvement in muscle endurance when breathing pattern is unconstrained. While it is possible that the training-related increases in muscle strength and power were necessary preconditions for these changes in breathing pattern these findings indicate that in order to be able to wholly attribute changes in Pthmax and Tlim to improvements in inspiratory muscle function, breathing pattern during these tests should be controlled.

Conclusion and recommendations

Inspiratory muscle endurance measured either by an incremental load test (Pthmax) or a constant load test (Tlim) increased significantly following eight-weeks of H-IMT. Such changes are clinically relevant as they are accompanied by a meaningful reduction in symptoms (dyspnea during activities of daily living and fatigue) and a significant increase in six-minute walk distance (16). The increases in both Pthmax and Tlim were greater following H-IMT than following S-IMT. The effect size and specificity of the increase in Pthmax was substantially greater than those calculated for Tlim. This was due, at least in part, to the substantial variability observed in the magnitude of change in Tlim following S-IMT. While these findings favor incremental loading tests over constant loading tests of inspiratory muscle endurance, it is possible that they are applicable only to tests of inspiratory muscle endurance in which individuals are free to adopt their own breathing pattern.

Marked changes in the breathing pattern adopted during each test were observed, particularly in the group who underwent H-IMT. The magnitude of the effect of changes in breathing pattern was such that the overall load on the inspiratory muscles was either unchanged or decreased, even though H-IMT resulted in increased inspiratory muscle strength, power and velocity of shortening. These data suggest that in order to accurately interpret improved performance during incremental or constant load tests as an increase in respiratory muscle endurance, protocols should be adopted in which breathing pattern is controlled.

Acknowledgements

The authors gratefully acknowledge Nola Cecins, Dr Daniel Green, Dr Martin Phillips, Dr Tom van der Touw, Gavin Sturdy, Dr Ritu Gupta, Dr Eli Gabbay, Peta Winship, the Department of Respiratory Medicine and the Physiotherapy Department of Royal Perth Hospital and Sir Charles Gairdner Hospital for their assistance.

Table 1: Breathing pattern variables collected during the pre- and post-training incremental load tests

	H-IMT (n = 16)		S-IMT (n = 17)	
	at Pthmax (pre-training)	*at Pthmax (post-training)*	*at Pthmax (pre-training)*	*at Pthmax (post-training)*
V_E (L/min)	10.8 ± 3.0	11.2 ± 3.5	12.4 ± 3.7	11.4 ± 3.5
V_T (L)	0.59 ± 0.27	0.69 ± 0.26	0.61 ± 0.39	0.69 ± 0.51
RR (bpm)	20 ± 6*	17 ± 6	22.8 ± 6.6	20.1 ± 7.5
Ti/Ttot	0.48 ± 0.07*	0.36 ± 0.09†	0.49 ± 0.09*	0.44 ± 0.08
Ti (sec)	1.6 ± 0.5	1.3 ± 0.3	1.4 ± 0.6	1.5 ± 0.7
Te (sec)	1.7 ± 0.7*	2.6 ± 1.5	1.5 ± 0.9*	2.1 ± 1.7
V_T/Ti (L/sec)	0.4 ± 0.1*	0.5 ± 0.2†	0.4 ± 0.1	0.4 ± 0.1
Peak inspiratory flow (L/sec)	1.0 ± 0.4*	1.6 ± 0.4†	1.2 ± 0.3	1.3 ± 0.4
Pthmax (-cmH_2O)	38.5 ± 9.7*	60.1 ± 18.0†	40.5 ± 18.3	42.8 ± 18.6
Pth/PImax	0.62 ± 0.13*	0.75 ± 0.15†	0.61 ± 0.20	0.58 ± 0.17
PTI	0.30 ± 0.08	0.26 ± 0.07	0.31 ± 0.13*	0.26 ± 0.09

Table 2: Breathing pattern variables collected during the pre- and post-training constant load tests

	H-IMT (n = 16)		S-IMT (n = 17)	
	at Tlim (pre-training)	*at Tlim (post-training)*	*at Tlim (pre-training)*	*at Tlim (post-training)*
V_E (L/min)	14.5 ± 3.1	13.6 ± 3.5	15.5 ± 5.0*	13.6 ± 4.5
V_T (L)	0.78 ± 0.29*	0.90 ± 0.27	0.81 ± 0.46	0.89 ± 0.65
RR (bpm)	20 ± 6*	16 ± 6	22 ± 8*	19 ± 8
Ti/Ttot	0.48 ± 0.08*	0.35 ± 0.10†	0.46 ± 0.12*	0.41 ± 0.13
Ti (sec)	1.6 ± 0.5	1.4 ± 0.3	1.4 ± 0.5	1.6 ± 0.9
Te (sec)	1.8 ± 0.8*	2.9 ± 1.4	1.9 ± 1.4*	2.7 ± 2.7
V_T/Ti (L/sec)	0.51 ± 0.16*	0.67 ± 0.23†	0.58 ± 0.21	0.58 ± 0.21
Peak inspiratory flow (L/sec)	1.2 ± 0.3*	1.6 ± 0.6†	1.4 ± 0.5	1.4 ± 0.6
Pth (-cmH_2O)	31.2 ± 9.4*	33.6 ± 10.3†	32.2 ± 16.4	32.2 ± 15.9
Pth/PImax	0.52 ± 0.17*	0.43 ± 0.14	0.48 ± 0.17*	0.44 ± 0.15
PTI	0.25 ± 0.10*	0.15 ± 0.07†	0.23 ± 0.11*	0.19 ± 0.09

Legend for Table 1 and 2:
Pthmax: maximum inspiratory pressure achieved during the incremental load test; Tlim: final one minute of the constant load test; V_T: inspiratory tidal volume; RR: respiratory rate; V_E: minute ventilation; Ti: inspiratory time; Te: expiratory time; Ti/Ttot: inspiratory duty cycle; V_T/Ti: mean inspiratory flow; Pth: inspiratory mouth pressure; Pth/PImax: inspiratory mouth pressure expressed as a proportion of the maximum inspiratory pressure achieved during the same assessment session; bpm: breaths per minute; PTI: pressure-time index; *: $p < 0.05$ vs. post-training measurements; † : $p < 0.05$ for magnitude of change following H-IMT vs. magnitude of change following S-IMT.

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Figure 1a

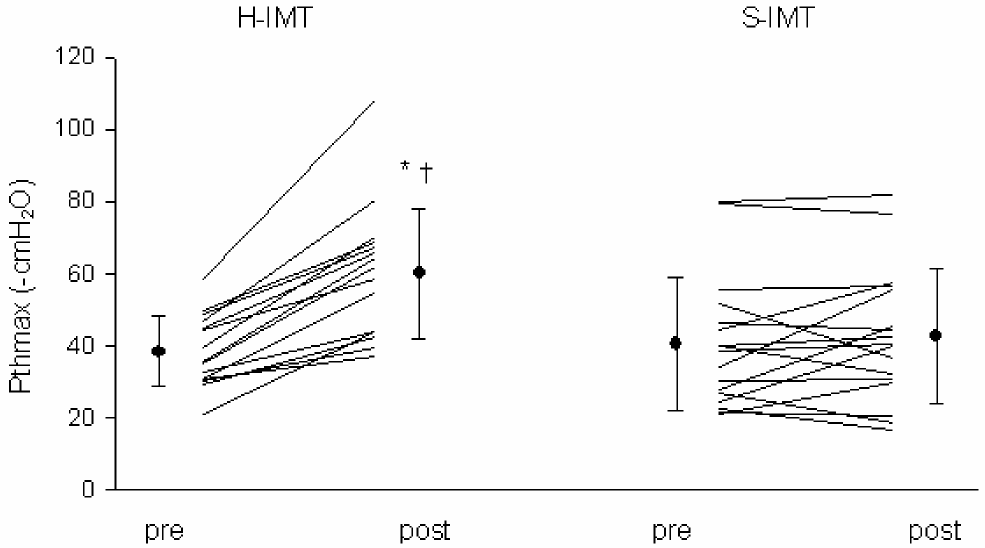

Figure 1a: Difference in the maximum threshold pressure (Pthmax) between the baseline (pre) and post-training (post) incremental load tests for each subject in the H-IMT and S-IMT groups. Group mean and SD shown. *: $p < 0.05$ vs. pre; †: $p < 0.05$ vs. change following S-IMT

Figure 1b

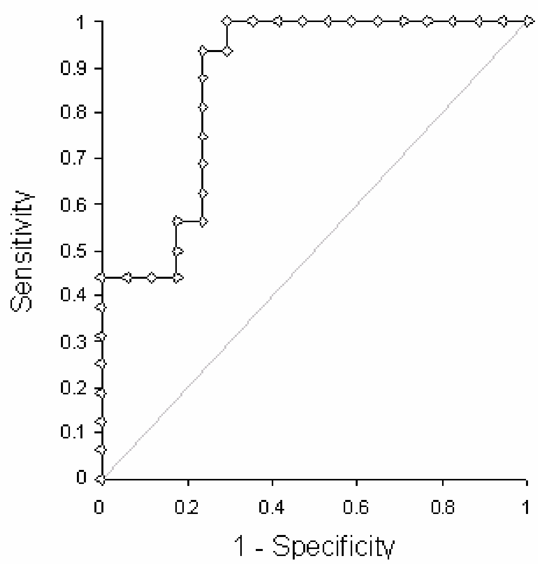

Figure 1b: Receiver Operating Characteristic curve for Pthmax

Figure 2a

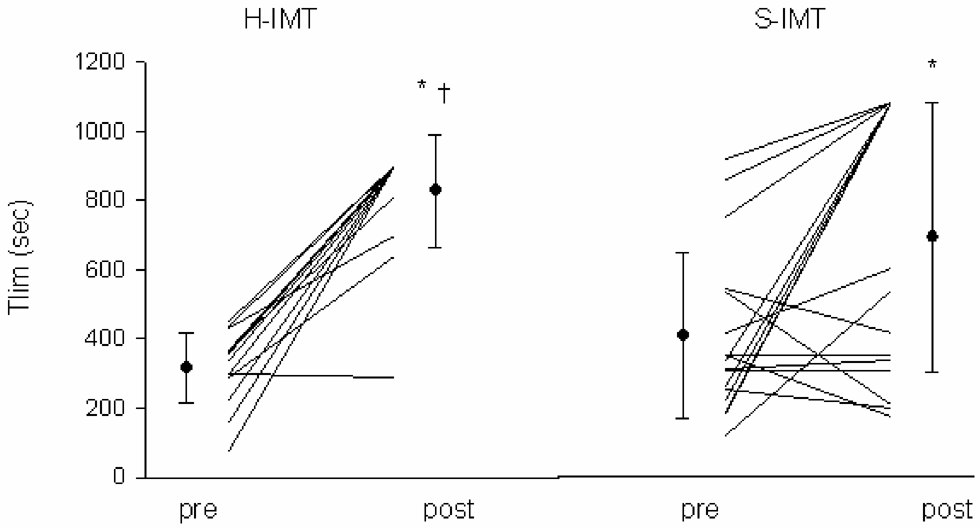

Figure 2a: Difference in the time to exhaustion (Tlim) between the baseline (pre) and post-training (post) constant load tests for each subject in the H-IMT and S-IMT groups. Group mean and SD shown. *: $p < 0.05$ vs. pre; †: $p < 0.05$ vs. change following S-IMT

Figure 2b

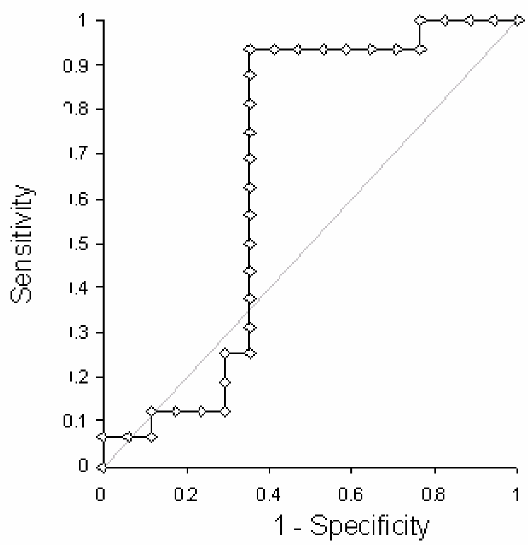

Figure 2b: Receiver Operating Characteristic curve for Tlim

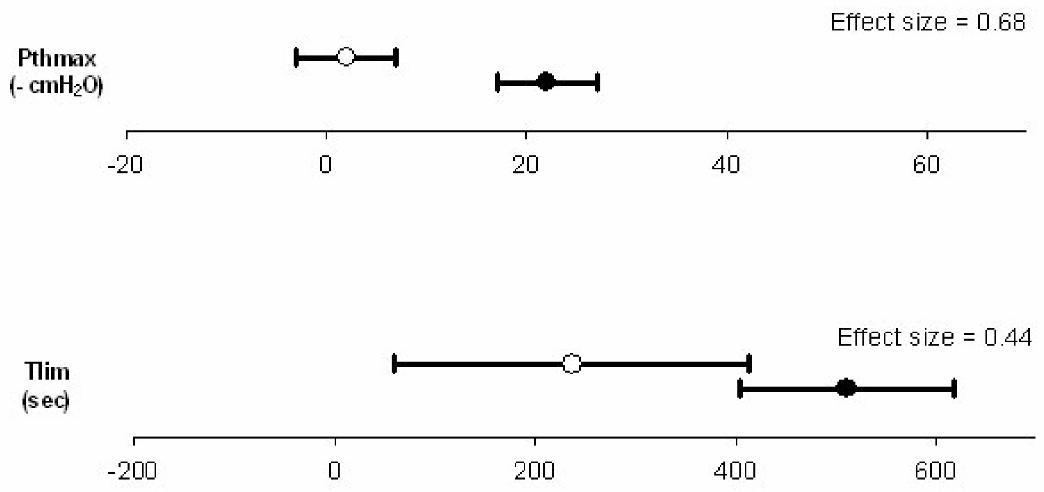

Figure 3. 95% confidence intervals with effect sizes for the baseline to post-training change in measurements of inspiratory muscle endurance; ●: H-IMT; ○: S-IMT; Pthmax: maximum threshold pressure achieved during the incremental load test; Tlim: time to exhaustion during the constant load test.