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 $\dot{V}O_2max$). 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 $\dot{V}O_2max$; 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.

The authors would like to thank IMT Technologies Ltd. for providing the inspiratory muscle training devices used in this study. The results of the present study do not constitute endorsement of the product by the authors or ACSM.

Address for correspondence: Stefanos Volianitis, The Copenhagen Muscle Research Center, Department of Anesthesia, Rigshospitalet 2041, Blegdamsvej 9, DK-2100 Copenhagen, Denmark: E-mail: stefanos.voliantis@excite.com.

REFERENCES

1. Aaron, E. A., B. D. Johnson, C. K. Seow, and J. A. Dempsey. Oxygen cost of exercise hyperpnea: measurement. *J. Appl. Physiol.* 72:1810–1817, 1992.
2. Aaron, E. A., K. C. Seow, B. D. Johnson, and J. A. Dempsey. Oxygen cost of exercise hyperpnea: implications for performance. *J. Appl. Physiol.* 72:1818–1825, 1992.
3. Borg, G. A. V. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* 14:377–381, 1982.
4. Boutellier, U., R. Buchel, A. Kundert, and C. Spengler. The respiratory system as a limiting factor in normal trained subjects. *Eur. J. Appl. Physiol.* 65:347–353, 1992.
5. Caine, M. P., and A. K. Mcconnell. Pressure threshold inspiratory muscle training improves submaximal cycling performance. In: *Procedings of the Third Annual Congress of the European College of Sport Science.* Manchester, United Kingdom. ISBN 0-9533549-0-3, 1998, p. 101.
6. Caine, M. P., and A. K. Mcconnell. The inspiratory muscles can be trained differentially to increase strength or endurance using a pressure threshold, inspiratory muscle training device. In: *Abstracts of the European Respiratory Society Annual Congress.* Geneva, Switzerland. ISBN 87-16-15712-5, 1998, p. 58s.
7. Carles, J., J. Dessertenne, J. Bertholon, A. Teillac, J. Y. Durand, and M. Auffredou. Modifications respiratoires et etude de l'effacite pulmonaire dans un sport de competition: L'aviron (Respiratory modifications and the efficiency of breathing in a competitive sport: rowing). *Med. Sport* 54:297–302, 1980.
8. Coast, J. R., P. S. Clifford, and T. W. Henrich. Maximal inspiratory pressure following maximal exercise in trained and untrained subjects. *Med. Sci. Sports Exerc.* 22:811–815, 1990.
9. Edwards, R. H. T. Human muscle function and fatigue. In: *Human Muscle Fatigue: Physiological Mechanisms.* R. Porter and J. Whelan (Ed.). London: Pitman, 1981, pp. 1–18.
10. El-Manshawi, A., K. Killian, E. Summers, and N. Jones. Breathlessness during exercise with and without resistive loading. *J. Appl. Physiol.* 61:896–905, 1986.
11. Gallagher, C. G., and M. Younes. Effect of pressure assist on ventilation and respiratory mechanics in heavy exercise. *J. Appl. Physiol.* 66:1824–1837, 1989.
12. Hamnegard, C. H., S. Wragg, D. Kyroussis, R. Aquilina, J. Moxham, and M. Green. Portable measurement of maximum mouth pressures. *Eur. Resp. J.* 7:398–401, 1994.