Respiratory muscle fatigue during exercise

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The traditional perspective is that the pulmonary system has a large reserve capacity that is more than capable of meeting the demands of very heavy physical exercise in healthy individuals. It is also postulated that the only exception to the latter is the exercise-induced arterial hypoxaemia that is observed in some highly trained individuals at maximal exercise. However, several studies have demonstrated that respiratory muscles (RM) can fatigue during prolonged and maximal exercise, and this may have significant effects on athletic performance. RM fatigue is usually quantified as a reduction in RM strength from resting values, where RM strength is indirectly estimated through maximal inspiratory pressure (MIP).

The metabolic cost of breathing
At rest, breathing is primarily an inspiratory activity, while expiration is a passive process. Thus, the oxygen cost of breathing at rest is only about 2% of total body oxygen consumption. During exercise, when expiration also becomes an active process, the oxygen cost of breathing increases from 3 - 5% during moderate exercise to 10% during strenuous exercise. In highly trained individuals the latter may rise to 15 - 16% of VO\textsubscript{2max}.

The implication of this greater oxygen cost of breathing is that the respiratory muscles require a greater proportion of the cardiac output with an increase in exercise intensity, thus leaving a smaller percentage of cardiac output available to the active limb locomotor muscles. This may significantly contribute to the onset of skeletal muscle fatigue.

Do respiratory muscles fatigue during exercise?
Numerous studies have shown that the respiratory muscles are subject to fatigue in a similar fashion to limb locomotor muscles. Evidence for this has been obtained during laboratory exercise tests, as well as during exercise in the field. Ozkaplan et al.\textsuperscript{3} found that MIP was significantly reduced in moderately trained men and women after an incremental exercise test to exhaustion. McConnell et al.\textsuperscript{4} demonstrated that an incremental shuttle-run to fatigue (exercise lasting 10 - 15 minutes) leads to a significant reduction in MIP (8.2%), and thus RM fatigue in moderately trained men. Lomax and McConnell\textsuperscript{5} demonstrated a significant reduction (29%) in MIP after a single 200 meter swim in 7 competitive swimmers. Chevrolet et al.\textsuperscript{6} found significantly lower MIP values in both marathon and half-marathon runners after a race, while Ker and Schultz\textsuperscript{7} observed similar results in athletes after an ultra-marathon event.

Although individuals with the weakest inspiratory muscles experience the greatest amount of RM fatigue, high levels of fitness do not protect individuals from developing RM fatigue. Thus, even athletes with above-average respiratory muscle strength and endurance experience RM fatigue. The magnitude of RM fatigue is directly related to the duration and intensity of exercise; most researchers agree that sustained exercise at intensities higher than 80 - 85% of VO\textsubscript{2max} consistently cause fatigue of the diaphragm at the end of exercise.\textsuperscript{8}

Does RM fatigue affect exercise performance?
Given the high demand for oxygen and blood flow by the respiratory muscles during whole-body endurance-type exercise, it is not surprising that exercise performance is impaired during high-intensity exercise. Harms et al.\textsuperscript{9} found that with respiratory muscle unloading, well-trained cyclists exercised for 1.3 ± 2.0 min longer (an increase of 14.4%) during a constant workload test at 90% VO\textsubscript{2max} than during control conditions. On the other hand, exercise time significantly decreased by 1.0 ± 0.8 min (15.1%) with respiratory loading compared with control conditions. Therefore, decreasing the work of breathing led to a significant improvement in time to exhaustion. Furthermore, respiratory muscle unloading also resulted in reduced VO\textsubscript{2}, a decrease in minute ventilation, and reduced perceptions of respiratory and limb discomfort. These findings were confirmed by Babcock et al.,\textsuperscript{10} who demonstrated that mechanical unloading of the respiratory muscles during heavy sustained exercise prevented diaphragm fatigue.

Does RM training affect exercise performance?
A number of studies investigated the effects of resistive loading on RM strength and have reported increases in MIP of 8 - 45%.\textsuperscript{11} Whether this improvement in RM strength translates to an increase in exercise performance, is somewhat controversial. McConnell and Romer\textsuperscript{12} analysed all the RM training studies and concluded that weak experimental designs, insufficient statistical power and inappropriate performance tests could explain the negative findings of earlier studies. Studies that have shown statistically significant improvements in performance utilised fixed work rate tests or time trial-type performance measures. In these cases, performance improvements between 24% and 50% (for fixed work rate tests) and between 1.8% and 3.5% (for time trial tests) were reported.

The magnitude of the observed training effects may be sufficient to provide athletes with a winning edge. Thus, for athletes constantly seeking for ways to enhance their performance, RM training may provide a legitimate ergogenic aid.
In conclusion

- Respiratory muscles of healthy individuals do fatigue during whole-body endurance exercise.
- The higher cost of breathing during exercise compromises blood flow to active limb locomotor muscles.
- Respiratory muscle fatigue can impair exercise performance in trained individuals.
- A number of studies show that respiratory muscle training may improve exercise tolerance and could thus have ergogenic benefits in trained individuals.

References