Effects of Submersion and Depth on Respiratory Mechanics Following Respiratory Muscle Training

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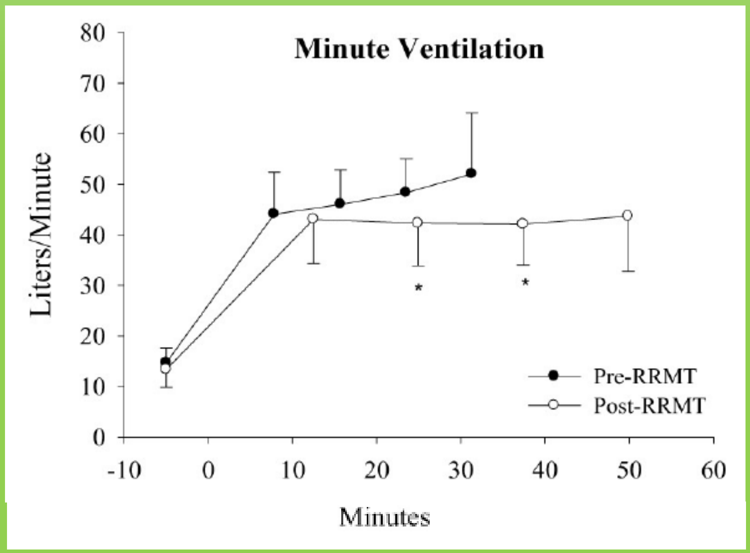
Introduction

- Respiratory muscle fatigue may limit exercise endurance
  - Near fatigue, ventilation rate and carbon dioxide elimination increase
- Respiratory muscle training (RMT) can increase exercise endurance time



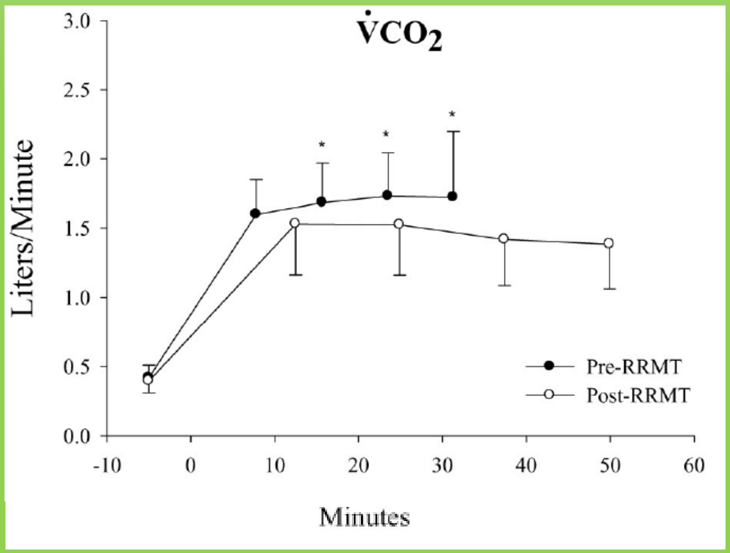


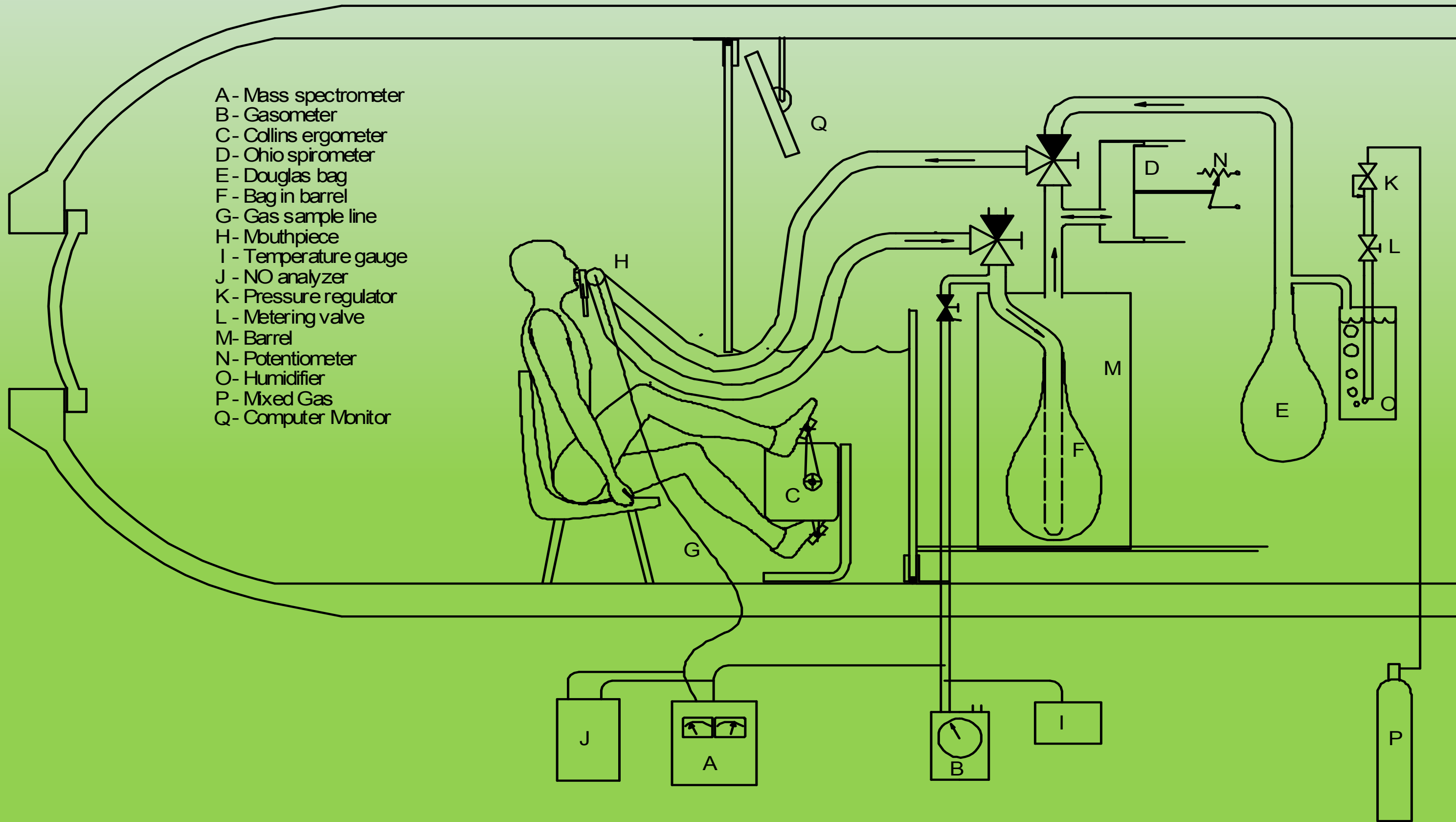
Fig. 1. Minute Ventilation and carbon dioxide production at rest and 25, 50, 75, and 100% of endurance swim time pre- and post-RMT

Images from Ray, A., D. Pendergast, et al. (2008). "Respiratory muscle training improves swimming endurance at depth." <u>Undersea Hyperb Med</u> **35**: 185-196.

Protocol

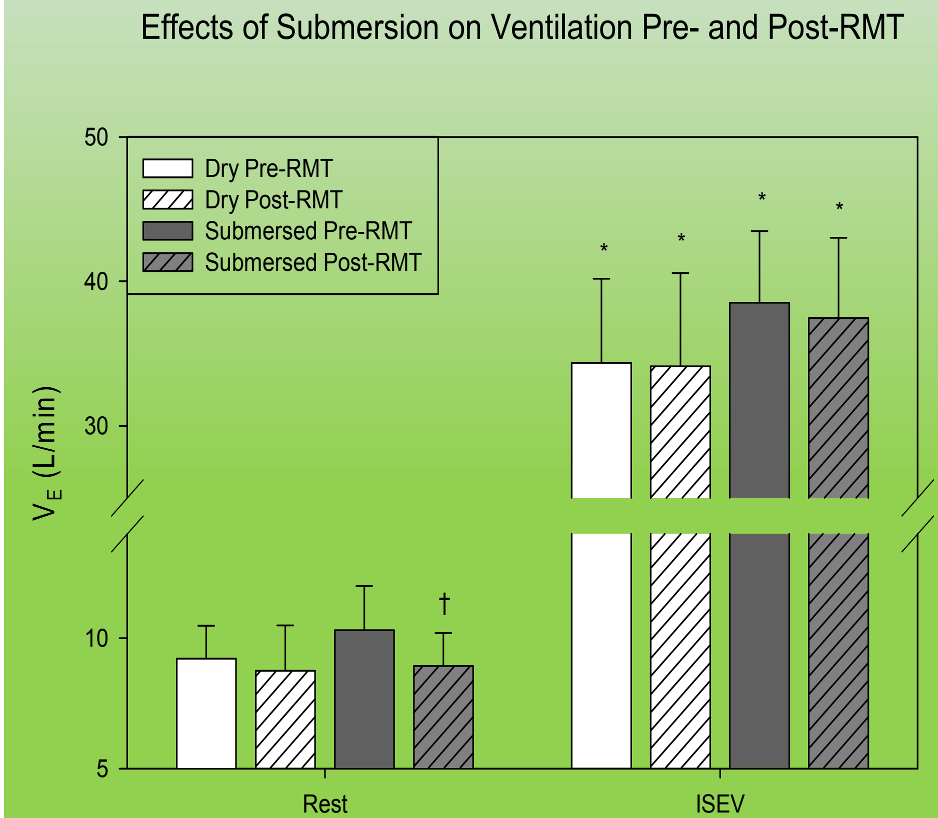
- Four subjects (32.20 ± 3.68yrs, 179.89 ± 0.97cm, 86.00 ± 6.23kg) underwent experiments both dry and fully submersed at the surface (1ATA), 55fsw (2.7 ATA), and 120fsw (4.6 ATA)
- Each experiment consisted of four periods:
  - *Rest* (10 min)
  - *Exercise* (100W, 10 min)
    - –Spirometer volume recorded continuously for playback
  - *Rest* (20 min)
  - *Isocapnic Simulated Exercise Ventilation (ISEV)*
    - –Ventilation paced to match the previously recording exercise V_E
    - –Subjects breathed air supplemented with CO_2 to prevent hypocapnia

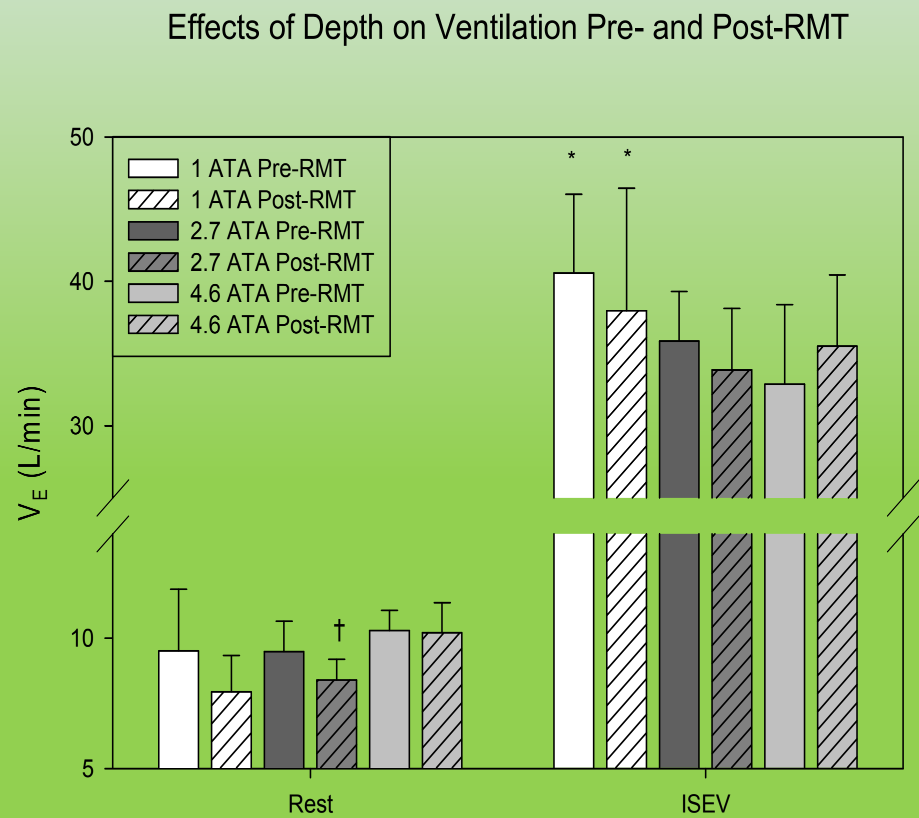
Experimental Setup



- Schematic of a subject seated behind the "Buffalo Barrier" inside hyperbaric chamber
- The subject breathes from a large bag-in-box system
- During submersion, the water level imposed a -15 cmH_2O static lung load (as commonly experienced in diving)

Results: Minute Ventilation



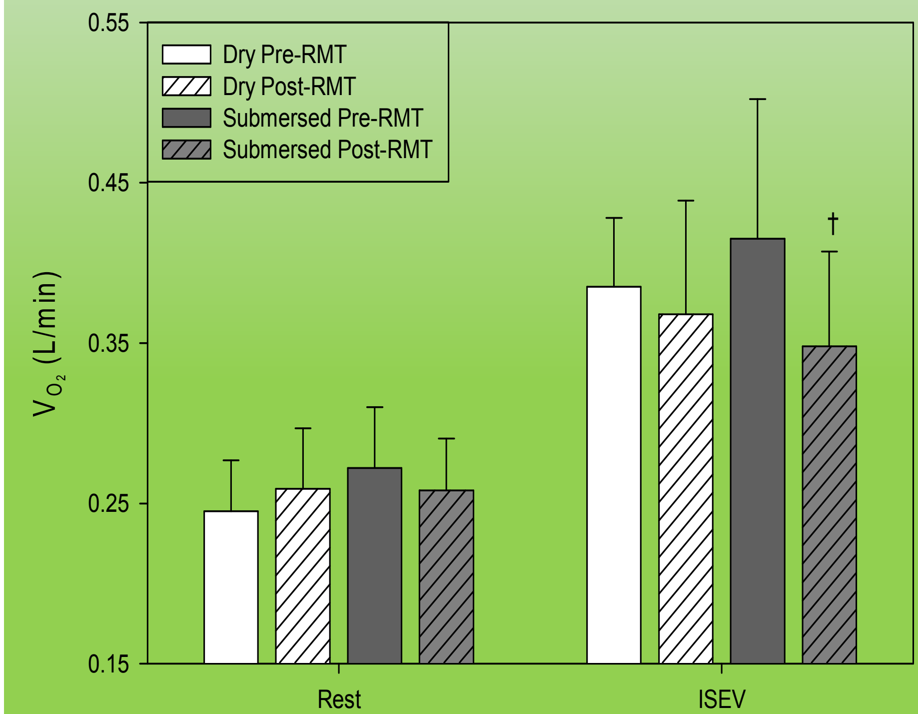


Data presented as mean ± standard deviation
* indicates significant difference between rest and ISEV for a single condition ($p < 0.05$ using one-way ANOVA)
† indicates significant difference between pre- and post-RMT for a single condition ($p < 0.05$ using a paired t-test)

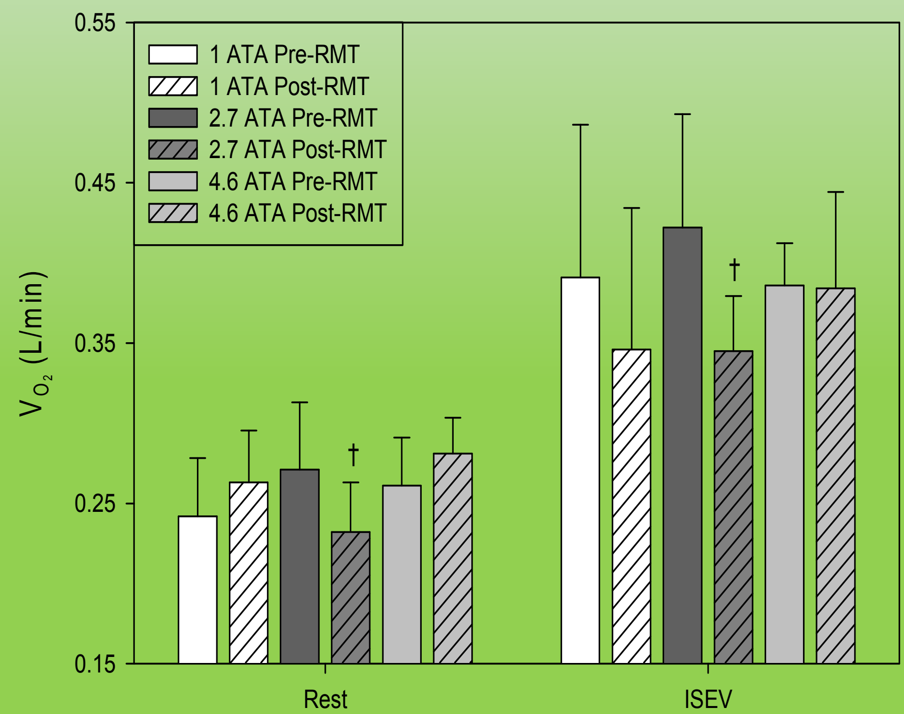
- Before RMT, V_E tended to increase with submersion and decrease with depth
- After RMT, V_E tended to decrease compared with Pre-RMT values

Results: Oxygen Consumption

Effects of Submersion on Oxygen Consumption Pre- and Post-RMT



Effects of Depth on Oxygen Consumption Pre- and Post-RMT



Data presented as mean ± standard deviation
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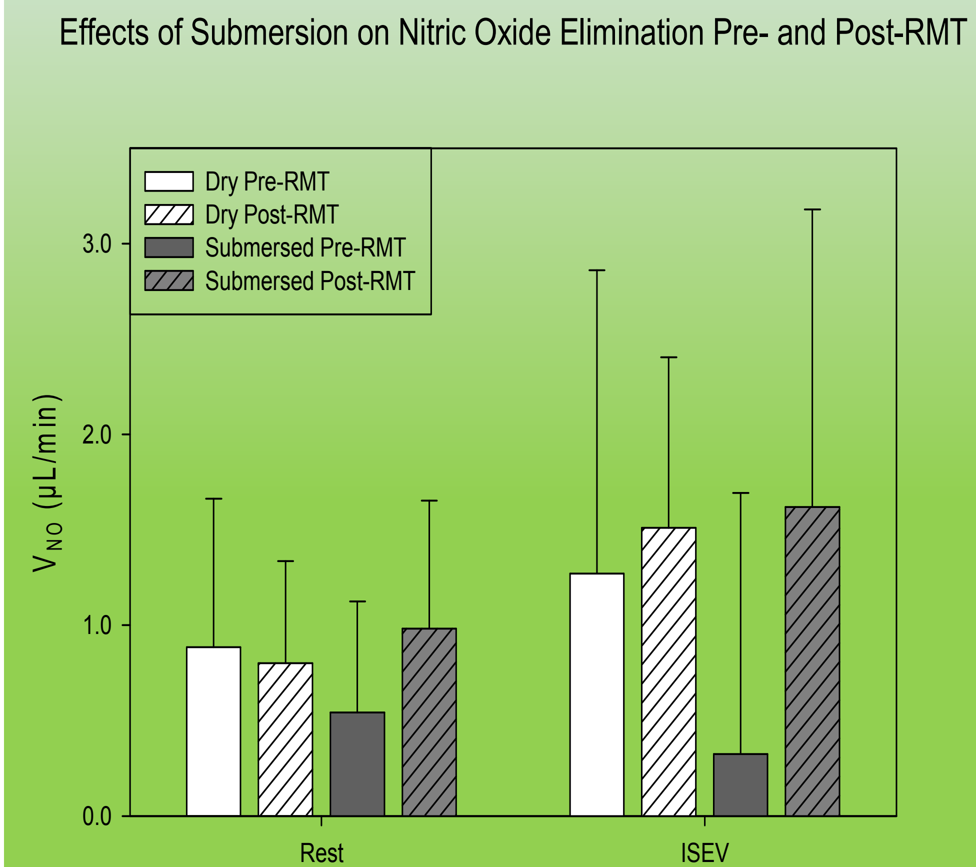
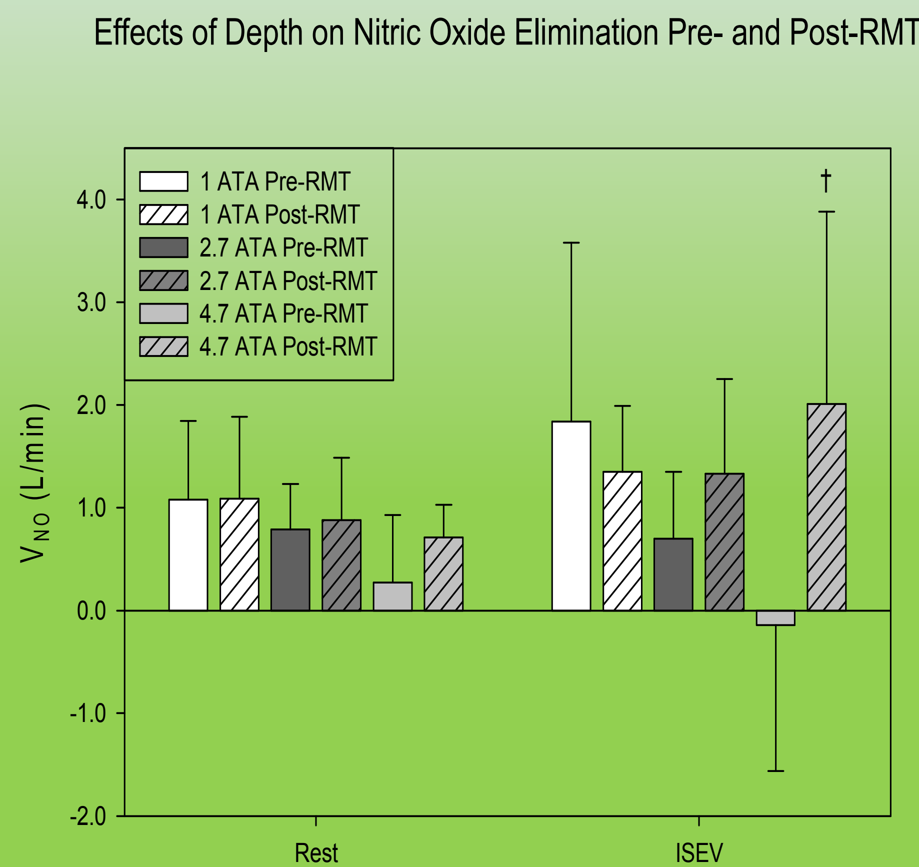
- Before RMT, V_{O2} tended to increase with submersion but showed no trend with depth
- Following RMT, V_{O2} tended to decrease compared with pre-RMT values

Results: Nitric Oxide Elimination





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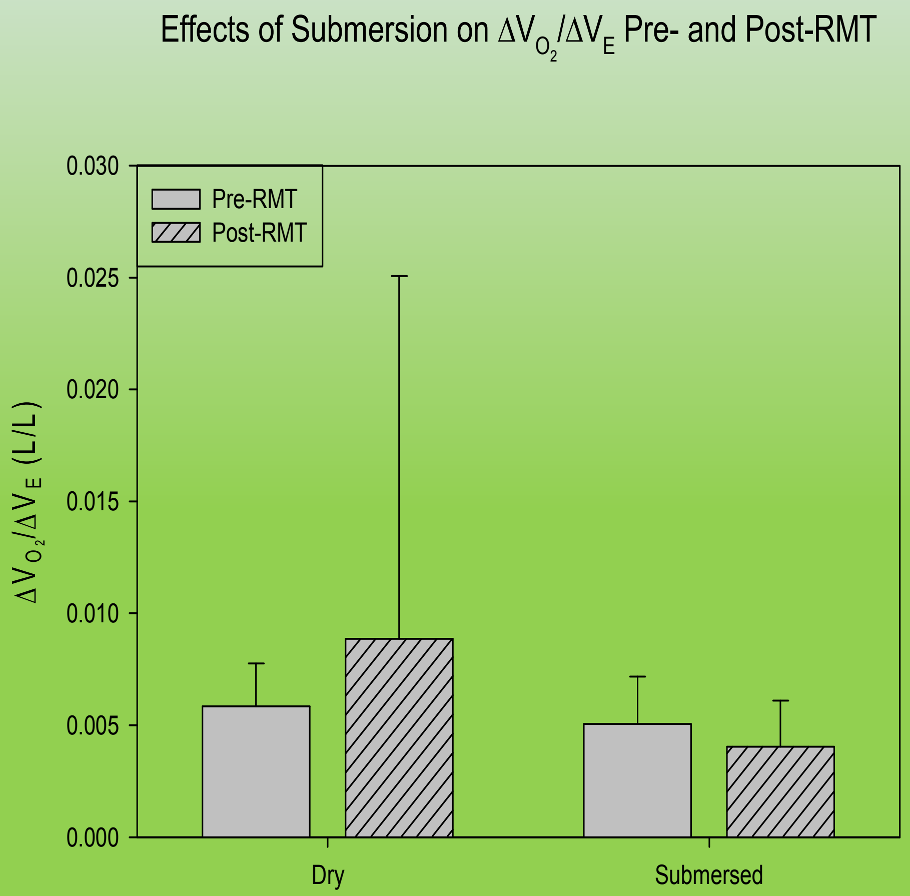
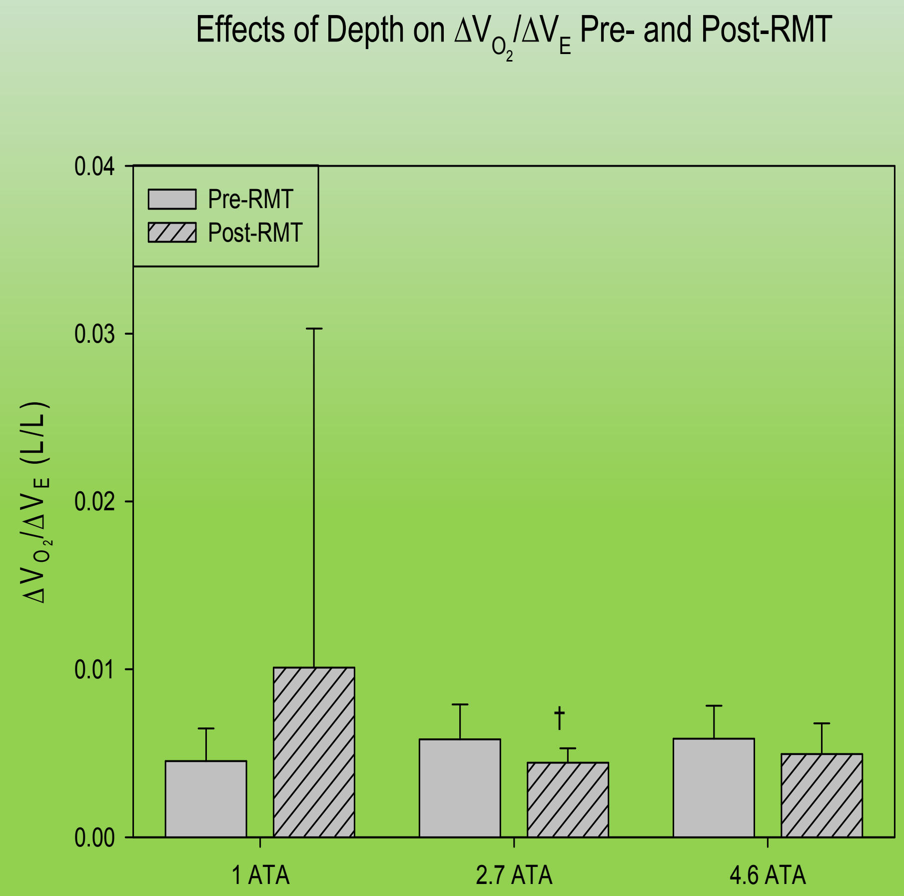
- Before RMT, V_{NO} tended to decrease with submersion and depth
- Following RMT, V_{NO} tended to increase compared with pre-RMT levels

Results: $\Delta V_{O2}/\Delta V_E$





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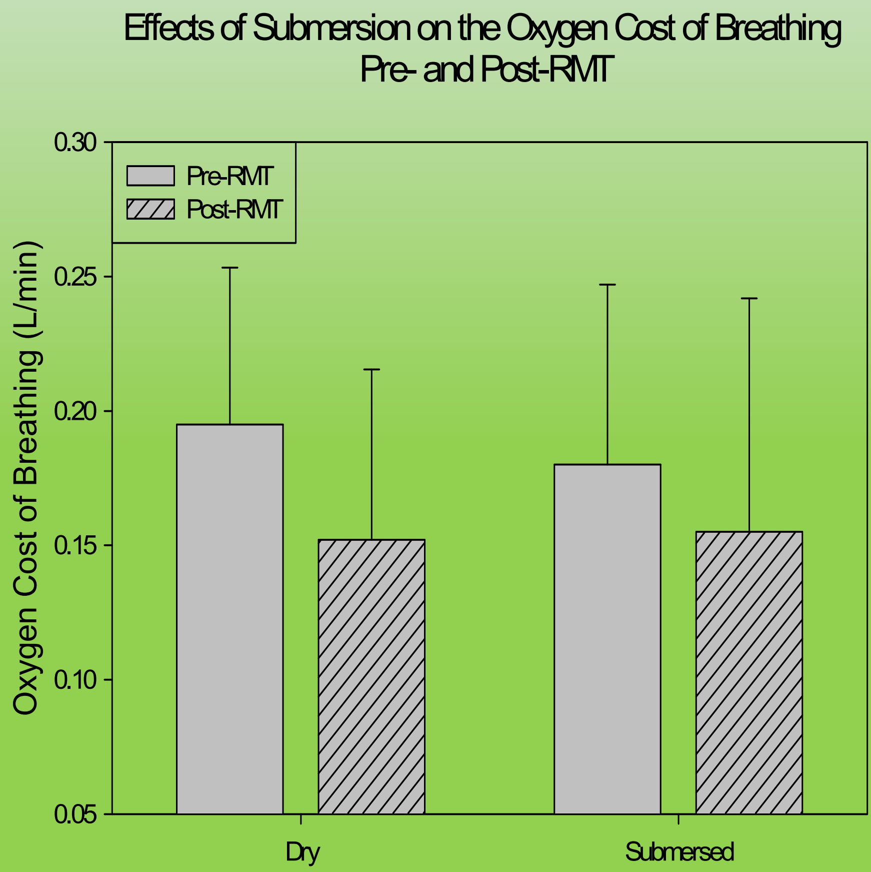
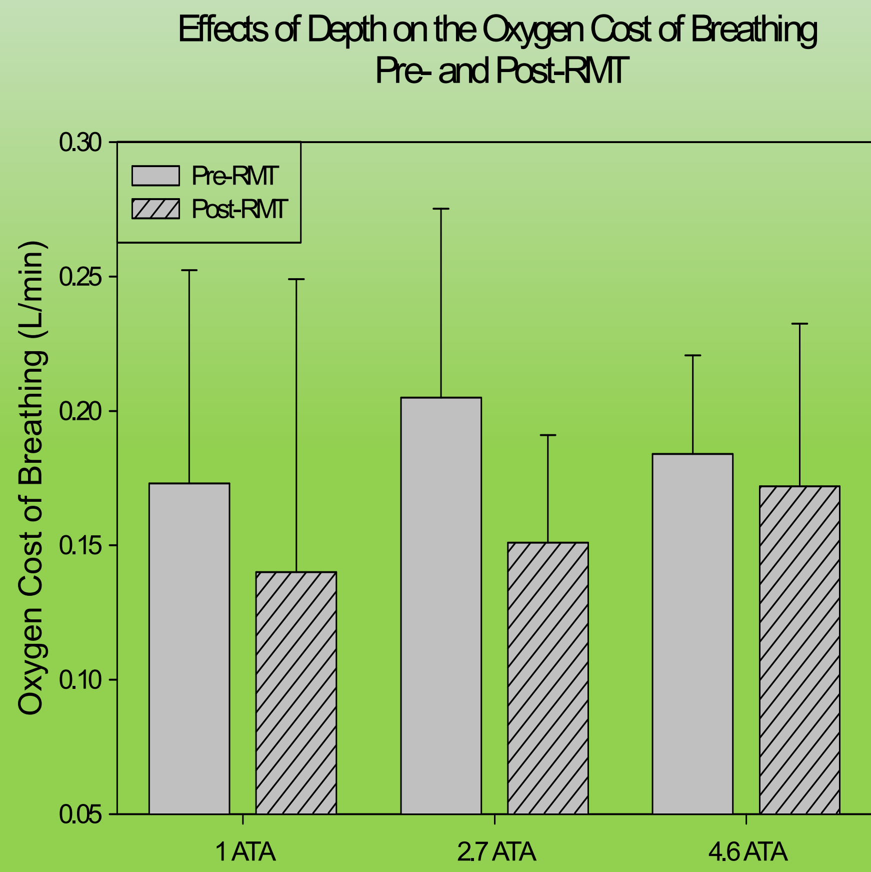
- $\Delta V_{O2}/\Delta VE = (V_{O2\ ISEV} - V_{O2\ Rest})/(V_{E\ ISEV} - V_{E\ Rest})$
- $\Delta V_{O2}/\Delta VE$ tended to decrease following RMT

Results: Oxygen Cost of Breathing



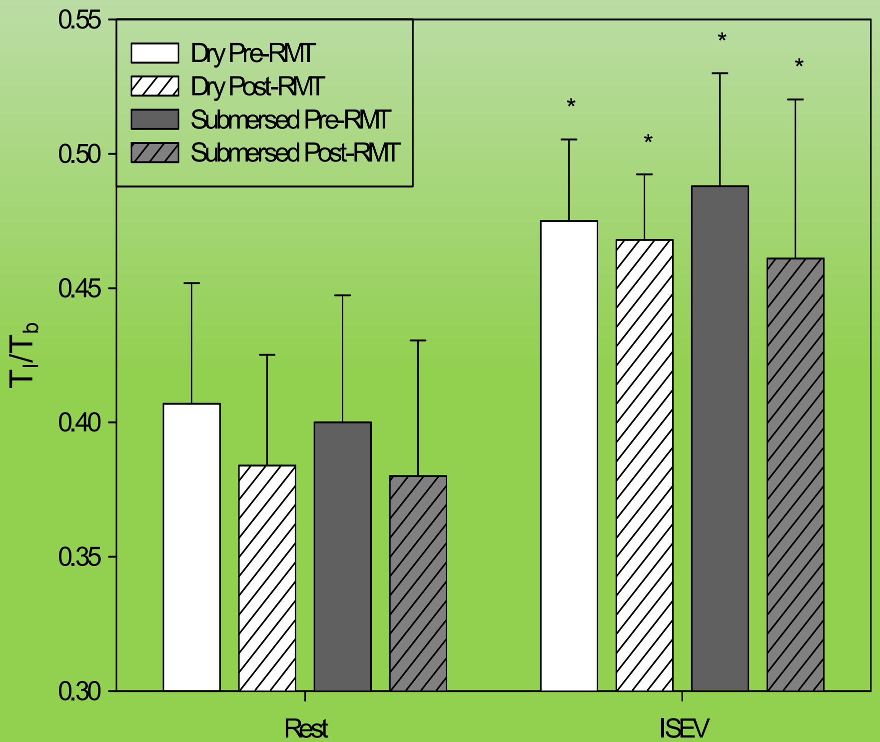
Data presented as mean ± standard deviation



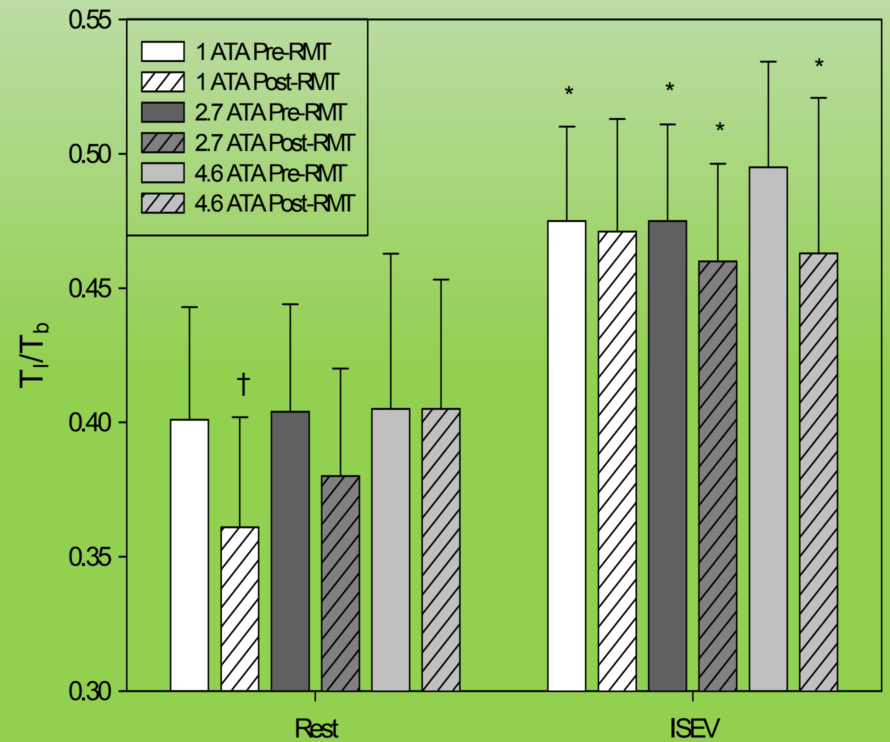
- Absolute Oxygen Cost of Breathing = $(\Delta V_{O2}/\Delta V_E)*V_{E\ ISEV}$
- The oxygen cost of breathing tended to decrease following RMT

Results: Respiratory Duty Cycle

Effects of Submersion on Respiratory Duty Cycle Pre- and Post-RMT



Effects of Depth on Respiratory Duty Cycle Pre- and Post-RMT



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- Duty cycle: $T_{inspiration} / T_{breath}$
- Respiratory duty cycle tended to decrease following RMT

Conclusions

- Following RMT, lower ventilation rate, increased nitric oxide elimination, and shorter duty cycle may lead to less turbulence in the airways, less chance of dynamic airway collapse during expiration, and unloading of the expiratory muscles.
- These changes may lead to a more efficient pattern of breathing, as evidenced by lower V_{O2} and oxygen costs of breathing.
- These changes likely indicate the mechanism by which RMT improves performance.

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