Expiratory muscle training and sensation of respiratory effort during exercise in normal subjects

Shunsuke Suzuki, Masamichi Sato, Takao Okubo

Abstract

Background - The sensation of respiratory effort may increase as expiratory muscles become fatigued during expiratory loading. A study was performed to determine whether expiratory muscle training (EMT) affects the sensation of respiratory effort during exercise in healthy subjects.

Methods - Six subjects performed EMT for 15 minutes twice daily for four weeks using a pressure threshold device; another six subjects served as a control group. The expiratory threshold was set at 30% of the individual's maximum expiratory mouth pressure (PEmax). The sensation of respiratory effort was evaluated during a progressive exercise test using the Borg scale.

Results - After EMT PEmax increased by 25% in the training group. The Borg score increased as exercise grade increased before and after EMT, but scores for each grade were lower after EMT. Minute ventilation during exercise decreased after EMT as did the breathing frequency during exercise, while the expiratory time increased. Although there was no difference in the relationship between Borg score and minute ventilation before or after EMT, the curve shifted to a lower Borg score after EMT. There were no changes in PEmax, Borg score, minute ventilation, or breathing pattern after the four week study period in the control group.

Conclusion - These findings suggest that EMT increases expiratory muscle strength and reduces the sensation of respiratory effort during exercise, presumably by reducing minute ventilation.

Keywords: expiratory muscle training, respiratory effort sensation, exercise, minute ventilation.

Methods

Twelve healthy volunteers (10 men, mean (SD) age 30.0 (5.5) years (range 24 to 44)) took part in the study. All were non-smokers with no history of chronic respiratory or circulatory disease. Subjects were randomly assigned to control (n = 6; 5 men) or training groups (n = 6; 5 men). Informed consent was obtained from each subject. The study was approved by the committee on human investigation of our institution.

On test days subjects were prohibited from drinking coffee or other caffeine-containing beverages. Spirometric measurements were performed using a dry seal spirometer (OST-80, Chest Co, Tokyo, Japan), and vital capacity.
(VC) and forced expiratory volume in one second (FEV₁) were measured. The maximal voluntary ventilation (MVV) was determined from maximal voluntary ventilation over a 15 second period. Lung volumes were measured using a body plethysmograph (Autobox 2800, Gould, Dayton, Ohio, USA).

MAXIMUM RESPIRATORY PRESSURE
Maximum static inspiratory and expiratory mouth pressures (Pimax and Pmemax) were measured according to the method of Black and Hyatt.16 Briefly, mouth pressure was measured using a differential pressure transducer (Validyne MP-45 ± 250 mm Hg, Northridge, California, USA). Pimax was determined from the maximal inspiration against a closed valve at functional residual capacity (FRC) and residual volume (RV). Pmemax was determined from the maximal expiration against a closed valve at FRC and total lung capacity (TLC) while subjects pressed their cheeks with their hands. They practised these pressure measurements two days before baseline measurements were obtained (control day) to reduce any learning effect. On test days Pimax and Pmemax were measured at least three times until a reproducible value was obtained and maximum values were reported.

RESPIRATORY EFFORT DURING EXERCISE
Respiratory effort during exercise was evaluated by a modified Borg scale.17 This scale consists of a series of integers from 0 to 10. The subject was told to estimate the effort required to produce each breath, but not shortness of breath or the effort of exercise. During exercise the Borg scale was kept in front of the subject who was asked to rate effort at one minute intervals.

EXERCISE TEST
A progressive exercise test was performed on a treadmill (Quinton Q50, Seattle, Washington, USA). Each subject breathed air through a two-way non-rebreathing valve (No. 2700, Hans Rudolph, Kansas City, Missouri, USA) so that concentrations of expired gas and ventilation could be measured. Expired gas was sampled and analysed breath by breath. Tidal volume (VT), breathing frequency, minute ventilation (V̇e), oxygen uptake (V̇O₂), output of carbon dioxide (V̇CO₂), and dead space/tidal volume ratio (V̇d/V̇t) were determined using the 2900 Energy Measurement System (Sensormedics, Anaheim, California, USA). Expiratory time (Te) was calculated from the flow signal. The V̇d/V̇t was determined using the Bohr equation. Arterial oxygen saturation was measured with a pulse oximeter (Biox 3740, Ohmeda, Boulder, Colorado, USA). An electrocardiogram was monitored throughout the experiment.

A modified Balke exercise protocol was used.16 The workload was increased by approximately 1 met (metabolic equivalent of resting O₂ uptake) at one minute intervals. At stage 1 the treadmill was kept at a constant speed of 2.0 mph and the grade at 0%. Beginning at stage 2, the grade was increased from 0% by 2.5% at one minute intervals - that is, one stage per minute – up to stage 10, and the speed was kept at a constant 3.3 mph. The exercise test was continued until the subject reached a state of exhaustion or stage 10 with a slope of 20%.

EXPLANATORY MUSCLE TRAINING (EMT)
Subjects in the training group trained with a threshold pressure breathing device (Threshold Inspiratory Muscle Trainer, Healthscan Products, Cedar Grove, New Jersey, USA) that uses a spring loaded poppet valve. We modified its spring to produce pressure loads ranging from 15 to 125 cm H₂O. This device is designed primarily for inspiratory muscle training. We modified the conventional method of using the device by asking the subjects to expire through the opposite side of the device. The threshold pressure used was equal to 30% of the individual's Pmemax at TLC before EMT and was kept constant throughout the four week training period. Subjects were instructed to expire air twice daily through the threshold device at their own breathing frequency and tidal volume for 15 minutes and to record their execution of EMT.

EXPERIMENTAL PROTOCOL
No other form of exercise training was started during the four week study, and all subjects maintained their usual habits during the study period. On day 1 spirometric parameters, lung volumes, Pimax, and Pmemax were determined to obtain baseline values. The sensation of respiratory effort was measured during the treadmill exercise test. After two weeks of EMT, Pimax and Pmemax were measured, and spirometric measurements and the exercise test were repeated. After four weeks of EMT spirometric measurements were again made, and lung volumes, maximum respiratory pressures, and the sensation of respiratory effort were determined during exercise.

DATA ANALYSIS
All values were reported as the mean (SD). Differences in respiratory muscle strength between groups were analysed by the unpaired t test.18 Spirometric values and respiratory muscle strength before and after EMT were analysed by the paired t test. The Borg score was analysed using Friedman's test. Ventilation parameters were analysed using two-way analysis of variance with repeated measures (ANOVA), followed by post hoc comparison using the Tukey's test. A p value of less than 0.05 was considered statistically significant.

Results
All subjects in the training group completed the study. Vital capacity, FEV₁, lung volumes, and MVV did not change over the four week
study period in either the control or the training group. $P_{\text{max}}$ at TLC and FRC and $P_{\text{max}}$ at FRC and RV were within normal limits in both groups. There were no differences in $P_{\text{max}}$ and $P_{\text{max}}$ before EMT between the two groups. In the training group, $P_{\text{max}}$ at TLC increased significantly compared with control day values at two weeks (average 20.0%) and four weeks (from 165(71) to 202(77) cm H$_2$O; average increase 25.4%) ($p<0.01$) (fig 1). $P_{\text{max}}$ at FRC increased by 20.2% after two weeks of EMT ($p<0.01$) and by 18.2% after four weeks (from 143(65) on the control day to 168(72) cm H$_2$O, $p<0.05$). Individual differences in $P_{\text{max}}$ did not change after EMT. $P_{\text{max}}$ did not change at RV or FRC. There were no significant changes in $P_{\text{max}}$ or $P_{\text{max}}$ at any lung volume in the control group.

All subjects completed the exercise test to stage 10 on both the control day and after four weeks, and consequently the exercise test was submaximal exercise. Before EMT the Borg score increased linearly with time in both groups ($r=0.96(0.05)$ and $0.97(0.04)$ for the control and training groups, respectively) (fig 2). On the control day there was no significant difference between the two groups in the Borg score at any stage of exercise. After EMT the Borg score was significantly lower than the control day at each exercise stage (fig 2, $p<0.01$). In the control group the Borg score did not change significantly at any exercise stage during the four week study period. The slope of the Borg score with time (or exercise stage) decreased from 0.63 (0.17) min$^{-1}$ to 0.43 (0.22) min$^{-1}$ at four weeks ($p<0.05$) in the training group, but did not change in the control group.

Minute ventilation ($V_{\text{E}}$) increased with exercise stage in both groups (fig 3). In the

![Figure 1](image1.png) Mean (SD) expiratory muscle strength before and after expiratory muscle strength training. In the training group, an increase in maximum expiratory muscle strength ($P_{\text{max}}$ at TLC) was observed at two and four weeks (both $p<0.01$). There was no change in the control group.

![Figure 2](image2.png) Relationship between Borg score and exercise stage in (A) control ($n=6$) and (B) training ($n=6$) groups on the control day (○, △) and after the four week study period (●, ▲). The Borg score in the training group decreased at four weeks but there was no change in Borg score in the control group. *$p<0.01$, compared with control day (Friedman's test). Values are mean (SD).

![Figure 3](image3.png) Minute ventilation ($V_{\text{E}}$) during exercise in (A) the control group ($n=6$) and (B) the training group ($n=6$) on the control day (○, △) and after the four week study period (●, ▲). After training the $V_{\text{E}}$ decreased ($p<0.05$, ANOVA) but there was no difference between control day and four week values in the control group. *$p<0.05$, ‡$p<0.02$, compared with control day (Tukey's test). Values are mean (SD).
Breathing effort and respiratory training

In the training group EMT shifted the position of the curve toward a lower Borg score without any change in relationship of Borg score to V̇O₂, but in the control group the position of the curve did not change.

Discussion

We have shown that a four week period of EMT using a pressure threshold device increased the strength of the expiratory muscles and reduced the sensation of respiratory effort during exercise in normal subjects. The relation of the sensation of respiratory effort to V̇E was not changed by EMT, although the sensation of respiratory effort and V̇E decreased after EMT at each exercise stage, suggesting that EMT diminishes the sensation of respiratory effort during exercise by reducing V̇E.

EXPIRATORY MUSCLE TRAINING (EMT)

Leith and Bradley demonstrated that ventilatory muscle training increased ventilatory muscle strength.8 Inspiratory muscle training has been attempted in patients with COPD,9 but no previous study has investigated the effect of EMT using expiratory loading. In the present study EMT was performed using pressure threshold loading at 30% of the subject’s Pmax at TLC. All subjects in the training group showed an increase in Pmax after EMT. We expected that an increase of this magnitude in expiratory muscle strength would allow us to examine the effects of strengthening of respiratory muscles on the sensation of respiratory effort.

SENSATION OF RESPIRATORY EFFORT DURING EXERCISE

While patients with COPD experience breathlessness more intensely during inspiration,20 the sensation generated during exercise in normal subjects is more intense during expiration.21 During exercise expiratory muscles, especially the abdominal muscles, contribute substantially to increased ventilation.14,15 although the work of inspiratory muscles also increases. The sensation generated during exercise is closely related to factors that contribute to respiratory muscle effort such as increased ventilation. Minute ventilation represents the overall output of the respiratory system.22 During exercise consistently linear relationships have been observed between V̇E and the intensity of breathing-related sensation in normal subjects.22 23 In the present study the relationship between Borg score and V̇E did not change over four weeks in either study group, suggesting that V̇E may be one of the most useful parameters for evaluating the sensation of respiratory effort during treadmill exercise.

EFFECT OF EMT ON THE SENSATION OF RESPIRATORY EFFORT

We expected that an enhancement of expiratory muscle strength would reduce the fraction of expiratory muscle force needed for a given
amount of work, which would reduce the magnitude of the central motor command to expiratory muscles, thereby reducing the sensation of respiratory effort. If a decrease in the fraction of expiratory muscle force during expiration directly affected the sensation of respiratory effort, the relationship of Borg score to V̇E would have been changed by EMT. In the present study the relationship of Borg score to V̇E was unchanged by EMT, although expiratory muscle strength was increased by EMT. We therefore concluded that an increase in expiratory strength may not directly affect the sensation of respiratory effort during exercise.

Abdominal muscles, which are major expiratory muscles, were trained by EMT in the subjects studied. In addition to contributing to expiration, abdominal muscles work to stabilise the body position during exercise. It is possible, therefore, that EMT may reduce the V̇O₂ of the abdominal muscles for both these functions during exercise. Also, physical training is known to reduce both V̇E and V̇O₂ of whole body. A reduction in V̇E may reduce the sensation of respiratory effort at each exercise stage.

In the present study EMT altered breathing patterns, such as breathing frequency, Ṫe and V̇t. The Te decreased with increasing exercise stage in the control group but increased after EMT in the training group. Burdon and co-workers showed that, during exercise, the breathing frequency increased; the Te showed a greater decrease than the inspiratory time. In our study EMT may have increased Te during breathing through expiratory loading to reduce the difficulty of breathing because subjects were asked to perform EMT using their own breathing patterns. Belman and co-workers showed that a change in breathing pattern improved ventilatory muscular performance. Thus, our subjects may have learned a breathing strategy that lengthened Te in the presence of increased work of breathing. A decrease in breathing frequency associated with lengthened Te may reduce V̇E. However, EMT altered the relationship of Borg score to Te and the breathing frequency. These findings suggest that the EMT-induced change in breathing pattern may not directly affect the sensation of respiratory effort during exercise.

Although EMT produced no change in V̇E/ V̇t, it reduced the equivalent for oxygen (V̇E/ V̇O₂), suggesting that it enhanced the effectiveness of ventilation during exercise. Increases in Te and Pemax may permit the expiratory muscles to play a major part in expiration during exercise, lengthening the diaphragm and improving the length-tension characteristics for generation of pressure required to produce a subsequent inspiration. Thus, EMT may improve diaphragmatic function, reducing the sensation of respiratory effort.

In conclusion, expiratory muscle training reduces the sensation of respiratory effort during exercise in normal subjects, although the exact mechanism of this effect is unclear. Before this expiratory muscle training programme can be applied to patients with respiratory disease, the effect of EMT on breathlessness should be investigated in a modified programme for patients.