Inspiratory muscle training improves rowing performance

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ABSTRACT

VOLIANITIS, S., A. K. MCCONNELL, Y. KOUTEDAKIS, L. MCNAUGHTON, K. BACKX, and D. A. JONES. Inspiratory muscle training improves rowing performance. *Med. Sci. Sports Exerc.*, Vol. 33, No. 5, 2001, pp. 803–809. **Purpose:** To investigate the effects of a period of resistive inspiratory muscle training (IMT) upon rowing performance. **Methods:** Performance was appraised in 14 female competitive rowers at the commencement and after 11 wk of inspiratory muscle training on a rowing ergometer by using a 6-min all-out effort and a 5000-m trial. IMT consisted of 30 inspiratory efforts twice daily. Each effort required the subject to inspire against a resistance equivalent to 50% peak inspiratory mouth pressure (PI_{max}) by using an inspiratory muscle training device. Seven of the rowers, who formed the placebo group, used the same device but performed 60 breaths once daily with an inspiratory resistance equivalent to 15% PI_{max}. **Results:** The inspiratory muscle strength of the training group increased by 44 ± 25 cm H_2O (45.3 ± 29.7%) compared with only 6 ± 11 cm H_2O (5.3 ± 9.8%) of the placebo group ($P < 0.05$ within and between groups). The distance covered in the 6-min all-out effort increased by 3.5 ± 1.2% in the training group compared with 1.6 ± 1.0% in the placebo group ($P < 0.05$). The time in the 5000-m trial decreased by 36 ± 9 s (3.1 ± 0.8%) in the training group compared with only 11 ± 8 s (0.9 ± 0.6%) in the placebo group ($P < 0.05$). Furthermore, the resistance of the training group to inspiratory muscle fatigue after the 6-min all-out effort was improved from an 11.2 ± 4.3% deficit in PI_{max} to only 3.0 ± 1.6% ($P < 0.05$) pre- and post-intervention, respectively. **Conclusions:** IMT improves rowing performance on the 6-min all-out effort and the 5000-m trial. **Key Words:** RESPIRATORY MUSCLE TRAINING, PERFORMANCE ENHANCEMENT, INSPIRATORY MOUTH PRESSURE, RESPIRATORY FATIGUE, DYSPNEA

Historically, exercise performance has not been considered to be limited by ventilation or respiratory muscle function. However, occurrence of respiratory muscle fatigue after prolonged submaximal exercise (23), as well as short-term maximal exercise (19,25), has suggested that the ventilatory system might contribute to exercise limitation. Some studies in which the inspiratory muscles were partially unloaded during prolonged exercise, and respiratory muscle fatigue was supposedly alleviated, reported no effect on ventilation or exercise performance (11,20), whereas other studies show significant improvements in performance (14,15).

In addition, several studies in recent years have examined the effects of specific respiratory muscle training upon exercise performance, but the literature is inconclusive; some have shown improvements (4,5,30), whereas others show no effect on performance (13,24). The discrepancies between studies may reflect differences in the exercise intensities and durations used for testing, as well as differences in experimental design and fitness level of the subjects.

Rowing is a sport requiring large aerobic power and a high minute ventilation, typically greater than 200 $L \cdot min^{-1}$ in elite males (26). Peak expiratory flow rates can reach values up to 15 $L \cdot s^{-1}$ in elite male rowers (7). The entrainment of breathing in rowing (31) places additional demands on the respiratory muscles, which must stabilize the thorax during the stroke, as well as bringing about breathing related excursions of the thorax. If respiratory muscle fatigue occurs during competitive rowing, it might be of physiological significance to the regulation of ventilation and breathing pattern, and to respiratory muscle recruitment and hence respiratory sensation. Furthermore, an alteration of the recruitment pattern could have an effect on the mechanical efficiencies of breathing and rowing, with detrimental consequences for performance.

In view of the unique respiratory demands of rowing and the discrepancies in the literature with regard to the benefits of inspiratory muscle training, this study investigated the effect of inspiratory muscle training upon rowing performance.

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METHODS

Subjects. Fourteen female competitive rowers (mean ± SD, age 23.8 ± 3.8 yr, height 173.4 ± 3.8 cm, weight 68.2 ± 4.6 kg, maximal oxygen uptake ($\dot{V}O_{2max}$) 3.56 ± 0.17 $L \cdot min^{-1}$, maximal power output (P_{max} 229 ± 22 W)) were assigned randomly to either an inspiratory muscle training (IMT) or placebo group. The subjects were informed about the nature and risks involved in participation in the experiments. The experimental protocol was approved by the local ethics committee, and all subjects acknowledged voluntary participation through written informed consent. The subjects were instructed to adhere to their usual diet and not to engage in strenuous activity the day before an exercise test. On test days, the subjects were asked not to drink coffee or other caffeine-containing beverages. The tests were performed at similar times of the day. The initial performance assessment took place at the end of October, which is the first month of the preparatory period of the rowing season. All the subjects where either national team members or candidates for the national team and had been competing for a minimum of 3–4 yr.

Procedure. At the beginning of the study, the subjects performed a submaximal incremental load test followed by a 6-min all-out test on a rowing ergometer (model c, Concept II, Nottingham, UK). On the same occasion, baseline spirometry values and maximum respiratory mouth pressures were taken before and after the rowing tests. Both groups commenced an 11-wk period of inspiratory muscle training. The effects of the intervention were evaluated, with the same battery of tests, at 4 wk and after completion of the training period. Mouth pressure measurements, for evaluation of respiratory muscle function during rowing, took place on all occasions. The maneuvers were performed within 30 s after the completion of the maximum effort.

Submaximal incremental load test. The test protocol consisted of five stages of 4 min each with a 1-min interruption for blood sampling. The initial work rate was individualized based on known work capacity. The rowers where asked to start rowing with a frequency of 18 $strokes \cdot min^{-1}$ at a work rate that they usually perform their daily warm-up. The work rate increments for each subsequent stage was 20 or 25 W, depending on the rower's capacity. Once the protocol for a particular rower was established at the beginning of the study, it was not varied thereafter. Heart rate was monitored via a short-range telemetry system (Polar Sporttester, Polar Electro, Kempele, Finland). A preexercise and poststage blood sample was collected from the earlobe and analyzed for lactate concentration. Stroke ratings ($st \cdot min^{-1}$) and power output (W) were recorded for each stage. Continuous analysis of expired gases and static spirometry (flow-volume loops) were performed with an Oxycon Alpha diagnostic system (Jaeger b.v., Manheim, Germany).

Maximal performance tests. After the submaximal incremental load test, the rowers performed a 6-min all-out effort, which is a simulation of the competitive rowing duration. Rowing events last between 5.5 and 7.5 min, depending on boat type, category, and gender of the rowers. We chose 6-min for our test as it represents the duration of the women's eight events. The rest period between the submaximal test and the 6-min test was standardized at 8–10 min to minimize any fatiguing effect of the submaximal test but at the same time to maintain readiness of the rowers. Additional performance data have been obtained at baseline and after 4 wk of inspiratory muscle training by means of a 5000 m ergometer trial that the subjects performed as part of their training control.

Maximum inspiratory pressure measurement. Maximal static inspiratory mouth pressure (PI_{max}) is commonly used to measure inspiratory muscle strength. A portable hand held mouth pressure meter (Precision Medical, London, United Kingdom) was used for this measurement. This device has been shown to measure inspiratory and expiratory pressures accurately and reliably (12). A minimum of five technically satisfactory measurements were conducted and the highest of three measurements with less than 5% variability or within 5 cm H_2O (1 kPa = 10.3 cm H_2O) difference was defined as maximum (34). The initial length of the inspiratory muscles was controlled by initiating each effort from residual volume (RV). This procedure was adopted because, from our experience, RV is more reproducible than functional residual capacity (FRC). Subjects were instructed to take their time and to empty their lungs slowly to RV, thereby avoiding problems associated with variability in lung volumes and dynamic airway compression. All maneuvers were performed in the upright standing position, and verbal encouragement was given to help the subjects perform maximally. The subjects had been familiarized with the nature of the maneuvers to reduce any learning effect.

Respiratory muscle fatigue. For practical purposes, "fatigue" was defined as the inability to continue to generate a given pressure with the same motor command as when the muscle was still fresh. A condition like this does not necessarily imply any "task failure" in the form of inadequate pressure generation for the required ventilation, but it is an indication that the functional capacity is compromised and it will eventually lead to "task failure." Therefore, the original definition of Edwards (9) of skeletal muscle fatigue as a "failure to maintain the required or expected force" has been extended for respiratory fatigue to include also the state of muscle weakness (27).

Perception of dyspnea. A category scale, the modified Borg (3) scale, was chosen to evaluate the respiratory effort during exercise. The scale consisted of a series of integers from 0 to 10. The rower was asked to estimate the effort required to breathe but not the effort of the exercise. During rowing, the Borg scale remained in front of the rower and an assessment was made at the end of every stage and after the all-out effort.

Inspiratory muscle training. The training group performed 30 inspiratory efforts twice daily. Each effort required the subject to inspire against a resistance equivalent to 50% peak inspiratory mouth pressure (PI_{max}) by using an inspiratory muscle trainer (POWERbreathe®, IMT Technologies Ltd., Birmingham, UK). POWERbreathe® is a pressure-threshold device that requires continuous application of inspiratory pressure throughout inspiration for the inspiratory regulating valve to remain open while it allows unrestricted expiration. Subjects were instructed to initiate each breath from RV and to continue the inspiratory effort up to the lung volume where the inspiratory muscle force output for the given load limited further excursion of the thorax. Because of the increased tidal volume, a decreased breathing frequency was adopted to avoid hyperventilation and the consequent hypocapnia. Previous studies from our lab (6) have suggested that the protocol used by the training group is successful in eliciting an adaptive response. The placebo group trained using the same device, but they performed 60 breaths once daily, at a resistance to inspiration equivalent to 15% PI_{max}, a load known to elicit a negligible training effect (5). The two seemingly different training protocols were designed to maintain the naivety of the subjects who were told that one group was training for strength and the other for endurance of the inspiratory muscles. All subjects kept a training diary recording their adherence to the program. Each of the two daily sessions of the training group lasted approximately 5 min, whereas the single training session of the placebo group lasted approximately 10–12 min, depending on the breathing frequency that each subject adopted.

Blood lactate. Arterialized capillary blood samples were taken from the ear lobe before the incremental load test and at the end of each stage. Analysis was done with an Analox GM7 (London, UK). The within-run precision was 1.6% at a whole blood lactate concentration of 5.0 $mmol \cdot L^{-1}$. At low levels of lactate concentration, measurement errors exceeding $\pm$ 0.2 $mmol \cdot L^{-1}$ were rare. Thus, a measured rise of more than 0.4 $mmol \cdot L^{-1}$ during the course of a progressive test was likely to represent a real increase in lactate concentration.

Statistical analysis. Results were analyzed using nonparametric repeated measures analysis of variance (Friedman's test) and Wilcoxon signed ranks test for intra- and inter-group comparisons, respectively. Probability values of less than 0.05 were considered significant. All results are expressed in means $\pm$ SD unless otherwise stated.

RESULTS

Respiratory Muscle Function: PI_{max}

After the initial 4 wk of the training period, PI_{max} increased by 40 $\pm$ 25 cm H_2O (40.7 $\pm$ 25.1%; $P < 0.01$) and by 5 $\pm$ 6 cm H_2O (4.6 $\pm$ 6.0%; $P = 0.083$) from baseline, in the IMT and placebo groups, respectively. After 11 wk of IMT, PI_{max} increased slightly more to a total increase of 44 $\pm$ 25 cm H_2O (45.3 $\pm$ 29.7%; $P < 0.01$) and 6 $\pm$ 11 cm H_2O (5.3 $\pm$ 9.8%; $P = 0.21$) from baseline, in the IMT and placebo groups, respectively (see Table 1.) The PI_{max} improvements of the training group, expressed in percentage, were significantly different both between groups and across time within the group. Analysis of the training diaries revealed that both groups compliance with the prescribed training was between 96–97%.

TABLE 1. PI_{max} in centimeters of H_2O (mean $\pm$ SE), and performance, in meters (m), during the 6-min all-out rowing effort for the training (IMT) and placebo groups, throughout the 11 wk of inspiratory muscle training.

	PI_{max} (cm H_2O)		Performance (m)	
	IMT	Placebo	IMT	Placebo
Baseline	104 ± 8	130 ± 12	1561 ± 9.3	1566 ± 20.7
4 wk	144 ± 10**	135 ± 11	1613 ± 12.2**	1582 ± 21.4*
11 wk	148 ± 10**	136 ± 12	1616 ± 13.4**	1592 ± 21.1**

*Significantly different from baseline ($P < 0.05$); **significantly different from baseline ($P < 0.01$).

Rowing Performance

6 min all-out. After the first 4 wk of the training period the performance in the 6-min all-out test improved, from baseline, by 3.4 $\pm$ 1.0% ($P < 0.05$) in the IMT group, and by 1.1 $\pm$ 0.4% ($P < 0.05$) in the placebo group. Upon completion of the training period, performance had increased from baseline a total of 3.5 $\pm$ 1.2% ($P < 0.05$) in the IMT group and 1.6 $\pm$ 1.0% ($P < 0.05$) in the placebo group from their baseline values (see Table 1.). These improvements were also significantly different between the two groups after 4 wk ($P < 0.05$) and after 11 wk ($P < 0.05$).

5000 m. The time for the completion of the 5000-m test, after the first 4 wk of IMT, decreased by 36 $\pm$ 9 s (3.1 $\pm$ 0.8%; $P < 0.05$), whereas the placebo group's time decreased by 11 $\pm$ 8 s (0.9 $\pm$ 0.6%; $P < 0.05$). The difference in the improvement between the two groups was also significant ($P < 0.05$). There were no data available for the 5000-m test upon completion of the 11-wk IMT period.

Lactate

After 4 wk of inspiratory muscle training blood lactate was lower relative to baseline values by 0.3 $\pm$ 0.3 $mmol \cdot L^{-1}$ ($P < 0.05$) in the third stage and 1.3 $\pm$ 1.3 $mmol \cdot L^{-1}$ ($P < 0.05$) in the fifth stage of the submaximal incremental test for the IMT group. Even though there was also a decreasing trend in the placebo group, it did not reach significance ($P = 0.11$, in the fifth stage). In the interval between the 4th and 11th week of inspiratory muscle training blood lactate decreased a further 0.37 $\pm$ 0.32 $mmol \cdot L^{-1}$ ($P < 0.05$) in the IMT group at the second stage of the incremental test with no significant changes in the placebo group. Overall, both IMT and placebo groups had a significant decrease in lactate of 1.3 $\pm$ 1.47 $mmol \cdot L^{-1}$ and 1.3 $\pm$ 1.2 $mmol \cdot L^{-1}$, respectively ($P < 0.05$) in the fifth stage of the incremental test. There was no significant difference between the groups. No changes occurred in the blood lactate response to the 6-min all-out effort throughout the study.

Respiratory Muscle Fatigue

Baseline fatigue, defined as the decrease of maximum mouth pressure generating capacity, after the baseline 6-min all-out rowing effort, was 11.2 $\pm$ 2.6% ($P < 0.05$) and 11.1

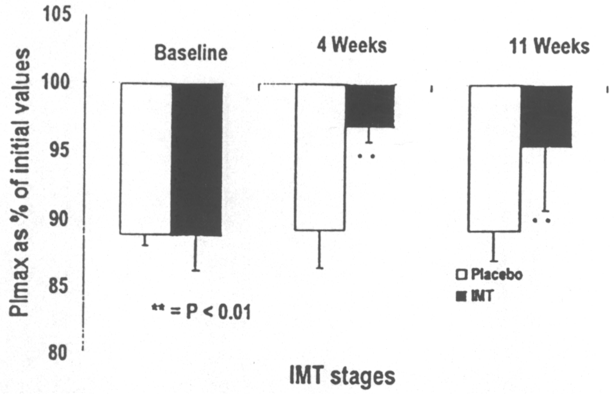

FIGURE 1—Decrement in inspiratory muscle strength after the 6-min all-out test, in percentage decrease from resting mouth pressure generating capacity, throughout the 11 wk of inspiratory muscle training in the training and placebo groups. Values are mean± SD ** $P < 0.01$ different from the placebo group. IMT, inspiratory muscle training group.

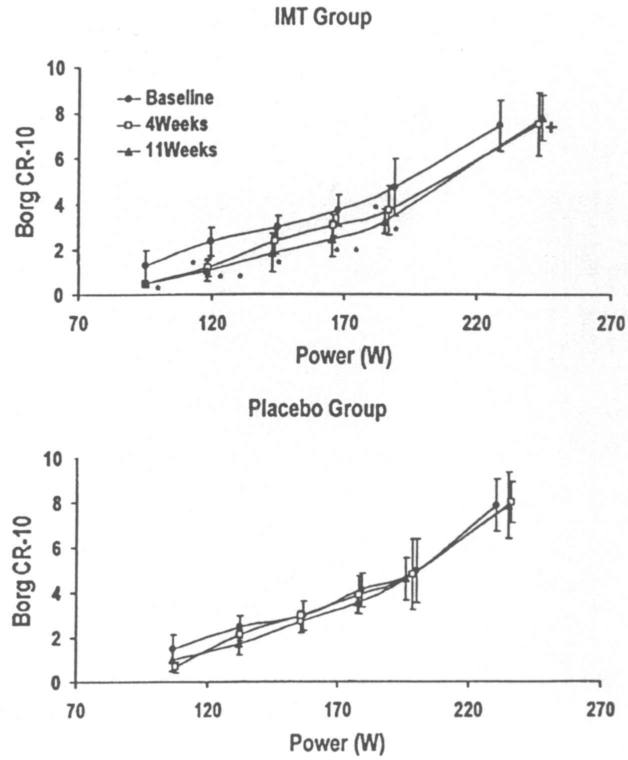

FIGURE 2—Dyspnea-power curves after 4 and 11 wk of inspiratory muscle training for the IMT (top) and placebo (bottom) groups. Values are means ± SD. * Significantly different ($P < 0.05$); ** significantly different ($P < 0.01$); + significantly different ($P < 0.05$) power output for the same dyspnea.

± 0.8% ($P < 0.05$) for the IMT and the placebo groups, respectively. After the first 4 wk of the training period the fatigue after the 6-min all-out effort in the IMT group decreased to 3.1 ± 1.1% ($P < 0.01$), whereas the placebo group remained at 10.7 ± 2.8%. Upon completion of the training period the fatigue for the IMT and the placebo groups did not change any further (4.5 ± 4.7%, $P < 0.01$ and 10.7 ± 2.2%, NS, respectively). Between-group differences in fatigue where also significant for both the 4 and 11 wk comparisons ($P < 0.05$; see Fig. 1).

Perception of Dyspnea

Significant improvements in the perception of respiratory effort during the incremental test were found in the IMT group throughout the training period (Fig. 2). However, no change was found in the dyspnea after the 6-min all-out effort. There were no significant changes in the control group either during the incremental test or the 6-min all-out effort (Fig. 2).

Ventilation and Breathing Pattern

After the completion of the training period, there were no significant changes in the ventilatory volumes at any stage of the incremental test, for either the IMT or the placebo group. However, during the 6-min all-out effort, minute ventilation increased for the placebo group, from a baseline of 120.3 ± 18.5 to 129.6 ± 13.4 $L \cdot min^{-1}$ ($P < 0.05$) The IMT group also increased minute ventilation from a baseline of 119.9 ± 12.8 to 122.5 ± 12.3 $L \cdot min^{-1}$, a difference that just failed to reach significance ($P = 0.051$). The breathing pattern of the IMT group at the 6-min all-out effort changed after the completion of the training period. There was a shift to a significantly deeper breathing pattern with an increase of the tidal volume from 2.01 ± 0.16 to 2.16 ± 0.16 L ($P < 0.01$). Breathing frequency did not change significantly. The placebo group did not exhibit any significant changes in breathing pattern, but there was a tendency toward a more tachypneic pattern with an increase of 4.5% in their breathing frequency compared with only 1.5% of the IMT group (see Table 2).

DISCUSSION

The most important finding of this study is that inspiratory muscle training improved rowing performance to a greater extent than conventional training alone. To our knowledge, ours is the only study investigating the effect of inspiratory muscle training upon an index of sports performance rather than a marker of physiological capacity such as the time-limit test (Tlim). In the reports of Caine and McConnell (5) and Lisboa et al.(22), cycling time to ex-

TABLE 2. A summary of statistical significance for within- and between-group comparisons after 11 wk of IMT in selected parameters.

Parameter	IMT Group	Placebo Group	Between-Group Comparisons
Resting PI_{max}	Improved	No change	Yes
PI_{max} after exercise	Improved	No change	Yes
Lactate incremental test	Decreased	Decreased	No difference
Borg scale 6-min test	Decreased	No change	No difference
??E Incremental test	No change	No change	No difference
??E 6 min test	No change	Increased	No difference
??T 6 min test	Increased	No change	No difference
Bf 6 min test	No change	No change	No difference
P_{ETCO_2}	No change	No change	No difference
P_{ETO_2}	Increased	No change	Yes
6-min test power	Improved	Improved	Yes
5000-m trial time	Improved	Improved	Yes

haustion, a 6-min walk, or an incremental test are used for evaluation of exercise tolerance. Even though the 6-min walk might be argued to be representative of a task encountered by patients with COPD, it is still not a simulation of any known sport. In contrast, the 6-min and the 5000-m time trial represent very close simulations of competitive rowing events and are therefore one step closer to actual sports performance than any test attempted in previous studies.

Because the early report of Leith and Bradley (21), many different groups have demonstrated that ventilatory muscle training increases maximal voluntary ventilation, ventilatory muscle strength, ventilatory muscle endurance, and functional exercise capacity. Our results of 45.3% improvement in PI_{max} are similar in magnitude to other studies (see Smith and colleagues' (29) meta-analysis on patients with COPD) ranging from 32% to 53% (22,32,33). However, because there may well be important differences between healthy subjects and those with COPD, a more appropriate comparison would be with studies using healthy subjects (5,13) where PI_{max} also increases in the range of 34% to 45.3%, respectively, after 4 wk of inspiratory muscle training.

Previous reports (4,5,30) have shown that after inspiratory muscle training a submaximal power output can be maintained for longer (Tlim test). However, the intensity used for the Tlim test in these studies was associated either with the anaerobic threshold (Th_{an}) or the maximum lactate steady state (MLSS). Even though these physiological markers correlate very well with endurance performance, this approach is one step removed from competitive sports performance. Our study shows that inspiratory muscle training can improve performance in two tests that simulate competitive performance as closely as possible in the laboratory context, viz. the 6-min all-out effort and the 5000-m trial. Both tests are routinely used for rowing-specific performance evaluation by coaches. Both IMT and placebo groups improved their performance after 11 wk of training. The margin of their improvement was expected because the study commenced at the beginning of the preparatory training period and lasted for the bigger part of it. Even though we acknowledge the possibility that the responses observed may have occurred as a result of the subjects' regular training, the 1.9% improvement of the IMT group in the 6-min all-out effort over and above the improvement of the placebo group suggests that this is unlikely. Therefore, the data suggest that the inspiratory muscle training had an additional effect upon rowing performance beyond that expected by regular training. The significance of this difference can be appreciated more within the context of competitive rowing where Olympic medals are decided with a much smaller margin than 1.9%.

We believe that there are a number of reasons why other studies have not reported any significant improvements in performance after IMT. Arguably, the most important of which is the low reliability of the tests used to evaluate performance in other studies, compared with the 6-min all-out effort used in our study, made the detection of a meaningful effect difficult. For example, the coefficient of variation for the Tlim test has been reported to be anything between 25% and 40%, whereas the 6-min all out test is only 2.4% (17). Therefore, much larger improvements were required to assure that the observations were not due to the variability of the test itself. Other studies (13,24) have reported improvements in performance but failed to reach significance. We suspect that insufficient statistical power, due to the small sample size of these studies, may have introduced a type II error and failed to reject the null hypothesis. Support of our findings is provided by studies using isocapnic hyperpnea training protocols, which suggest that respiratory muscle training induces significant improvements in cycling performance (Tlim) (4,30). In addition, a recently completed study showed that after 5 wk of respiratory muscle training, using a high velocity (flow) and a high resistance (pressure) training protocol, cycling time trials improved significantly by approximately 5% (J. Dempsey, personal communication). In the absence of any clear insight into the hard evidence of the underlying physiological mechanisms for the observed effects, we are forced to speculate on possible mechanisms, three of which are discussed below.

Respiratory Muscle Fatigue

First, even though respiratory muscle fatigue of the IMT group was diminished, there was no evidence for significantly different ventilatory response between the two groups. These data support the notion that respiratory muscle fatigue was without significant consequence for the ventilatory response. This is consistent with the suggestion that when the diaphragm is confronted by fatiguing contraction patterns, the accessory inspiratory muscles become more active and the overall ventilation is not compromised. Therefore, since the respiratory pump did not fatigue to the point of "task failure," it is unlikely that the improvements in performance were the result of improved gas exchange or a better compensation for metabolic acidosis. However, the altered breathing pattern observed after IMT suggests that respiratory muscle fatigue might have been of physiological significance to the regulation of the breathing pattern. In the IMT group, tidal volume increased significantly, whereas the placebo group resorted to a more tachypneic breathing pattern, characteristic of respiratory muscle fatigue for the maintenance of minute ventilation. Indeed, as the breathing pattern during exercise seems to be optimized to avoid exhaustive fatigue and "task failure" of the respiratory muscles, the increased strength of the IMT group might have enabled them to increase tidal volume without fatiguing. In contrast, the placebo group, which was susceptible to fatigue, resorted to an increased breathing frequency. Even though we did not assess the degree of entrainment between breathing and stroke rate, it is possible that the prevention of a tachypneic breathing pattern in the IMT group enhanced the mechanical efficiency of the rowing work by enabling the maintenance of entrainment. Indeed, our data are in agreement with previous suggestions that breathing in rowing occurs at times where muscle synergy produces larger ventilatory volumes for a given amount of respiratory work, or alternatively, the same volume for less respiratory work (28); consequently performance may be improved.

Altered Respiratory Sensation

The second putative mechanism for the improved rowing performance may be that the reduced respiratory muscle fatigue induced changes in the respiratory sensation. Respiratory muscle fatigue has been documented after prolonged submaximal exercise (23) as well as short-term maximal exercise (19,25). There is some suggestion that the respiratory muscles of "athletic" individuals have superior strength and greater fatigue resistance (8). Our data showing significant inspiratory muscle fatigue after a 6-min all-out rowing effort is in agreement with Johnson and colleagues (18), who suggest that a high level of fitness does not protect the diaphragm muscle from fatigue during heavy exercise (95% of $\dot{V}O_2$max). After inspiratory muscle training, the IMT group showed significantly reduced fatigue after the 6-min all-out effort. Indeed, a recent report has shown that the baseline strength of the inspiratory muscles influences their fatigability (25). Interestingly, the fatigue of the placebo group remained the same which suggests that normal training for rowing does not elicit the same adaptations as a specific inspiratory muscle training program. The increase in strength may have attenuated the development of fatigue by decreasing the proportion of the maximal force capacity required for each breath (16). Similarly, with greater inspiratory muscle strength, a smaller fraction of maximum tension is generated with each breath, and it has been suggested that this reduces the motor output to the respiratory muscles and decreases the perceived sense of respiratory effort (10). Even though we do not have measures of dyspnea during the 5000-m test, when asked to describe their feeling afterward most subjects said that either the onset of breathlessness was delayed, allowing a longer maintenance of the previous pace, or a higher pace was kept throughout the test with the same breathing effort.

Altered Ventilatory Efficiency

Finally, it has been suggested that through inspiratory muscle training an increase in the mechanical efficiency of ventilation might take place, thereby reducing the metabolic requirements of the respiratory muscles. Previous studies have shown that during maximal exercise the $\dot{V}O_2$ of the respiratory pump can reach values up to 15% of the total $\dot{V}O_2$ (1,2). Indeed, the metabolic cost of breathing becomes so great that any additional increase in total $\dot{V}O_2$ contributes minimally to the external work. In studies conducted at $\dot{V}O_{2max}$, the respiratory muscles have been perceived as "stealing" blood flow from the peripheral musculature to cover their metabolic requirements (14). Thus, decreasing the metabolic requirements of the inspiratory muscles could result in a diminished blood flow demand and reduce the competition with the locomotor muscles for limited blood flow. Because we did not see any significant differences in the $\dot{V}O_2$max; by implication cardiac output was also unchanged. Thus, we can assume that the fraction of the total cardiac output distributed to leg muscles may have increased after IMT and this may have led to improvements in performance (15).

In summary, significant improvements in the 6-min all-out effort and 5000-m time trial performance were observed after a period of inspiratory muscle training. These performance improvements were accompanied by a decrease in inspiratory muscle fatigue and perception of dyspnea. Even though the small sample size does not allow us to make inferences about the population from which the sample was drawn, it has not escaped our attention that our findings may have some bearing on rowing performance. The elucidation of the precise mechanisms responsible for our observations requires further studies involving the cardiovascular consequences of inspiratory muscle training and larger sample sizes.

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