#A27 Respiratory Muscle Training Against Resistance Improves Respiratory and Underwater Swimming Performance

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Abstract

INTRODUCTION: Swimming at depth is associated with increased work of breathing, premature respiratory muscle fatigue and reduced swimming performance. Resistance respiratory muscle training (RRMT) has been shown to improve divers' respiratory function and swimming endurance. However, it is unknown by what mechanism RRMT increases performance. It was hypothesized that RRMT will strengthen the respiratory muscles, reduce the work of breathing, alter end expiratory lung volume (EELV), and, by so doing, prolong underwater swimming endurance time at 120 fsw (469.78 kPa) where the work of breathing is pronounced.

MATERIALS AND METHODS: Nine male subjects (30.3 6.0 years) performed vital capacity maneuvers (RRMT) every 30 seconds against spring loaded inspiratory and expiratory valves (average 59 cmH_2O) for 30 min/day, 5 d/ wk, for 4 wks. Pre- and Post-RRMT, subjects swam under water in a hyperbaric chamber against a pre-determined load (70% max) until exhausted. Maximal expiratory ($P_E$max) and inspiratory pressures ($P_I$max) were measured pre- and post-RRMT at 1 ATA. End expiratory lung volume was measured every five minutes throughout the swimming endurance. The mechanical work of breathing was calculated as the electronically integrated product of the transpulmonary pressure (esophageal pressure - mouth pressure) and ventilatory flow (spirometer) signals and averaged over 10 breathing cycles.

RESULTS: After RRMT, $P_I$max and $P_E$max were increased 40% and 30%, respectively and swimming endurance time was prolonged by 87% (26.4 9.7 (SD) min vs. 49.4 21.6). The longer swimming time was associated with a decrease in total and alveolar ventilation, breathing frequency and the work of breathing, while tidal volume and EELV did not change following RRMT.

CONCLUSION: These results suggest that RRMT improves under water swimming endurance at depth and that the increase in performance may be the result of a reduced work of breathing or to an increase in respiratory muscle efficiency following RRMT.

Introduction

- The work of breathing under water is significantly increased and challenges the respiratory muscles due to the: 1) increases in gas density as a function of depth; 2) added resistance associated with breathing from a self contained underwater breathing apparatus (scuba), and 3) the static lung load (SLL), or the pressure difference outside of the chest vs. alveolar pressure.
- End expiratory lung volume (EELV) may also be altered because of the effects of immersion and negative pressure breathing (negative SLL) on the respiratory system.
- The implications associated with altering EELV is that breathing at a lung volume that represents either a lower or higher percentage of total lung capacity, i.e. at a decreased or increased EELV, places the respiratory muscles (inspiratory and expiratory) at a less than optimal position on their length-tension curve and reduces their ability to generate and maintain adequate force (Braun et al. 1982; McCully et al. 1983).
- The increased work of breathing and/or altered lung volumes predispose the diver to premature respiratory muscle fatigue and as a result decreased exercise performance.
- It remains to be determined if stronger respiratory muscles can attenuate the immersion and negative SLL effects on pulmonary performance during sustained exercise, thus reducing the development of respiratory and locomotor muscle fatigue at greater depths (gas density).

Purpose

To evaluate whether a progressive resistance respiratory muscle training (RRMT) protocol would improve respiratory muscle strength and fin-swimming performance at greater depths (120 feet of sea water, 4.64 ATA, 469.78 kPa) and to test whether the improvements in swimming performance are correlated to improvement in pulmonary mechanics or to a reduced work of breathing, or both following training

Hypotheses

It is hypothesized that RRMT will: 1) increase respiratory muscle strength, 2) increase submaximal swimming time, 3) reduce the work of breathing, and 4) improve respiratory mechanics by altering lung volumes

Methods

- Nine certified male divers participated (29 ± 6 (SD) years, 160.4 ± 5.7 cm, 74.3 ± 29 kg).
- Prior to RRMT, subjects completed a 4 week (3 days/week) fin-training program to eliminate changes in fitness as a covariate in swimming performance.
- A progressive RRMT protocol was performed 30 min/day, 5 days/week for 4 weeks. Resistance started at 50% of max and was increased 10 cmH_2O/week.
- Subjects performed 3 endurance tests at 70-75% of VO_2 max: pre-RRMT, post-RRMT (open ended), post-RRMT stop (iso-time as pre-RRMT), the latter two in random order.
- The fin-swimming endurance test was completed inside the wet compartment of a hyperbaric chamber swimming against a set resistance (Fig. 1, 120 feet, 4.63 ATA)
- The diver was positioned at a -15 cmH_2O static lung load during exercise (SLL)
- During the endurance swim the subjects breathed 34% oxygen from a closed circuit breathing system.
- EELV was measured every five minutes throughout the swimming endurance test.
- Measurement of transpulmonary pressure (esophageal pressure - mouth pressure) and ventilatory flow (spirometer) were recorded and averaged over 10 breathing cycles throughout the swim.
- Maximal expiratory (P_E max) and inspiratory (P_I max) pressures were measured immediately before and after each fin-swimming trial.
- The mechanical work of breathing was calculated as the electronically integrated product of the transpulmonary pressure and flow.

Results

Fig. 1

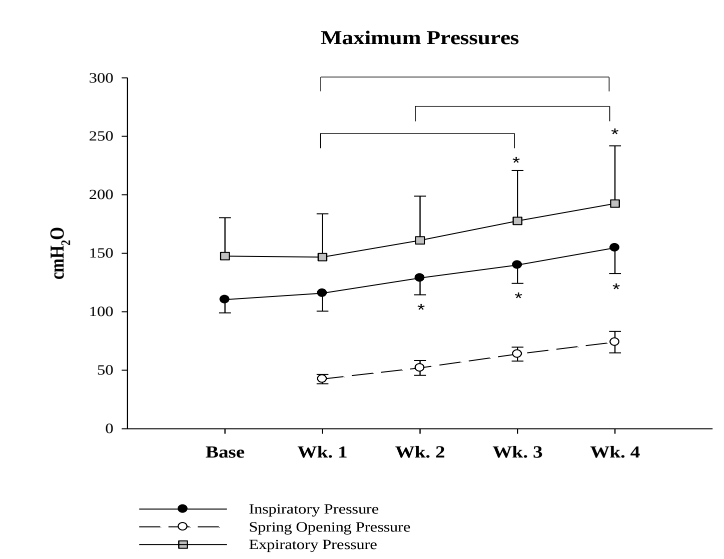

Fig. 1 Maximal inspiratory and expiratory pressures and the average inspiratory and expiratory training resistance (mouth piece spring pressure) at baseline and at the end of weeks 1-4. * Sig. different from their respective baseline measures. Brackets represent significant comparisons between pre- and post-RRMT for both inspiration and expiration, $p < 0.05$.

Fig. 2

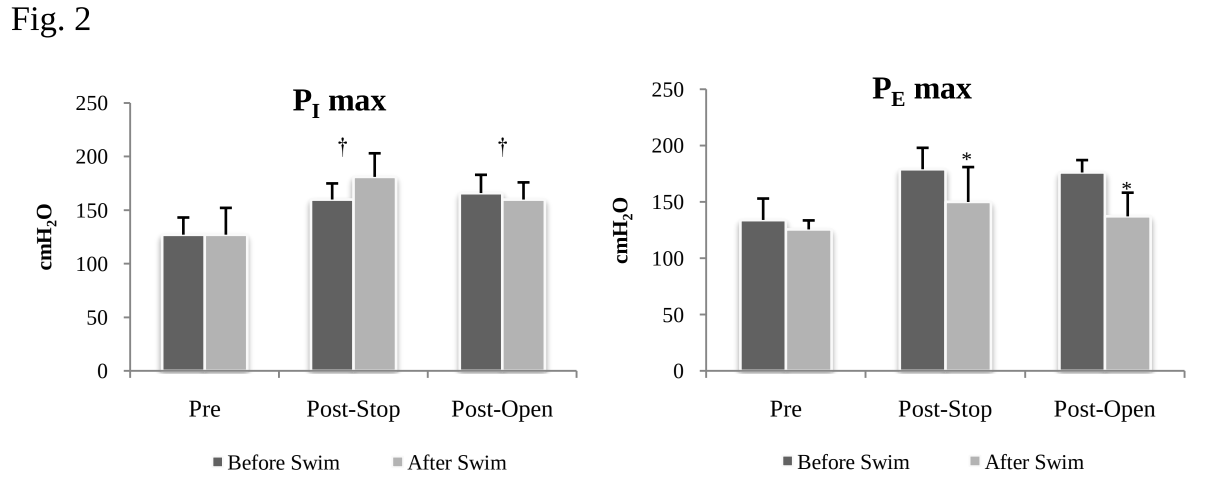

Fig. 2. Means + SD of the maximal inspiratory and expiratory pressures before and immediately after each swimming trial, Pre-RRMT, Post-Stop RRMT (iso-time) and Post-Open RRMT. † Sig. group differences from Pre-RRMT, $p<0.05$; * Sig. different from Pre-RRMT and between before and after swim

Results

Fig. 3

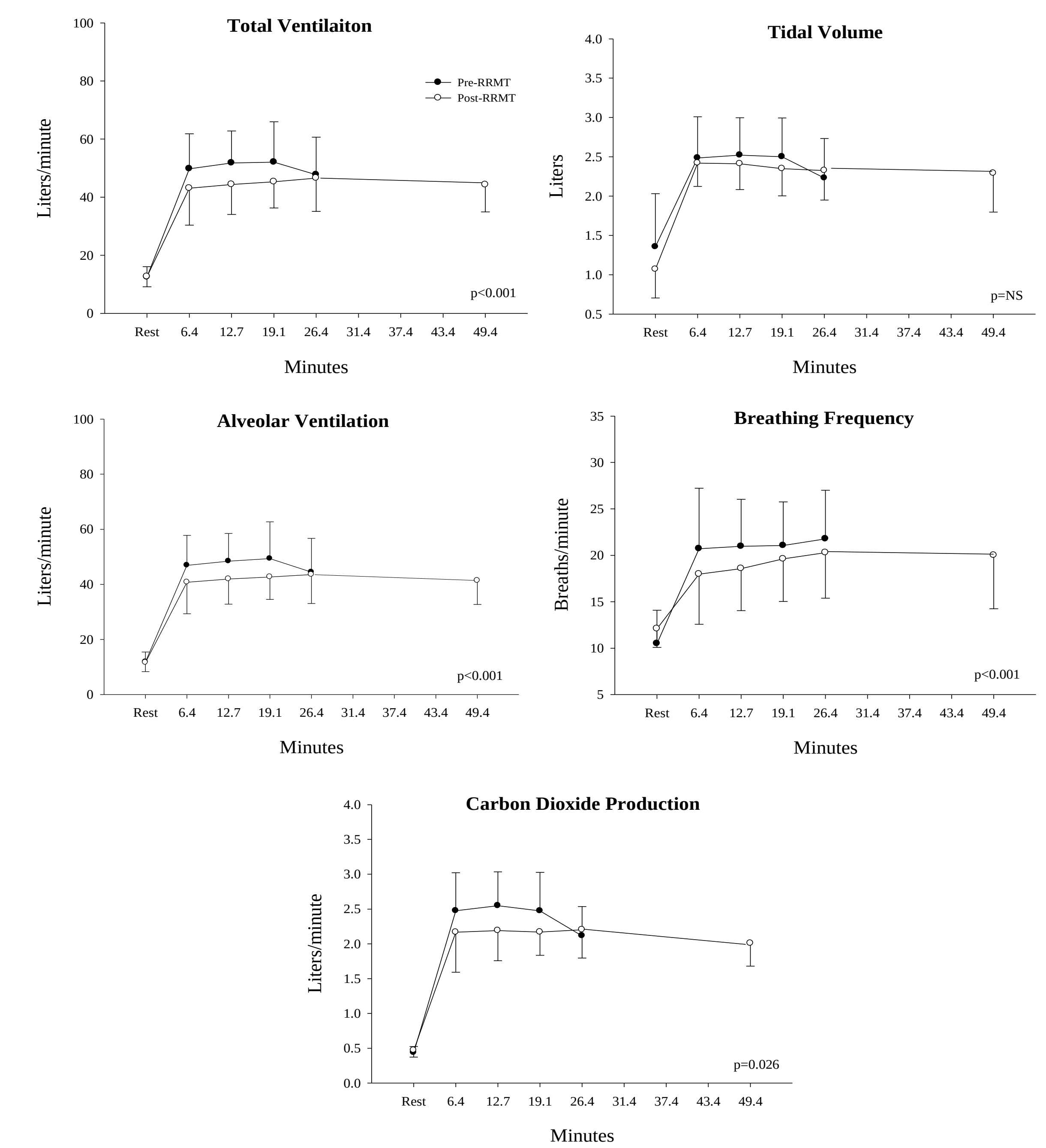

Fig. 3. Mean ± SD of the ventilatory variables and carbon dioxide production during the fin-swimming tests pre-RRMT (dark circles) and post-RRMT (open circles). Data were collected at rest, 25%, 50%, 75%, and 100% of pre-fin-swimming time. Pre-RRMT and post-RRMT fin-swimming times were 26.4 ± 9.7(SD) min vs. 49.4 ± 26.min, respectively. *P*-values represent significant differences between treatment groups (pre- vs. post-RRMT).

Fig. 4

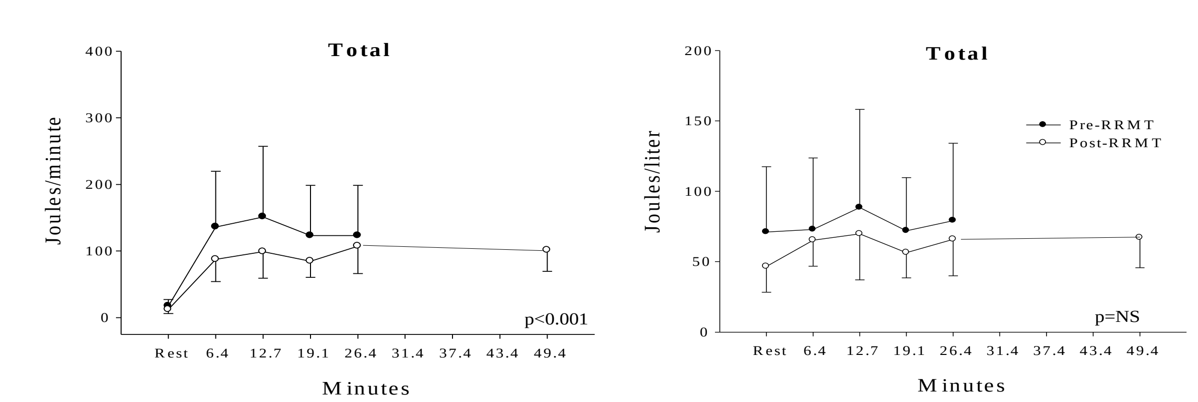

Fig. 4. Mean ± SD of the total (inspiratory + expiratory) work of breathing in joules/min and the work of breathing per liter of expired air during the fin-swimming tests pre-RRMT (dark circles) and post-RRMT (open circles). Data was collected at rest, 25%, 50%, 75%, and 100% of pre-fin-swimming time. *P*-values represent significant differences between treatment groups (pre- vs. post-RRMT).

Results

Fig. 5

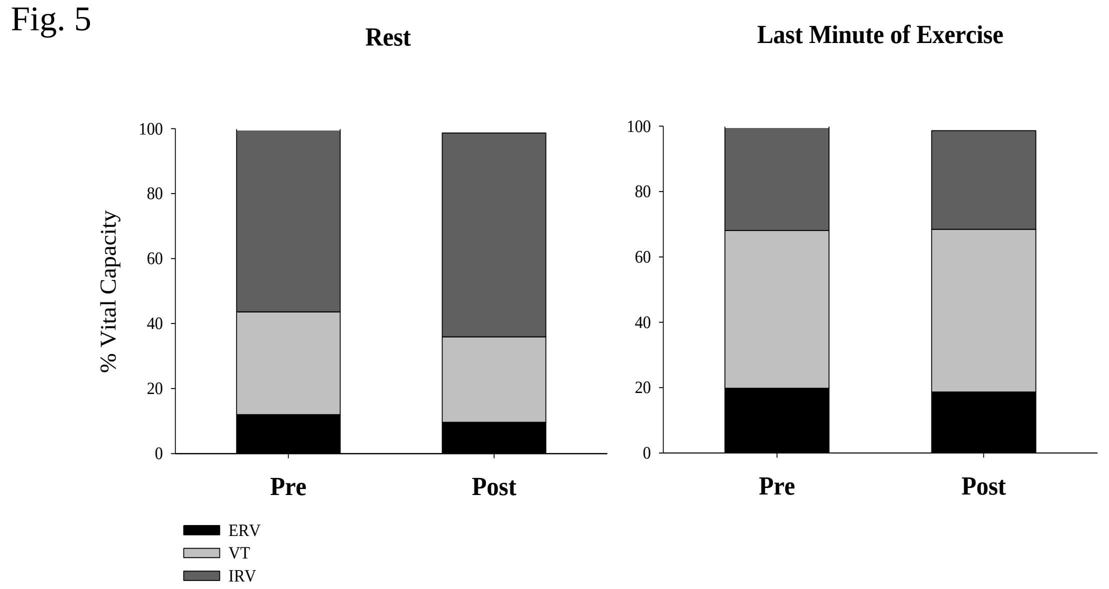

Fig. 5. Lung volumes expressed as a percentage of vital capacity at rest and during the 26th minute of exercise pre-RRMT and post-RRMT. ERV = expiratory reserve volume; IRV = inspiratory reserve volume; and VT = tidal volume. There were no significant differences in lung volumes.

Summary

The primary findings from this study are that RRMT:

- Increased inspiratory and expiratory muscle strength by 40% and 30% respectively
- Improved fin-swimming performance at depth (87%) where the work of breathing is significantly elevated
- Decreased ventilation and breathing frequency post-RRMT
- Decreased the work of breathing (joules/liter) post-RRMT
- Did not alter exercising EELV post-RRMT

Conclusions

It is concluded that RRMT improves respiratory muscle strength, endurance and swimming performance underwater at 120 feet of depth, a response that is consistent with our previous work (Wylegala, et al. 2007 and Ray et. al. 2007), and others during land exercise. A decrease in the work of breathing (reduced breathing frequency) but not respiratory mechanics helps to explain the improvements in swimming performance. Thus, it is reasonable to suggest that the adaptations to the respiratory muscles are associated with improvements in respiratory muscle metabolism and/or efficiency post-RRMT.

Acknowledgments

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