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RERPORT

Effects of Inspiratory and Expiratory Muscle Training in Normal Subjects

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Abstract. The present study aimed to clarify the effects of inspiratory muscle training (IMT) and expiratory muscle training (EMT) on ventilatory muscle strength, pulmonary function and responses during exercise testing. Young healthy women were randomly assigned to 3 groups: IMT (n=16); EMT (n=16); or untrained normal controls (NC, n=8). Subjects in the IMT and EMT groups trained for 15 minutes twice daily over 2 weeks at loads of 30% maximal inspiratory and expiratory muscle strength, respectively. Ventilatory muscle strength (maximal inspiratory and expiratory muscle strength; PI_{max} and PE_{max}, respectively), pulmonary function and progressive exercise testing was performed. Both PI_{max} and PE_{max} increased in the IMT group, and PE_{max} increased in the EMT group. Neither trained group demonstrated any change in pulmonary function or peak values during exercise testing. In the IMT group, exercise-induced increases in heart rate, oxygen uptake (VO_2/kg) and rating of perceived exertion (RPE) decreased with training, as did increases in VO_2/kg and RPE in the EMT group. The increased ventilatory muscle strength in both IMT and EMT groups might improve ventilatory efficacy during exercise, and increased inspiratory muscle strength might facilitate oxygen delivery through improved circulatory responses.

Key words: inspiratory muscle training, expiratory muscle training, ventilatory muscle strength, exercise tolerance, dyspnea

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Ventilatory muscle training (VMT) represents one component of respiratory rehabilitation[1)2)]. The rationale behind VMT is that enhancing respiratory muscle function can potentially reduce the severity of breathlessness and improve exercise tolerance[1)]. From evidence-based guidelines produced by a joint panel of the American College of Chest Physicians (ACCP) and the American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR)[1)], VMT may be considered for individual patients with chronic obstructive pulmonary disease (COPD) who remain symptomatic despite optimal therapy, although scientific evidence does not support routine use of VMT in pulmonary rehabilitation. After a meta-analysis of VMT by Smith and coworkers[3)], whose analysis was referred to in the evidence-based guidelines, Lötters and colleagues[4)] concluded that VMT significantly increases respiratory muscle strength and respiratory muscle endurance, decreases sensations of dyspnea at rest and during exercise, and tends to improve functional exercise capacity. Conversely, Salman and colleagues[5)] undertook meta-analysis, and concluded that VMT did not improve walking distance or sensation of dyspnea.

All the above studies of VMT referred to inspiratory muscle training (IMT). However, respiratory muscle fatigue is generated in both expiratory and inspiratory muscles[6)], and experiments have attempted to verify the effects of expiratory muscle training (EMT)[7)8)]. Suzuki *et al.*[7)] reported that EMT increased expiratory muscle strength and decreased sensation of respiratory effort during exercise, and Akiyoshi *et al.*[8)] indicated that EMT increased both expiratory and inspiratory muscle strength.

To clarify the effects of EMT and IMT on ventilatory muscle strength measured by mouth pressure, pulmonary function and responses during exercise testing, both

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Table 1. Characteristics and peak values during exercise testing for each group at baseline

	IMT group (n=16)	EMT group (n=16)	NC group (n=8)	ANOVA (significance)
Age (years)	18.8 ± 0.7	19.3 ± 1.0	20.4 ± 2.3	N.S.
BMI (kg/m^2)	20.5 ± 1.4	22.7 ± 3.0	21.5 ± 2.8	N.S.
PI_{max} (cmH_2O)	68.6 ± 19.8	75.4 ± 18.6	76.1 ± 16.0	N.S.
PE_{max} (cmH_2O)	68.6 ± 21.2	76.6 ± 18.6	72.8 ± 15.6	N.S.
VC (*l*)	3.2 ± 0.4	3.4 ± 0.4	3.3 ± 0.4	N.S.
$FEV_{1.0}$ (*l*)	2.8 ± 0.5	3.0 ± 0.3	2.9 ± 0.3	N.S.
Peak VE (*l*/min)	37.3 ± 6.7	43.1 ± 8.9	38.9 ± 2.4	N.S.
Peak TV (*l*)	1.3 ± 0.2	1.4 ± 0.3	1.3 ± 0.3	N.S.
Peak RR (breaths/min)	29.3 ± 4.6	31.2 ± 4.5	31.0 ± 5.1	N.S.
Peak VO_2/kg (ml/kg/min)	25.5 ± 3.7	26.4 ± 4.1	25.2 ± 3.4	N.S.
Peak RPE	6.8 ± 1.9	7.6 ± 2.4	6.3 ± 2.1	N.S.

mean ± SD, IMT; inspiratory muscle training, EMT; expiratory muscle training, NC; normal control, BMI; body mass index, PI_{max}; maximal inspiratory pressure, PE_{max}; maximal expiratory pressure, VC; vital capacity, $FEV_{1.0}$; forced expiratory volume in one second, VE; minute ventilation, TV; tidal volume, RR; respiratory rate, VO_2/kg; oxygen uptake/body weight, RPE; rating of perceived exertion, N.S.; not significant.

methods were examined in young healthy subjects.

Methods

Subjects

A total of 40 young healthy women participated in this study. Mean (± SD) age, height, weight and body mass index (BMI) were 19.3 ± 1.4 years, 158.7 ± 4.6 cm, 54.5 ± 7.6 kg and 21.6 ± 2.6 kg/m^2 respectively. Subjects were randomly assigned to the IMT group (n=16), EMT group (n=16) or untrained normal control (NC) group (n=8). Informed consent was obtained from each subject. Table 1 presents characteristics and peak values during exercise testing for each group before the trial. No significant difference in age, physique, pulmonary function or peak values during exercise testing were observed among the three groups.

Device for VMT

Subjects in the IMT group used Threshold-IMT (HealthScan, New Jersey, USA) (Fig. 1A). This device comprises a plastic tube incorporating a spring-loaded valve occluding the inspiratory orifice at one end and a mouthpiece at the other end. When the subject breathes through the mouthpiece, they must generate sufficient vacuum pressure to open the spring-loaded valve and initiate airflow; exhalation is unloaded. The amount of resistance can be adjusted by varying the compression of the spring-loaded valve. Adjustment from 7 cmH_2O to 41 cmH_2O is possible.

Subjects in the EMT group used Souffle (Kayaku, Tokyo, Japan) (Fig. 1B). This device comprises a central container with a dead space of 400 or 800 ml, a mouthpiece and a metal positive end-expiratory pressure (PEEP) plate elastic-loaded valve occluding the expiratory orifice. When subjects exhale through the mouthpiece they must generate positive pressure equivalent to 5, 10 or 15 cmH_2O to open the PEEP plate elastic-loaded valve. As subjects re-inhale a portion of the expired gas in the container during inhalation, ventilation is promoted. The present study utilized the 800-ml container, adjusted to an appropriate pressure by modifying load pressure and measuring inner pressure of the Souffle during expiration using a manometer (Bird; 3M, Tokyo, Japan).

Experimental protocol

IMT subjects trained using a Threshold-IMT at 30% of maximal inspiratory muscle strength for 15 minutes twice daily. EMT subjects trained using Souffle at 30% of maximal expiratory muscle strength for 15 minutes twice daily. Training was continued for two weeks, and no training was undertaken by the NC group. Subjects in the two training groups predominantly performed under supervision by an examiner, and trained at home on holidays. After the trial period, a record of performance was made to indicate state of training.

Measurement of ventilatory muscle strength, pulmonary function testing (using spirometry) and progressive exercise testing were undertaken before and after training. Ventilatory muscle strength was measured using Vitalopower KH-101 equipment (Chest, Tokyo, Japan), and mouth pressure was considered as ventilatory muscle strength. According to the methods of Black and Hyatt[9], subjects utilized a nose-clip and mouthpiece, and

A. Threshold-IMT B. Souffle

Fig 1. Training devices.

maintained inspiratory and expiratory effort against a closed valve at least 1 second from residual volume (RV) and total lung capacity (TLC), respectively. In addition, both efforts were measured at functional residual capacity (FRC). All efforts were repeated three times, with peak values recorded as maximal inspiratory and expiratory muscle strength (PI_{max} and PE_{max}, respectively). Pulmonary function testing was performed using an Autospiro AS-300 electrical spirometer (Minato Medical Science, Osaka, Japan), using vital capacity (VC) and forced expiratory volume in one second ($FEV_{1.0}$). Exercise tolerance testing involved a progressive walking exercise test on a treadmill (Rehabilitation Tread Mill; BIODEX, New York, USA). A modification of the 3MPH protocol by Balk[10] was selected for the exercise testing protocol. This protocol was up to stage 7, with slope increasing every 2 minutes from 0% to 2%, 5%, 7%, 10%, 12% and 15% at a steady speed of 3 miles/hour after a 3-minute warm-up at 2 miles/hour. Subjects lay quietly on a platform for at least 20 minutes prior to exercise testing. The exercise test was performed after fitting a transmitter for electrocardiography (Life Scope 8; Nihon Kohden, Tokyo, Japan) and mask for an expiratory gas analyzer (Metabolic Measurement System 2900c; Sensor Medics, California, USA). Baseline data were measured in the standing position on the treadmill. Target heart rate was considered (220 – age) × 85%, and testing was ceased when target heart rate was reached. The air conditioner was set at 23°C, so the environmental temperature in the experiment room could be kept relatively constant.

Statistical analysis

All values were reported as mean ± SD. For ventilatory muscle strength (PI_{max} and PE_{max}) and pulmonary function (VC and $FEV_{1.0}$), pre- and post-training comparisons were analyzed using paired t-tests. Differences in changes with training between groups were analyzed using two-way repeated measures analysis of variance (ANOVA). Heart rate (HR), minute ventilation (VE), tidal volume (TV), respiratory rate (RR), oxygen uptake/body weight (VO_2/kg) and rating of perceived exertion (RPE) using the Borg score[11] were selected as parameters of exercise testing. For these parameters, comparisons of peak values between pre- and post-training were analyzed using paired t-tests, and differences in exercise-induced increases between pre- and post-training within each group were analyzed using two-way repeated measures ANOVA.

Results

The trained state in the training groups and the lifestyle in all subjects

Based on training state records, while of 28 times in the trial period, subjects were performing training 26.6 times on the average (range ; 24–28 times) in IMT group, and 27.1 times on the average (range ; 25–28 times) in EMT group. Those who have a movement custom from the investigation in question paper were one competition level and two recreation levels. The number of those with a smoking custom was eight. All subjects were reported to have been changeless to which lifestyle during the trial.

Changes in ventilatory muscle strength

Changes in ventilatory muscle strength with training are shown Table 2. In the NC group, neither PI_{max} nor PE_{max} changed over the two weeks. In the IMT group, PI_{max} differed significantly compared to that in the NC group (df 1, F=10.844, $p<0.01$), and had increased significantly from

Table 2. Change of ventilatiory muscle strength for ventilation muscle training

	IMT group (n=16)	EMT group (n=16)	NC group (n=8)	ANOVA (interaction)
PI_{max} (cmH_2O)				
Pre	68.6 ± 19.8	75.4 ± 18.6	76.1 ± 16.0	
Post	79.7 ± 20.4	81.4 ± 17.9	78.0 ± 19.6	$p<0.01$
t test	$p<0.01$	N.S.	N.S.	
PE_{max} (cmH_2O)				
Pre	68.6 ± 21.2	76.6 ± 18.6	72.8 ± 15.6	
Post	73.6 ± 22.2	84.5 ± 22.1	76.9 ± 11.4	N.S.
t test	$p<0.05$	$p<0.05$	N.S.	

mean ± SD, IMT; inspiratory muscle training, EMT; expiratory muscle training, NC; normal control, PI_{max}; maximal inspiratory muscle strength, PE_{max}; maximal expiratory muscle strength, N.S.; not significant.

Table 3. Change of pulmonary function for ventilation muscle training

	IMT group (n=16)	EMT group (n=16)	NC group (n=8)	ANOVA (interaction)
VC (*l*)				
Pre	3.2 ± 0.4	3.4 ± 0.4	3.3 ± 0.4	
Post	3.2 ± 0.4	3.4 ± 0.3	3.2 ± 0.4	N.S.
t test	N.S.	N.S.	N.S.	
$FEV_{1.0}$ (*l*)				
Pre	2.8 ± 0.5	3.0 ± 0.3	2.9 ± 0.3	
Post	2.9 ± 0.5	3.1 ± 0.3	2.9 ± 0.3	N.S.
t test	N.S.	N.S.	N.S.	

mean ± SD, IMT; inspiratory muscle training, EMT; expiratory muscle training, NC; normal control, VC; vital capacity, $FEV_{1.0}$; forced expiratory volume in one second, N.S.; not significant.

68.6 ± 19.8 cmH_2O to 79.7 ± 20.4 cmH_2O ($p<0.01$). PE_{max} in the IMT group increased significantly from 68.6 ± 21.2 cmH_2O to 73.6 ± 22.2 cmH_2O ($p<0.05$). In the EMT group, PE_{max} increased significantly from 76.6 ± 18.6 cmH_2O to 84.5 ± 22.1 cmH_2O ($p<0.05$), whereas no changes in PE_{max} were observed compared to the NC group. PI_{max} was unchanged in the EMT group.

Changes in pulmonary function

Changes in pulmonary function with training are shown in Table 3. In the NC group, changes were observed in neither VC (pre; 3.3 ± 0.4 *l,* post; 3.2 ± 0.4 *l*) nor $FEV_{1.0}$ (pre; 2.9 ± 0.3 *l,* post; 2.9 ± 0.3 *l*) over the training period. In both trained groups, no changes in pulmonary function were identified compared to the NC group and pre- and post-training.

Changes in peak values during exercise testing

In the NC group, peak values during progressive exercise testing were unchanged for all parameters: VE (pre; 38.9 ± 2.4 *l,* post; 39.5 ± 6.8 *l*); RR (pre; 31.0 ± 5.1 breaths/min, post; 29.8 ± 3.2 breaths/min); VO_2/kg (pre; 25.2 ± 3.4 ml/kg/min, post; 24.5 ± 5.6 ml/kg/min); and RPE (pre; 6.3 ± 2.1, post; 6.4 ± 2.7). In both trained groups, no changes in peak values during exercise testing were observed compared to the NC group and pre- and post-training (Table 4).

Changes in exercise-induced increases for parameters during exercise testing

Changes in exercise-induced increases for each parameter during progressive exercise testing are shown in Figs. 2–4. Since all subjects could reach stage 4, data up to this stage was analyzed. In the IMT group, magnitude of increases in HR decreased from pre- to post-training (df 5, F=2.503, $p<0.05$). In the other groups, no change in HR increases was identified (Fig. 2). Increases in ventilatory parameters (VE, RR and TV) during exercise were

Table 4. Change of peak values during exercise testing for ventilation muscle training

	IMT group (n=16)	EMT group (n=16)	NC group (n=8)	ANOVA (interaction)
Peak VE (*l*)				
Pre	37.3 ± 6.7	43.1 ± 8.9	38.9 ± 2.4	
Post	39.2 ± 5.8	44.8 ± 7.0	39.5 ± 6.8	N.S.
t test	N.S.	N.S.	N.S.	
Peak TV (*l*)				
Pre	1.3 ± 0.2	1.4 ± 0.3	1.3 ± 0.3	
Post	1.4 ± 0.1	1.5 ± 0.3	1.3 ± 0.3	N.S.
t test	N.S.	N.S.	N.S.	
Peak RR (breaths/min)				
Pre	29.3 ± 4.6	31.2 ± 4.5	31.0 ± 5.1	
Post	28.9 ± 4.3	30.8 ± 6.0	29.8 ± 3.2	N.S.
t test	N.S.	N.S.	N.S.	
Peak VO_2/kg (ml/kg/min)				
Pre	25.5 ± 3.7	26.4 ± 4.1	25.2 ± 3.4	
Post	25.9 ± 4.2	27.1 ± 3.2	24.5 ± 5.6	N.S.
t test	N.S.	N.S.	N.S.	
Peak RPE				
Pre	6.8 ± 1.9	7.6 ± 2.4	6.3 ± 2.1	
Post	6.1 ± 2.3	6.7 ± 2.0	6.4 ± 2.7	N.S.
t test	N.S.	N.S.	N.S.	

mean ± SD, IMT; inspiratory muscle training, EMT; expiratory muscle training, NC; normal control, VE; minute ventilation, TV; tidal volume, RR; respiratory rate, VO_2/kg; oxygen uptake/body weight, RPE; rating of perceived exertion, N.S.; not significant.

unchanged by training. In the IMT group, the magnitude of exercise-induced increases in VO_2/kg decreased from pre- to post-training (df 5, F=2.693, $p<0.05$). In the EMT group, VO_2/kg was lower at all stages in post-training compared with pre-training (df 1, F=5.584, $p<0.05$). In the NC group, no changes were identified (Fig. 3). Transitions of RPE decreased in both the IMT and EMT groups (df 1, F=4.201, $p<0.05$ and df 1, F=7.527, $p<0.05$, respectively) (Fig. 4).

Discussion

Both training methods were found to strengthen ventilatory muscles. In the IMT group, in which both inspiratory and expiratory muscles were strengthened, HR, VO_2/kg and RPE at the same exercise intensity were decreased after training. In the EMT group, in which only expiratory muscles were strengthened, VO_2/kg and RPE at the same exercise intensity were decreased after training, despite no change in HR.

Effect of ventilatory muscle strengthening

Inspiratory muscle training increased both inspiratory and expiratory muscle strength. Studies of patients with respiratory disease (including many with COPD) have variously reported that IMT does not[12)13)] and does[14–20)] strengthen inspiratory muscles. In a meta-analysis of 11 studies, Smith and coworkers[3)] concluded that inspiratory muscle training does not offer significant treatment effects. However, meta-analysis of only five of the 11 studies controlled for training flow rate found positive training effects. Joint guidelines in the USA[1)] have indicated that adequate training loads (i.e., intensity ≥30% of PI_{max}) are needed acquire treatment effects. In the studies which found the effect of inspiratory muscle strengthening by IMT, patients trained for 30 minutes once[15)16)] or 15 minutes twice[14)18)20)] daily. Since the meta-analysis by Smith et al., most studies[21–26)] have revealed effects of increased inspiratory muscle strength, and a recent meta-analysis[4)] has established this effect. Also in the relative recent studies[24–26)], the training setting was prescribed at 30% or more of the maximal inspiratory muscle strength for 30 minutes once or 15 minutes twice daily.

In patients with COPD, no increases in expiratory muscle strength have been found with IMT[12)18)26)]. A study of healthy subjects by Akiyoshi *et al.*[8)] reported that no significant change was observed in expiratory muscle strength following IMT for two weeks at 30% of PI_{max}, although expiratory muscle strength increased by about 18 cmH_2O. Sato and colleagues[27)] found expiratory muscle strength significantly increased by about 39 cmH_2O after

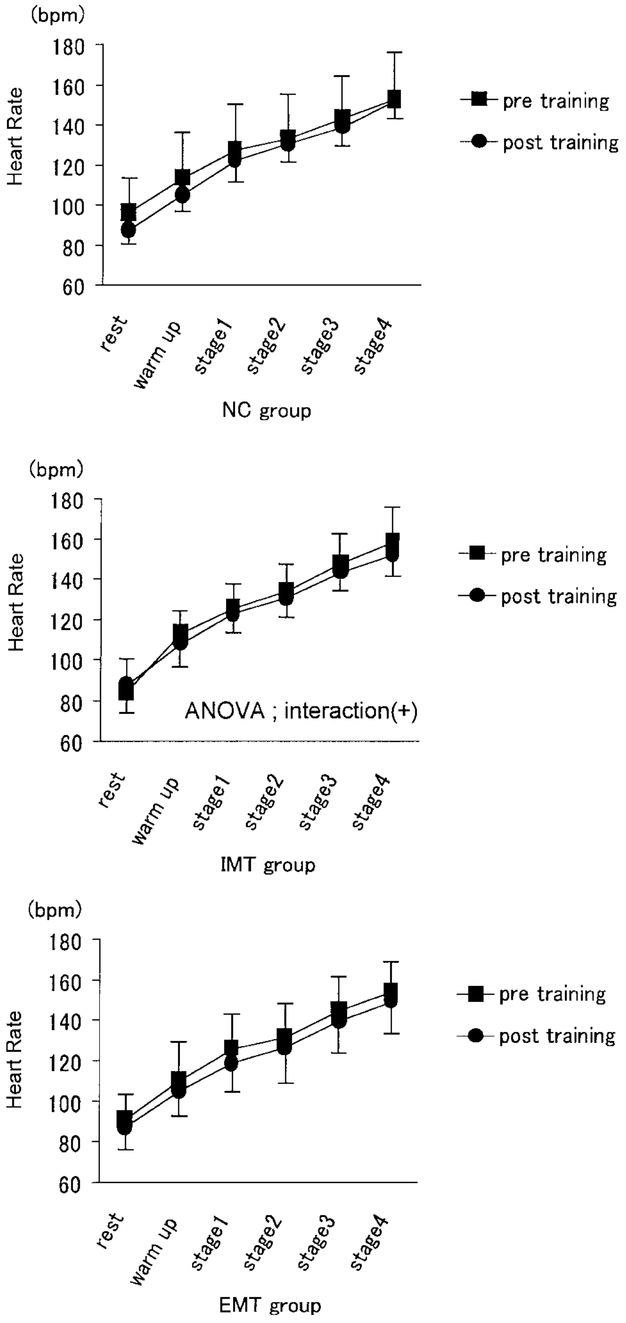


Fig. 2. Change of heart rate increment during exercise testing for ventilation muscle training.

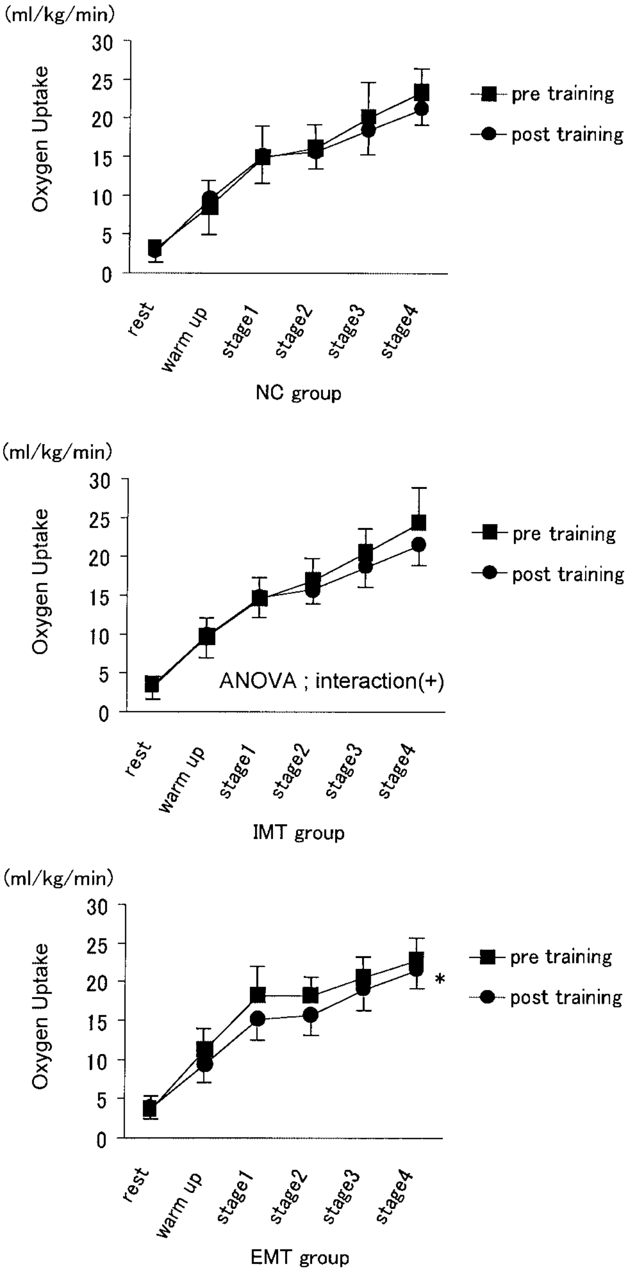
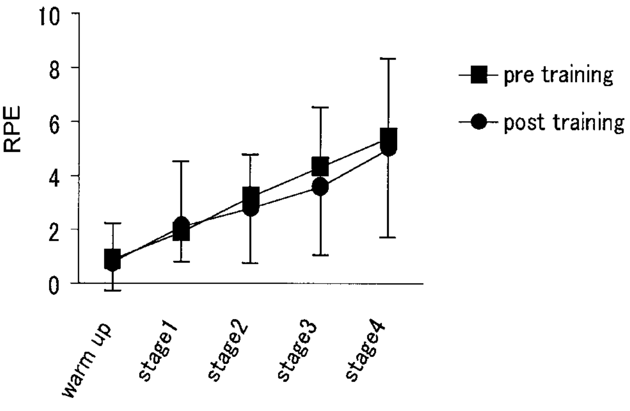


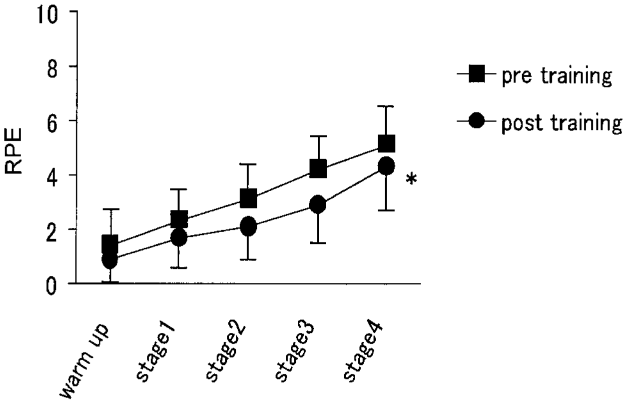
Fig. 3. Change of oxygen uptake/body weight increment during exercise testing for ventilation muscle training. * $p<0.05$; comparison with increment during exercise testing at pre training.

IMT for three weeks at 40% of PI_{max}. Intercostal interni muscles, which are generally considered muscles of expiration, also function in inspiration during forced ventilation. In the present study, depth expiration reached to approximately RV may have been promoted at introduction of inspiration during training. This effect, which would not be expected in patients with COPD due to increased compensatory participation of muscles assisting ventilatory and pulmonary hyperinflation, could probably appear in healthy individuals.

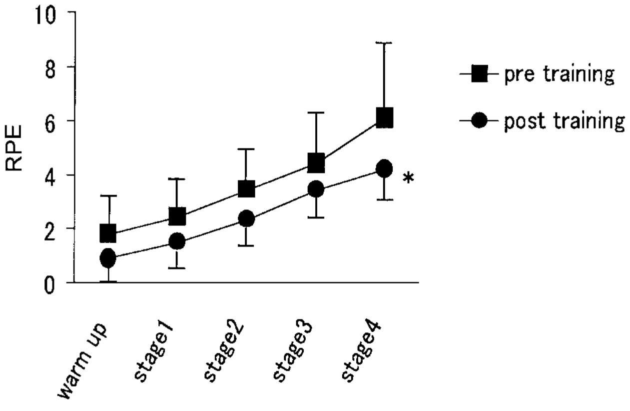
In our study, only expiratory muscle strength increased after EMT, whereas inspiratory muscle strength was unchanged. Akiyoshi and coworkers[8] revealed that EMT significantly increases not only expiratory but also inspiratory muscle strength. This may be attributable to the function of abdominal muscles in inspiration, as well as expiration[8)27]. EMT did not increase inspiratory muscle strength in studies by Suzuki *et al.*[7] and Sato *et al.*[27], in which training was performed at 30% or 40% of PE_{max} for four weeks, respectively.



NC group



IMT group



EMT group

Fig. 4. Change of rating of perceptive exertion (RPE) increment during exercise testing for ventilation muscle training. * $p<0.05$; comparison with increment during exercise testing at pre training.

Influence of VMT on pulmonary function

Most studies[15)18)19)28)] have reported that IMT does not influence pulmonary function in patients with respiratory disease. Meta-analysis[3)] confirmed this, and subsequent studies[21)23)25)] found that pulmonary function was unaffected if inspiratory muscle strength was also increased. These reports correspond to our results.

The effect of EMT on pulmonary function was examined in healthy subjects. In all three studies investigating this effect[7)8)27)], EMT leading to increased ventilatory muscle strength exerted no influence on pulmonary function. Again, these results correspond to our data.

Influence of VMT on exercise tolerance and dyspnea

Many studies[16)18)20–24)] have stated that exercise tolerance and dyspnea during exercise can be improved by increasing ventilatory muscle strength. A recent meta-analysis[4)] concluded that VMT improves dyspnea during exercise and may tend to increase exercise capacity. Many subsequent studies[25)26)] have also demonstrated that increased ventilatory muscle strength improves exercise tolerance. Wanke *et al.*[23)] analyzed expiratory gases during exercise testing, and found that VO_{2max} during bicycle ergometry increased with increased inspiratory muscle strength. Conversely, most studies[14)15)19)25)] have found that peak values of expiratory gas data during exercise testing remain unchanged. Suzuki and coworkers[7)] examined the effects of EMT on exercise capacity. In their report, VO_2 at each stage tended to decrease and Borg scale at each stage was decreased during progressive exercise testing. Findings such as these are basically in accordance with the results of the present study.

In relation to mechanisms behind the effects of increased ventilatory muscle strength on exercise capacity and dyspnea in patients with respiratory disease, Wanke *et al.*[23)] suggested that conditioning of the respiratory muscles might enable patients to tolerate higher $PaCO_2$ levels, and improved inspiratory muscle performance might increase ventilatory efficacy for physiological dead space/tidal volume (V_D/V_T). Furthermore, Larson *et al.*[16)] suggested that IMT might desensitize patients to fear of dyspnea, while Preusser *et al.*[22)] considered that IMT might improve ventilatory limitation during endurance exercises in patients. However, since these mechanisms do not apply to the subjects of the present study, who were healthy individuals, other factors were considered responsible, such as improved neuromuscular coordination[16)], changes to ventilatory patterns[24)], reduced inspiration time and longer expiration time[7)16)], and delayed ventilatory muscle fatigue[20)].

In our study, the magnitude of HR increases with increasing exercise intensity reduced following IMT. As this result was likely associated with reduced VO_2/kg increases, exercise load might be assumed to decrease through reduced oxygen demand with improvements in ventilatory efficacy. However, EMT did not influence HR, despite reduced oxygen demand during exercise. As a contrast between the two types of VMT, we consider that strengthening inspiratory muscles might increase intrathoracic negative pressure during exercise, while stroke volume increases with improved venous return, thus contributing to reduced HR following IMT.

Limitations of the present study

Subjects in this study were selected young healthy women, because we thought that it was easy to recruit them as participants in our study. They were students of a physical and occupational therapy school whose male-to-female ratio of students was about 1:4. In patients with respiratory disease, however, there are more males than females and most of them are elder. Healthy subjects could take effects by training term only for two weeks. But patients with respiratory disease will need the longer training period in order to acquire the training effects. In addition, the effects of VMT on respiratory muscle strengthening may differ by healthy subjects and patients, since ventiratory phase in total lung capacity is not same in both subjects during VMT.

Another limitation is the difference between both subjects of the mechanism to which the effects of ventiratory muscle strengthening affects the responses during exercise testing. Generally, it is unthinkable that a healthy individual's exercise limitation factors are abnormality of artery blood gas, alveolar hypoventilation, fear of dyspnea and so on. We mentioned above, when the factors of change of the responses during exercise testing by VMT might be an improvement of respiratory efficacy. In this study, however, since we could not present data of respiratory pattern and ventiration cycle during exercise, thus was still a matter of conjecture.

We are confident that the further study for respiratory disease patients will prove the result of this study.

Conclusion

We examined the effects of IMT and EMT on ventilatory muscle strength, pulmonary function and responses during exercise testing in young healthy subjects. Both types of training increased ventilatory muscle strength, but did not affect pulmonary function or peak values during exercise testing. However, significant reductions were observed in HR, VO_2/kg and RPE at same load during exercise testing after IMT, and in VO_2/kg and RPE after EMT. Increased ventilation muscle strength might improve ventilatory efficacy during exercise in both IMT and EMT, and increased inspiratory muscle strength might facilitate oxygen delivery through advantageous circulation responses.

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