#J11 Respiratory Muscle Training Improves Swimming and Respiratory Muscle Performance at Depth

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Abstract

Background: It is known that respiratory muscle fatigue can reduce endurance, i.e. the time sub-maximal exercise can be performed and that respiratory muscle training (RMT) can significantly improve running, cycling and swimming endurance. Although RMT has been shown to improve divers' swimming endurance at 4 feet of water its effectiveness at greater depths, where the respiratory work due to the increased trans-thoracic pressure, gas density and breathing gear resistance is greater, has not been studied. The present study tested the hypothesis that resistance respiratory muscle training (RRMT) will improve respiratory function and swimming endurance in divers' at 55 feet of water (2.67 ATA). **Materials and Methods:** Nine male subjects (25.9 ± 6.8 years) performed vital capacity maneuvers every 30 seconds against a combination of static and resistive loads of 50-70 and 40-47 cmH_2O, respectively, for 30 minutes/day, 5 days/ week, for 4 weeks. Pre- and post-RRMT, subjects swam at depth against a pre-determined load (70% max) until exhausted. As indices of respiratory muscle effort, maximal inspiratory ($P_I$max) and expiratory ($P_E$max) pressures were measured before and immediately following the swims pre-and post-RRMT. **Results:** At comparable swim duration the respiratory muscles were considerably less fatigued following RRMT and ventilation was significantly lower during the swims. The reduced ventilation was due to a lower breathing frequency following RRMT. The ventilatory changes following RRMT coincided with significantly increased swimming time to exhaustion (~60%, p=0.016). **Conclusions:** These results suggest respiratory muscle fatigue limited swimming endurance at depth, as well as at the surface, and that the post-RRMT improvement was the result of reduced work of breathing, increased efficiency or improved respiratory muscle performance.

Introduction

- Respiratory muscle fatigue has been shown to reduce exercise performance in healthy individuals at sea level
- The work of breathing under water is severely challenged due to:
  1. The hydrostatic pressure differences across the chest wall
  2. An increase in gas density at greater depths
  3. The added resistance associated with breathing from a self contained underwater breathing apparatus (scuba)
- The increased work of breathing predisposes the diver to premature respiratory muscle fatigue and a decrease in exercise performance
- Recently, resistance respiratory muscle training has been shown to improve fin-swimming performance (66%) at a depth of 4 feet of water

Purpose

The purpose of the current study was to evaluate whether resistance respiratory muscle training (RRMT) was capable of improving respiratory muscle strength and fin-swimming performance at greater depths (55 feet of water, 2.67 ATA), where gas density and the work of breathing are significantly increased

Hypothesis

Based on our previous findings at the surface and at 4 feet of water

1. Respiratory muscle limitations at depth (55 feet of water, 2.67 ATA) will be eliminated following a specific RRMT protocol and that fin-swimming endurance will be improved
2. Respiratory muscle strength will be increased at depth immediately following endurance exercise, despite the increases in gas density

Methods

- Nine certified male divers participated (25.6 ± 6.8 (SD) years, 177.0 ± 2.8 cm, 80.0 ± 11.9 kg)
- Subjects completed a 4 week (3 days/week) fin-training program prior to RRMT
- RRMT was performed 30 min/day, 5 days/week for 4 weeks (Fig. 1, equipment)
- Testing was completed pre- and post-RRMT:
  - Pulmonary function tests: maximal ventilation in 15 seconds (MVV_{15}), slow vital capacity (SVC), forced vital capacity (FVC), and forced expiratory volume in one second (FEV_1)
  - Maximal expiratory (P_E max) and inspiratory pressures (P_I max) were measured immediately before and after each fin-swimming endurance test
  - The underwater fin-swimming endurance test (55 feet of water, 2.67 ATA) was performed against a weighted harness inside the wet compartment of a hyperbaric chamber (Fig. 2).
  - Subjects performed 3 endurance tests: pre-RRMT, post-RRMT (open ended), post-RRMT stop (iso-time as pre-RRMT)
  - The fin-swimming workload was adjusted to require 70% of $\dot{V}O_2$ max
  - The diver was positioned at a -15 cmH_2O static lung load (Fig. 3)
  - $\dot{V}_E$, $\dot{V}_A$, Vt, f_b and $\dot{V}CO_2$ were recorded during the test
  - Subjects breathed 60% oxygen and 40% nitrogen from a closed circuit breathing system (Fig. 4)

Fig. 1. RRMT equipment

Fig. 1. In the back left is the carry case. To the back right is the pressure transducer and computer. In the front is shown the mouth piece with inspiratory and expiratory spring loaded valves.

Fig. 2. Subject in chamber

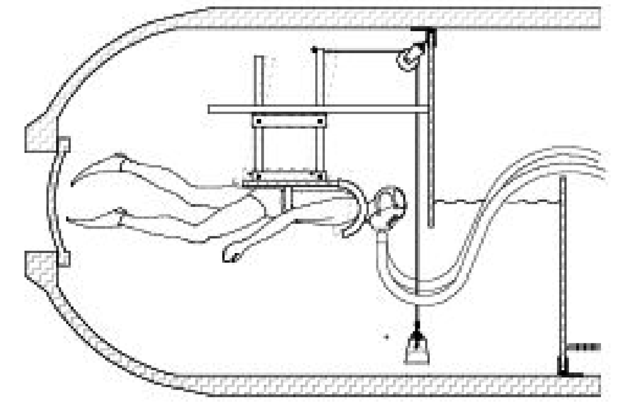

Fig. 2. Drawing of a subject fin-kicking behind the "Buffalo Barrier" system in the hyperbaric chamber. The forward thrust generated from fin-kicking raises the weight from the chamber bottom.

Fig. 3. Static lung loading

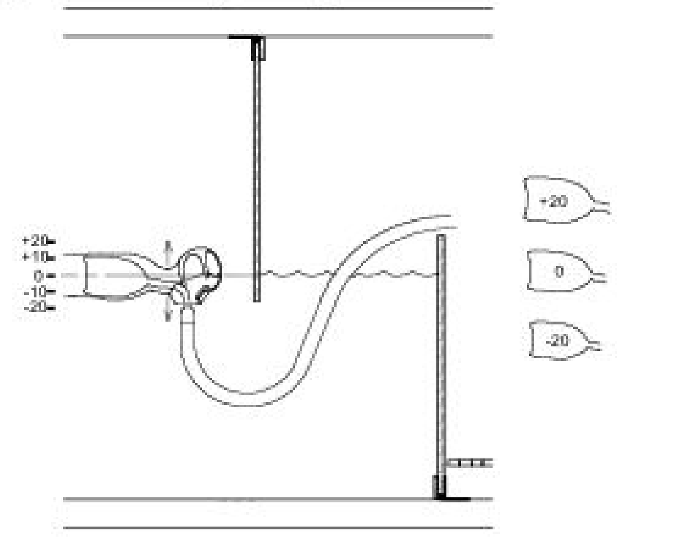

Fig. 3. Drawing of the "Buffalo Barrier" system and method of producing various static lung loads. By moving the diver up and down, the diver will be exposed to various hydrostatic pressures relative to chamber ambient pressure.

Fig. 4. Closed circuit breathing system

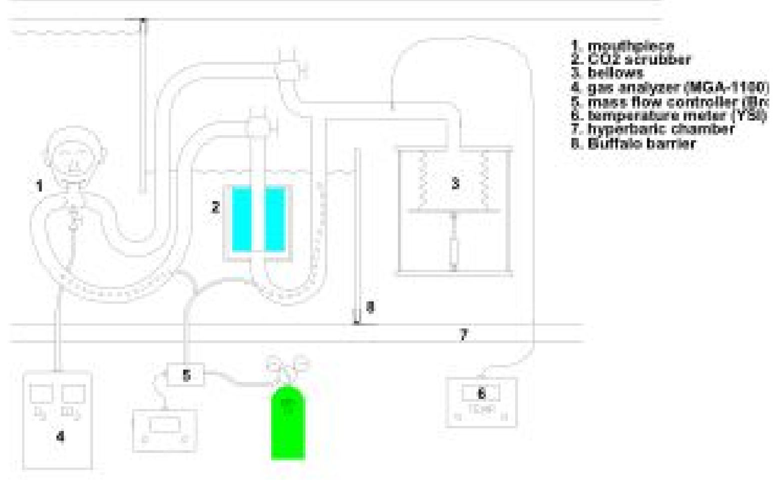

Fig. 4. Diagram of the subject behind the "Buffalo Barrier" breathing from the closed circuit breathing system. Equipment is labeled on the right side of the figure.

Results

Table 1. Pulmonary function pre- and post-RRMT

	Pre-RRMT	Post-RRMT
FVC liters	5.7 ± 0.5	5.8 ± 0.6
SVC liters	5.9 ± 0.6	6.0 ± 0.5
FEV_1 liters	5.0 ± 0.6	5.1 ± 0.7
MVV_{15} liters/sec	194 ± 32	219 ± 46 *

FVC = forced vital capacity, SVC = slow vital capacity FEV_1 = forced expiratory volume in one second, MVV_{15} = maximal voluntary ventilation in 15 seconds. Values are ± SD. * Sig. > pre-RRMT, p < 0.05

Table 2. Maximal pressures pre-and post-RRMT

	1.0 ATA	2.67 ATA				
		Pre-RRMT		Post-RRMT		
	Baseline	*Before*	*After*	*Before*	*After Open*	*After Stop*
P_E	135 ± 39	123 ± 27	118 ± 20	140 ± 43	130 ± 31	152 ± 26*
P_I	-115 ± 34	-117 ± 40	-103 ± 88	-138 ± 77	-124 ± 24	-194 ± 71*

Maximal expiratory (P_E) and inspiratory (P_I) pressures *Before* and immediately *After* each fin-swimming trial, pre-RRMT, post-RRMT (with stop), and post-RRMT (open ended). The post-RRMT *Before* pressures are the averages of the post-RRMT open-ended and stop-dive data combined. Values are cmH_2O ± SD, * Sig. > pre-RRMT *After*

Fig. 5

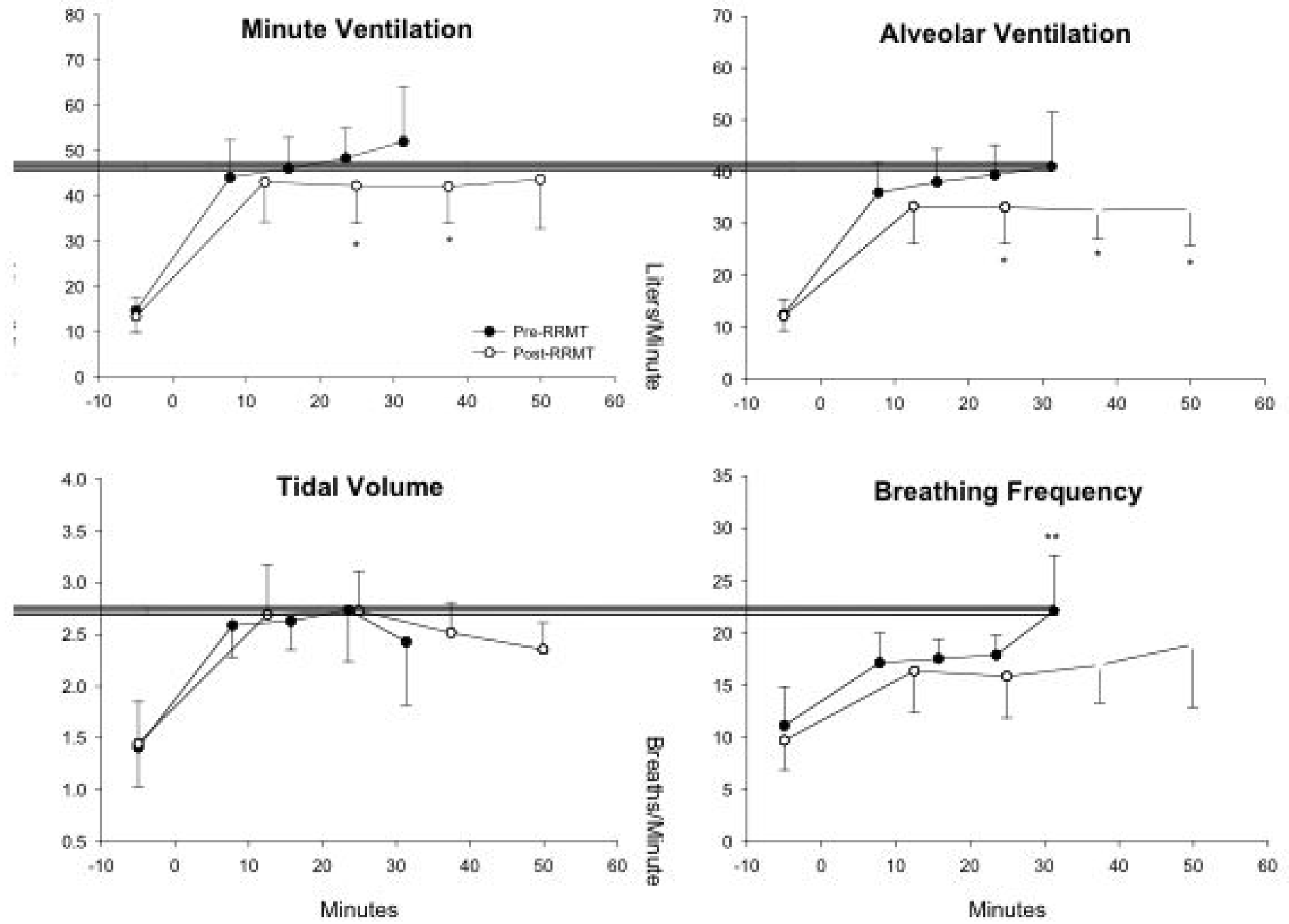

Fig. 5. Total and alveolar ventilation, tidal volume and breathing frequency during the fin-swimming tests pre-RRMT (dark circles) and post-RRMT (open circles). Data was collected at rest (-5), 25%, 50%, 75%, and 100% of the fin-swimming time. Pre-RRMT and post-RRMT fin-swimming times were 31.3 ± 11.6 (SD) min vs. 49.0 ± 16.0 min, respectively. * Sig. < pre-RRMT (at 100% swim time), p < 0.05, ** Sig. > pre-RRMT rest, p < 0.05

Results

Fig. 6

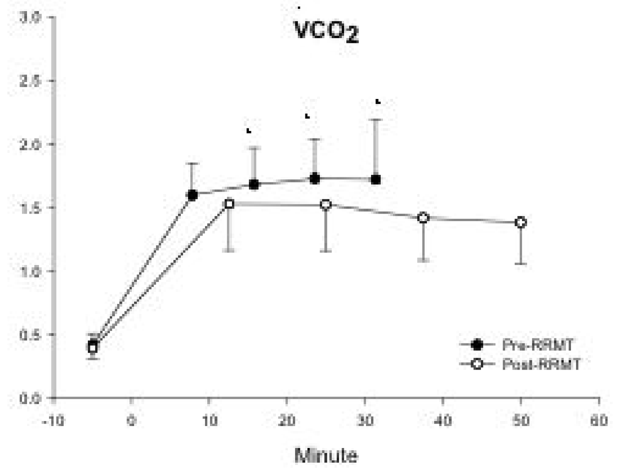

Fig. 6. Carbon dioxide production during the swims pre- (dark circles) and post-RRMT (open circles). Data was taken from rest (-5), 25%, 50%, 75%, and 100% of the fin-swimming time. Pre- and post-RRMT fin-swimming times were 31.3 ± 11.6 min vs. 49.0 ± 16.0 min. * Significantly > than post-RRMT (at 75% and 100% of swim time), p < 0.05.

Summary

The primary findings from this study are that RRMT:

1. Improved fin-swimming performance at depth (60%) where the work of breathing is significantly elevated
2. Resulted in a decrease in $\dot{V}_E$, f_b and $\dot{V}CO_2$ during the fin-swimming test
3. Prevented the decline in Vt that was observed during the pre-RRMT test
4. Delayed and almost eliminated the hyperventilatory response at the end of exercise during the pre-RRMT test

Conclusions

- The improvements in respiratory muscle strength were sufficient to overcome the added resistance from the increase in gas density
- The current study also demonstrates that respiratory muscle fatigue may be the performance limiting factor during underwater fin-swimming
- Fin swimming performance may be improved through one or both of the following mechanisms:
  1) Respiratory muscle adaptations following training may reduce the work of breathing and/or improve respiratory muscle efficiency, thus reducing the respiratory muscle blood flow requirements and the "stealing effect" from the fin-kicking muscles
  2) RRMT allows the respiratory muscles to produce and sustain muscular contractions for longer periods of time at an increased end-expiratory lung volume, thus reducing airway resistance
- Although both of these mechanisms may contribute to the improvements in underwater fin-swimming endurance following RRMT, the current study can not distinguish one from the other and therefore, further studies are required to address each mechanism individually

Acknowledgments

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