#A22 ENERGY COST OF BREATHING AT DEPTH

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Abstract

BACKGROUND: Respiratory muscle training against resistance (RRMT) increases respiratory muscle strength and endurance, and swimming endurance at depth. We hypothesized that such effects result from RRMT reducing the high energy cost of ventilation at depth.
METHODS: Eight subjects breathed air in a hyperbaric chamber at a pressure equivalent to 55 fsw, before and after RRMT. They rested for 10 min, cycled an ergometer at 100W for 10 min, rested for 10 min, and then performed paced isocapnic (CO2 admixture to inspired air) simulated exercise ventilation (ISEV).
RESULTS: Pre-RRMT minute-ventilation (VE) was 11.95 ± 3.09 L/min during rest, 47.74 ± 8.44 L/min during exercise, and was not different during ISEV (49.98 ± 10.41 L/min). Post-RRMT the values at rest, exercise and ISEV were not different. The end-tidal PCO2's were matched to the VE and were 34.65 ± 4.6 at rest, 44.49 ± 4.49 during exercise and 44.26 ± 2.54 mmHg during ISEV, and were not significantly different post-RRMT (33.58 ± 4.30, 43.59 ± 5.12, 43.40 ± 2.08 mmHg). Oxygen uptake (VO2) was 0.32 ± 0.08 L/min at rest, 1.78 ± 0.15 during exercise and not different pre and post-RRMT, while during ISEV VO2 decreased significantly from pre to post-RRMT (0.46 ±0.06 vs. 0.36 ± 0.11 L/min). The energy cost of ventilation (VO2/VE) was 0.027 ± 0.0063 L/L at rest and 0.038 ± 0.0067 during exercise, and did not change after RRMT; the values were significantly lower during ISEV (0.0094± 0.0021 L/L vs. 0.0074 ± 0.0023 L/L).
CONCLUSION: The energy cost of ventilation, measured as VO2, at a simulated depth of 55 fsw was reduced significantly by RRMT. Whether this change was due to reduced work of breathing, and/or increased efficiency of the respiratory muscles (or some other factor) remains to be determined.

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:

- The hydrostatic pressure differences across the chest wall
- An increase in gas density as a function of depth
- The added gas flow resistance of scuba

The increased work of breathing at depth predisposes the diver to muscle fatigue and a decrease in exercise performance.

Resistance respiratory muscle training (RRMT) has been shown to improve fin-swimming performance (~60%) and reduce V_{O2} and V_E at 4 and 55 fsw, although the mechanisms for these improvements have not been fully determined.

Hypothesis

The purpose of the current study was to determine the energy cost of ventilation and if it is decreased by RRMT.

RRMT will decrease the energy cost (V_{O2}) of ventilation

Methods

Subjects: Eight male divers participated (28 ± 6 (SD) yrs) in testing pre- and post-RRMT

Measurements: Non-immersed subjects breathed air through a mouthpiece connected to a bag-in-box collection system (Fig. 1) in a hyperbaric chamber at 2.67 ATA (55 fsw).
They:

- rested for 10 min
- cycled ergometer at 100 Watts for 10 min
- rested for 10 min. and then
- ventilated, paced by a computer, at a level equal to that observed during exercise (Fig. 2) (isocapnic simulated exercise ventilation (ISEV)). The alveolar CO_2 level was kept normocapnic by CO_2 admixture.

During the last 2-4 min of each period, expired gas was collected and analyzed for volume and O_2 & CO_2 (mass spectrometer). End-tidal CO_2 was sampled continuously.

RRMT: Paced by a computer (Fig. 3), subjects performed a vital capacity maneuver once every 30s for 30 min against an average resistance of ~59 cmH_2O. This was performed 3 days/week for 4 weeks (Ray Poster #A27).

Figure 1. Bag-in-Box Equipment Schematic

A - Barrel
B - Bag In Barrel
C - Mouthpiece
D - Vacuum Limiter
E - Spirometer
F - Potentiometer
G - Ball Valve
H - Ball Valve
J - Barrel Fill Valve
K - Gasometer
L - Mass Spectrometer
M - Pressure Regulator
N - Bag Empty Valve
O - Pressure Transducer
P - Pressure Transducer
Q - Douglas Bag
R - Demand Regulator
S - Metering Valve
T - Mixed Gas Supply
U - Esophageal Catheter
V - Temperature Gauge
W - Differential Pressure Gauge
X - Humidifier
Y - Ergometer

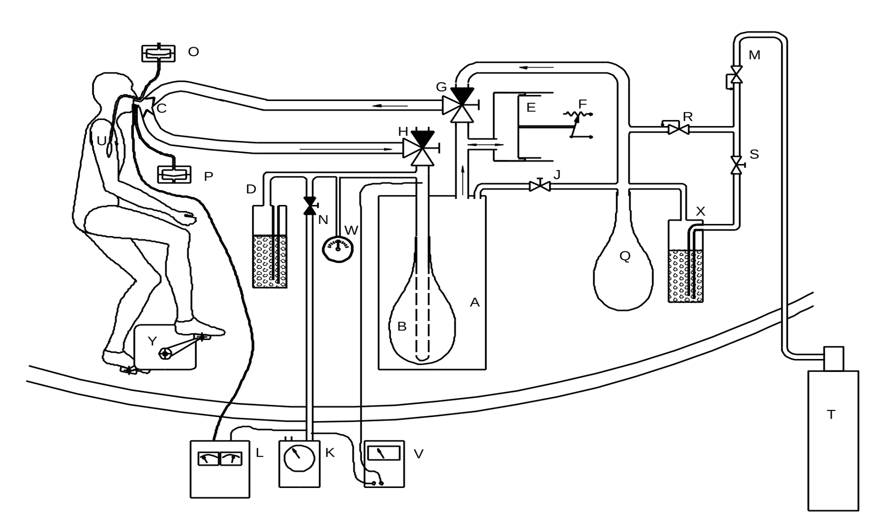


Figure 2. Ventilatory Computer Tracing

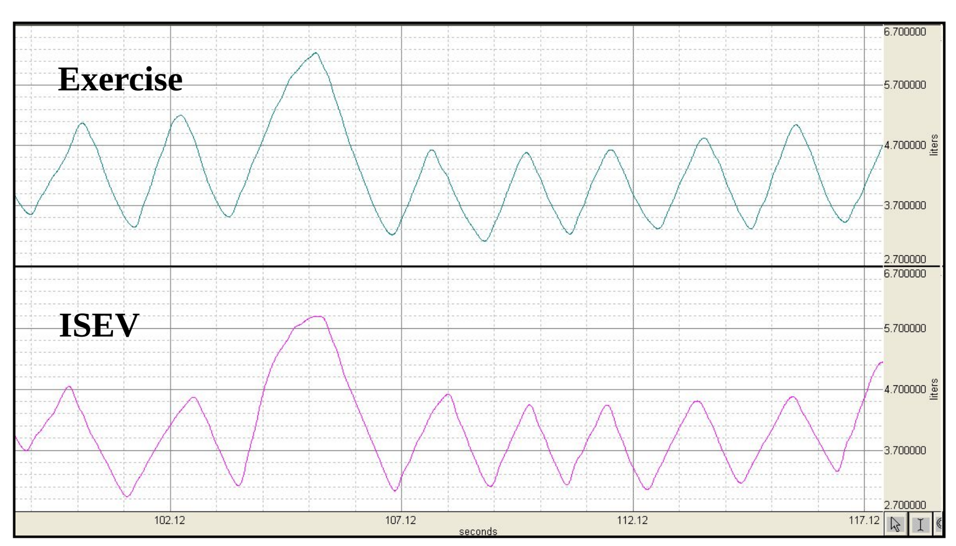
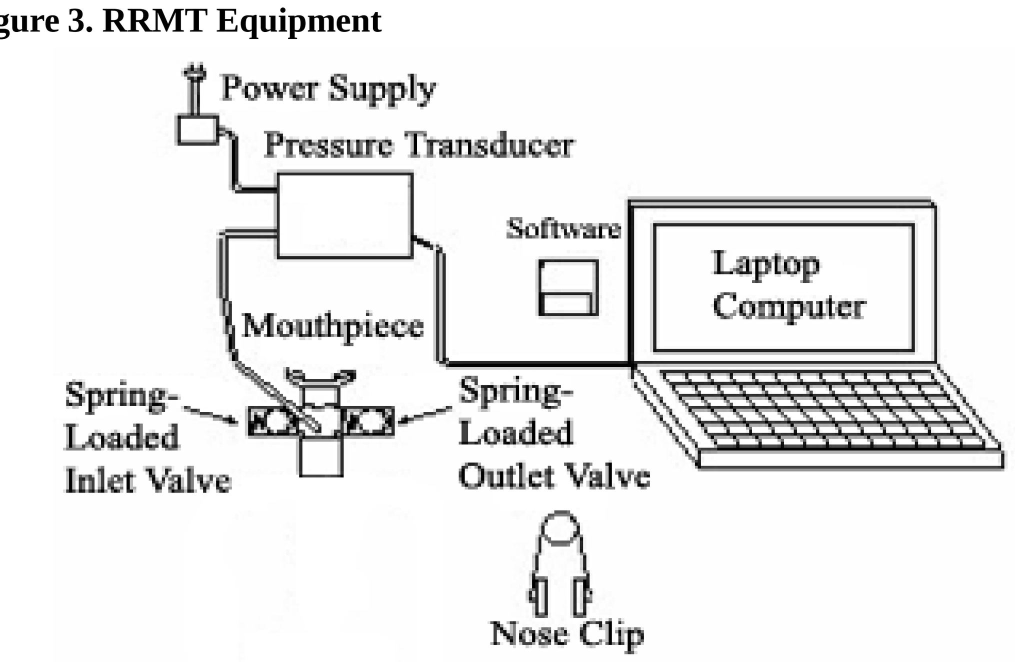


Fig. 2 Trace showing ISEV ventilation pattern paced to match exercise ventilation.

Figure 3. RRMT Equipment



Results

Figure 4 . Ventilation pre- and post-RRMT

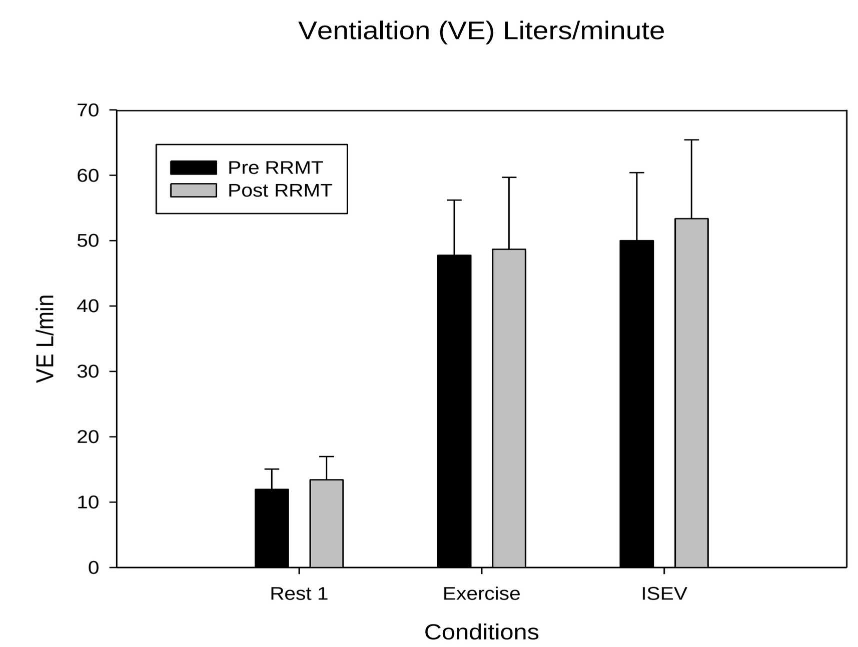


Fig 4. There was no significant difference between pre-RRMT and post-RRMT at rest. The ISEVs pre-and post-RRMT matched the respective exercise V_Es. V_E was not different between pre- and post-RRMT for exercise and ISEV.

Figure 5. End Tidal P_{CO2} pre-and post-RRMT

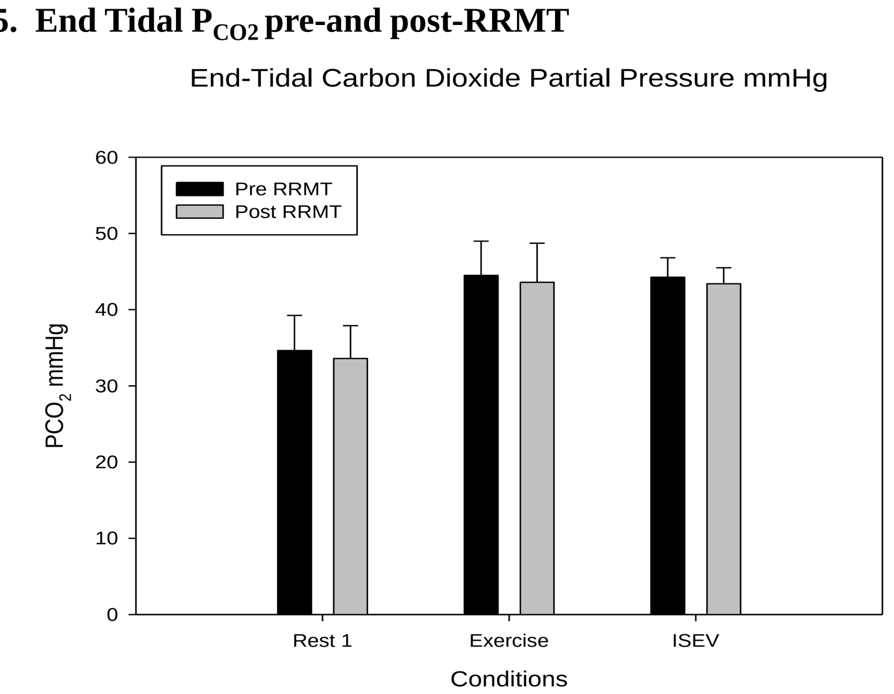


Fig. 5 End-tidal P_{CO2} was not different among the conditions pre- and post-RRMT

Figure 6. Oxygen Uptake L/min pre- and post-RRMT

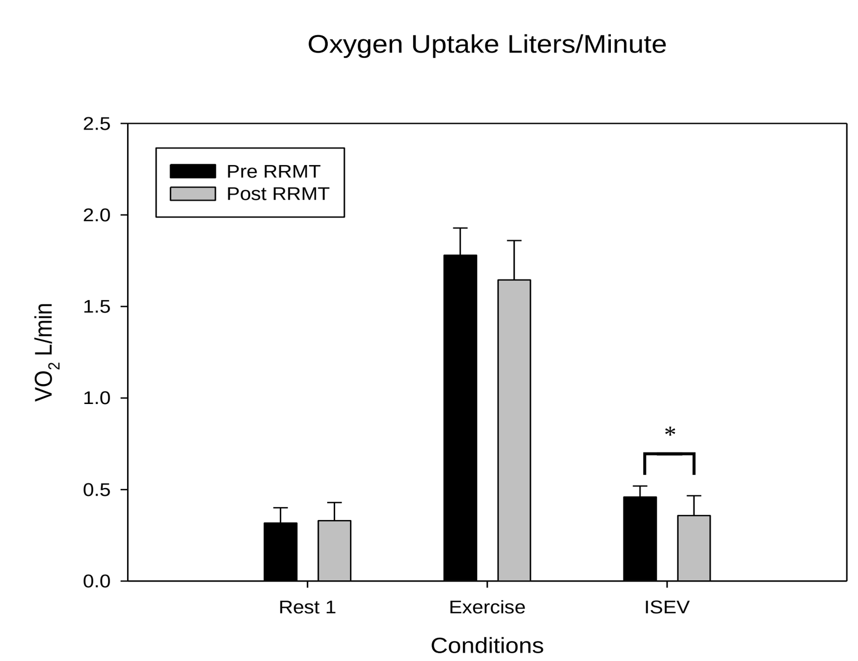


Fig. 6 There were no significant differences in VO2 at rest or during exercise pre- and post-RRMT. During ISEV VO2 decreased significantly (, p<0.05) from pre-RRMT to post-RRMT.*

Results

Figure 7. Energy Cost of Ventilation pre- and post-RRMT

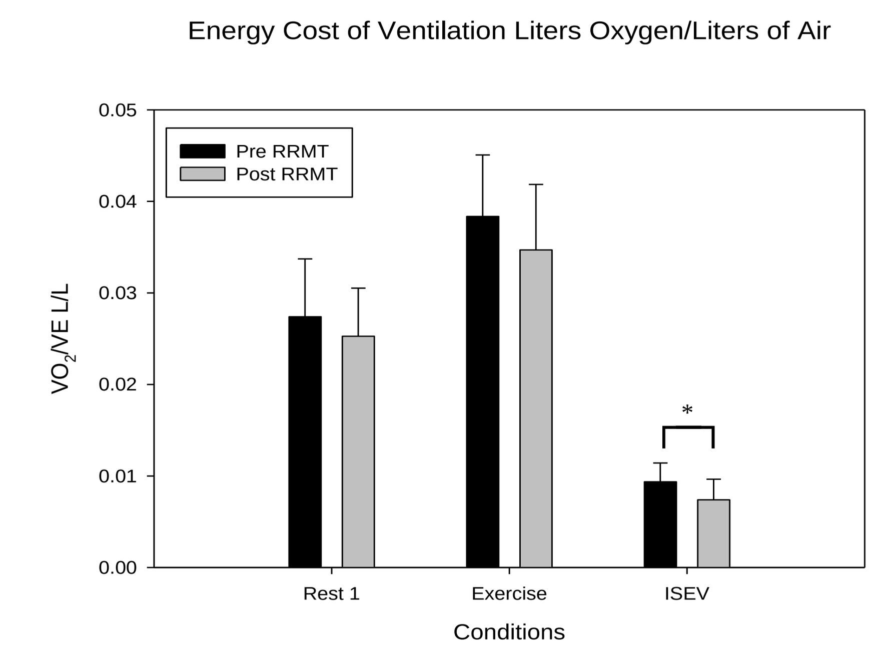


Fig. 7. There were no significant differences in the ventilatory equivalent (V_{O2}/V_E) among conditions at rest or during exercise. V_{O2}/V_E was significantly (, $p<0.05$) lower during ISEV post-RRMT than pre-RRMT.*

Summary

The primary findings from this study are that:
1. The V_{O2} during ISEV at 2.67 ATA (55 fsw) was reduced by ~22% after RRMT.
2. RRMT resulted in a decrease (~22 %) of the energy cost of ventilation (V_{O2}/V_E),as determined during ISEV, at depth.

Conclusions

The reduction in the energy cost of ventilation observed after RRMT is associated with an increase in exercise performance (Ray Poster #A27). Possible mechanisms for this are:
1. Reduced work of breathing
2. Improved respiratory muscle efficiency , *i.e* work of breathing required per volume of O_2 metabolized (WOB/V_{O2}).

Further research is ongoing in our laboratory to determine the mechanisms involved in the energy cost of breathing at depth.

Acknowledgements

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