



# Human Performance and Pulmonary O<sub>2</sub> Toxicity Guidance for Repeated 6-hour Resting and Exercise Dives

**Background:** We have documented objective measures of excessive fatigue and exercise intolerance following longer duration repeated dives. However, no guidance exists regarding the anticipated impact of repeated dives on diver performance. To simulate resting and active diver scenarios, this project will continue resting dive characterization and include exercise dives.

**Work Effort Benefits:** The current work will provide guidance to enable better dive planning for SDV, combat swimmer, or other longer duration repeated dive operations. This effort may also enable the future development of countermeasures to enhance safety, human performance, and mission completion.

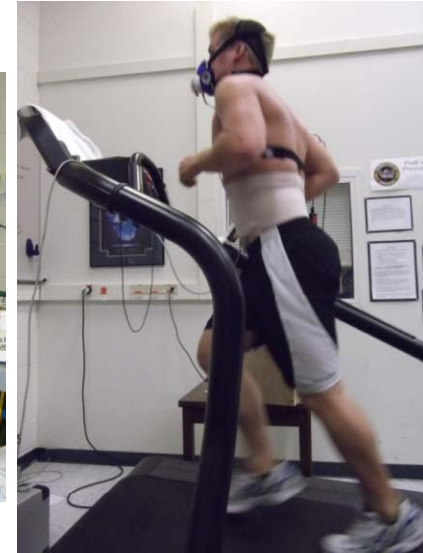
**Status:** NEW START

## Objectives:

1) Characterize diver physiological/cognitive function and performance following repeated 6-hour resting and exercise dives. 2) Develop guidance regarding the anticipated impact (onset of symptoms, adaptation, recovery) from repeated dives on diver performance.

## Deliverables:

- ☐ Guidance based on performance, cognitive function, orthostatic tolerance, and pulmonary O<sub>2</sub> toxicity
- ☐ Technical Report
- ☐ Manuscript prepared for submission to peer-reviewed journal



## Goals/Milestones:

**FY11 Goal** – Repeated Test Pool and Ocean Simulation Facility (OSF) dives

- ☒ Complete oxygen dives in Test Pool
- ☒ Conclude air dives in Test Pool
- ☒ Commence repeated 6-hour dry dives in OSF

**FY12 Goal** – Exercise dives and analyses

- ☐ Complete exercise dives in Test Pool
- ☐ Develop performance and pulmonary O<sub>2</sub> toxicity guidance for repeated resting and exercise dives

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# **Effects of Repeated 6-hour 100% Oxygen Dives on Diver Performance and Orthostatic Tolerance**

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**Sponsoring Institution: NAVSEA DSB DP**

**New Start**



# Objectives



## Human Performance and Pulmonary O<sub>2</sub> Toxicity Guidance for Repeated 6-hour Resting and Exercise Dives

### Project Objectives

- **Objective 1:** Characterize diver physiological/cognitive function and performance following repeated 6-hour resting and exercise dives.
- **Objective 2:** Develop guidance regarding the anticipated impact (onset of symptoms, adaptation, recovery) from repeated dives on diver performance.

### Abstract Objective

- Characterize postdive performance and orthostatic tolerance following repeated air dives and to determine any added effects of breathing 100% oxygen



# Experimental Design



- Protocols**

1) Resting 100% O<sub>2</sub> dives in Test Pool

2) Resting air dives in Test Pool

3) Resting 100% O<sub>2</sub> dry dives in Simulation Facility

4) 100% O<sub>2</sub> dives with intermittent exercise in Test Pool

Experimental Condition  
Recruit (N=12)

Consent  
Medical screening, VO<sub>2</sub> max

Control

Experimental Series

Control ET baseline  
(treadmill test to fatigue)

Control – 1 dive  
Pre-/post-dive testing

Post-control ET test  
Post-control PFT

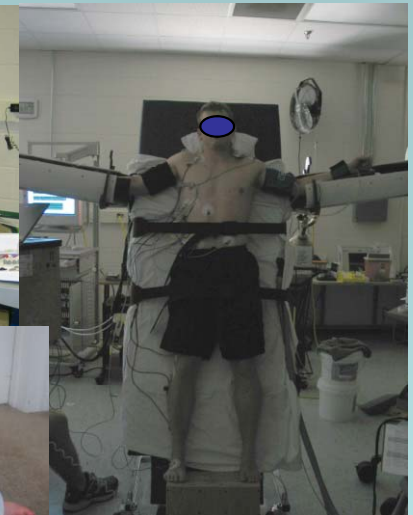
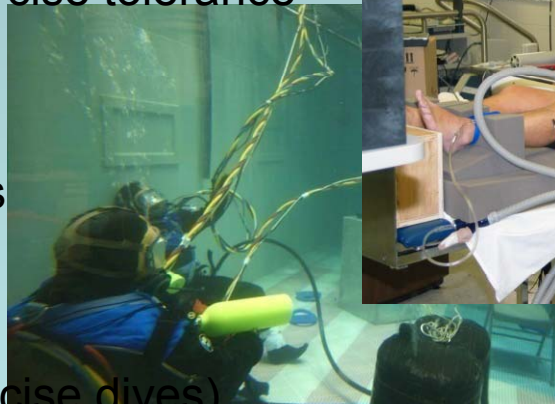
Series ET baseline  
(treadmill test to fatigue)

5 consecutive dives  
Pre-/post-dive testing

Post-series ET test  
Post-series PFT

- Variables**

- Dynamic and static exercise tolerance
- Hormones, electrolytes
- Pulmonary function
- Hemodynamic variables
- Heart rate variability
- Bioelectrical impedance
- Cognitive function (exercise dives)





# Subject Characteristics



Sex (M)	10	10
Age (years)	34 $\pm$ 2	34 $\pm$ 3
Height (cm)	179 $\pm$ 2	179 $\pm$ 3
Weight (kg)	88 $\pm$ 3	85 $\pm$ 2
BMI (kg/m <sup>2</sup> )	27 $\pm$ 1	26 $\pm$ 0
Body fat (%)	18 $\pm$ 1	19 $\pm$ 1
VO <sub>2</sub> max (ml/kg/min)	55 $\pm$ 3	54 $\pm$ 3
Total cholesterol (mg/dl)	202 $\pm$ 7	179 $\pm$ 10
HDL (mg/dl)	50 $\pm$ 5	50 $\pm$ 5
LDL (mg/dl)	131 $\pm$ 11	116 $\pm$ 7
Hemoglobin (mg/dl)	15 $\pm$ 0	15 $\pm$ 0
Hematocrit (% PCV)	44 $\pm$ 1	45 $\pm$ 1

- Inclusion criteria
  - Healthy
- Nonsmoker
  - Not hypertensive
  - No medications
  - BMI < 30 and body fat < 20%
  - Total chol < 220 mg/dl
- Study requirements
  - No alcohol (2 days) or caffeine (1 day)
  - No O<sub>2</sub> dive (2 weeks) or air dive (1 week)
  - Fast for 2 hrs and no exercise prior to dives

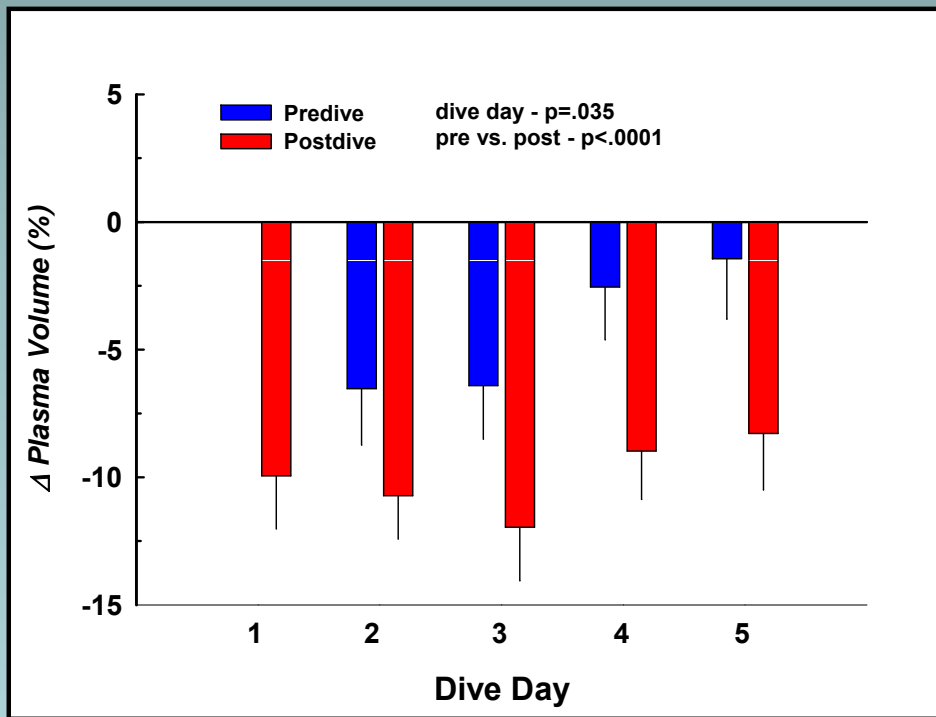




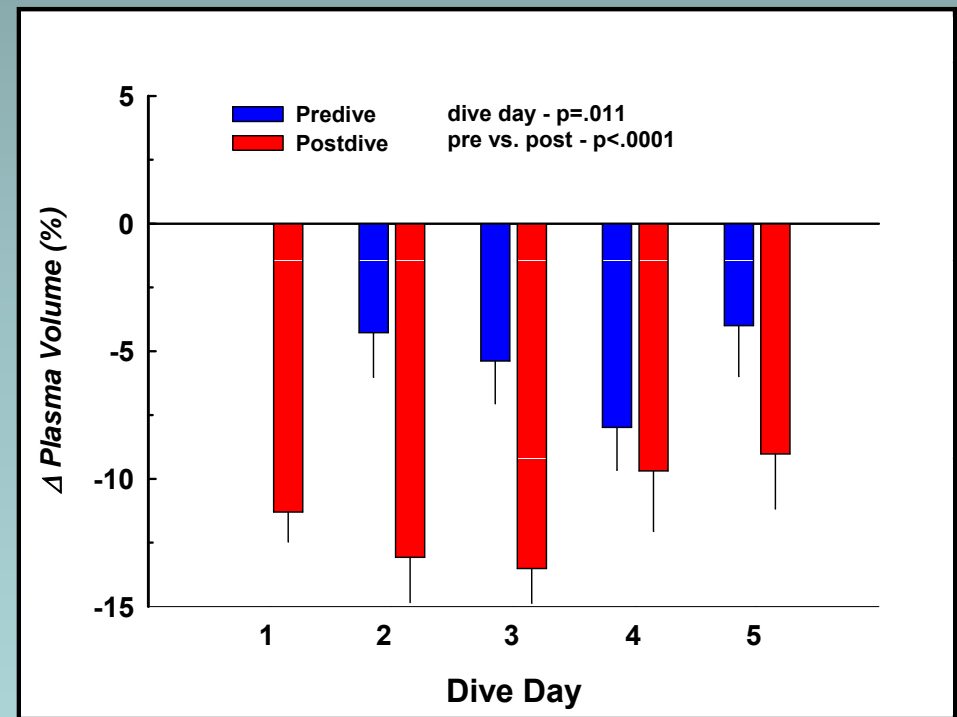
# Plasma Volume



## 100% O<sub>2</sub> Dives



## Air Dives



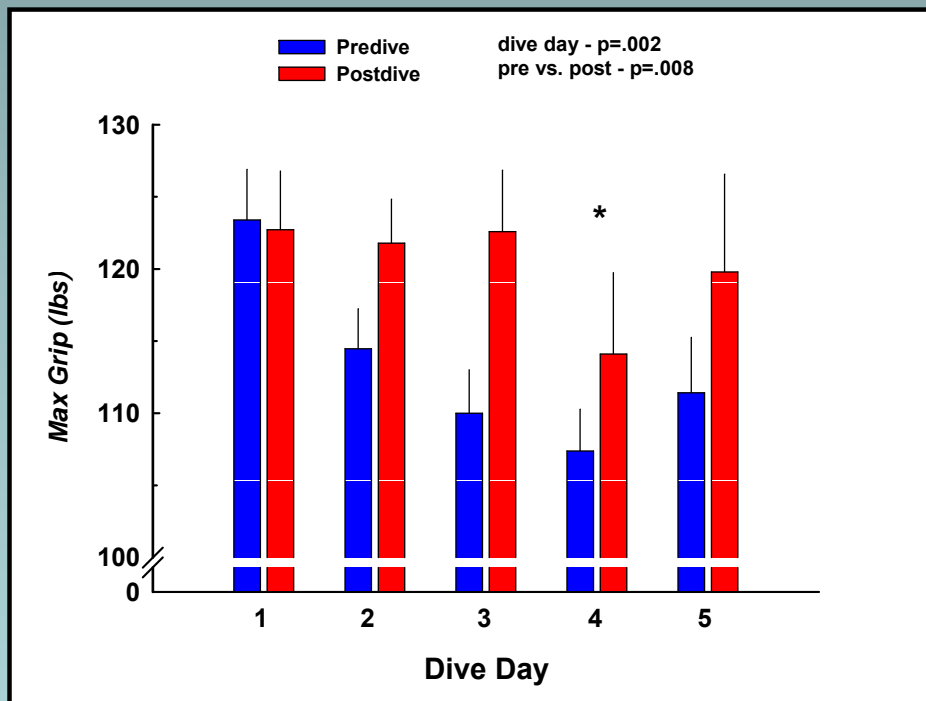
- Urine output greater for air (1490 ml) vs O<sub>2</sub> (1210 ml) dive –  $p=0.001$
- Trend toward greater weight loss after air (1.9 kg) vs O<sub>2</sub> (1.7 kg) dives –  $p=0.09$
- No difference in fluid intake



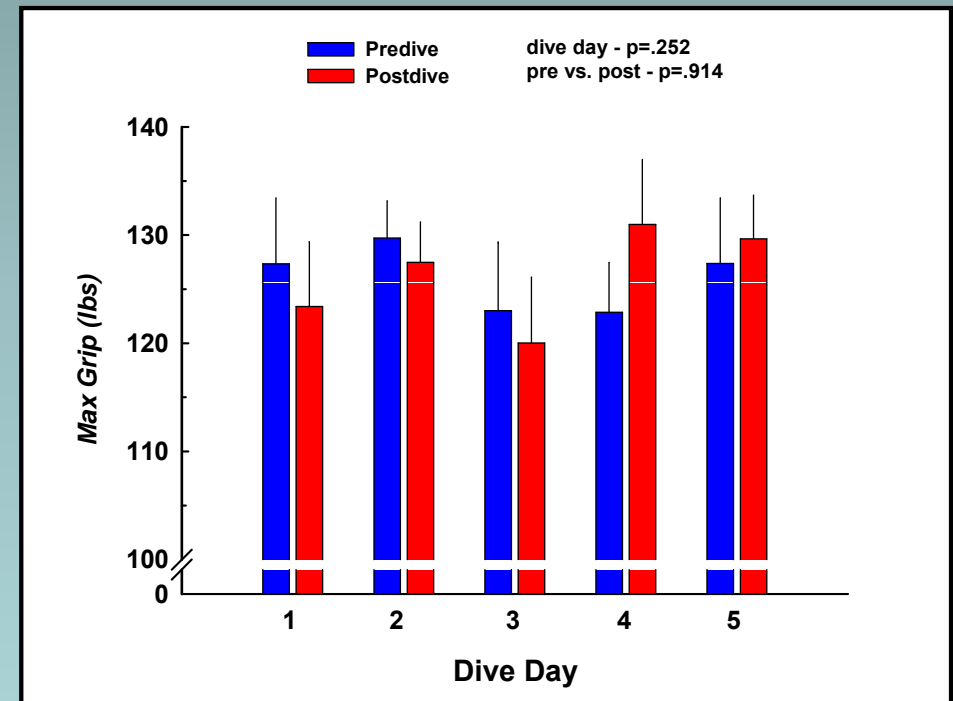
# Static Exercise



## 100% O<sub>2</sub> Dives



## Air Dives

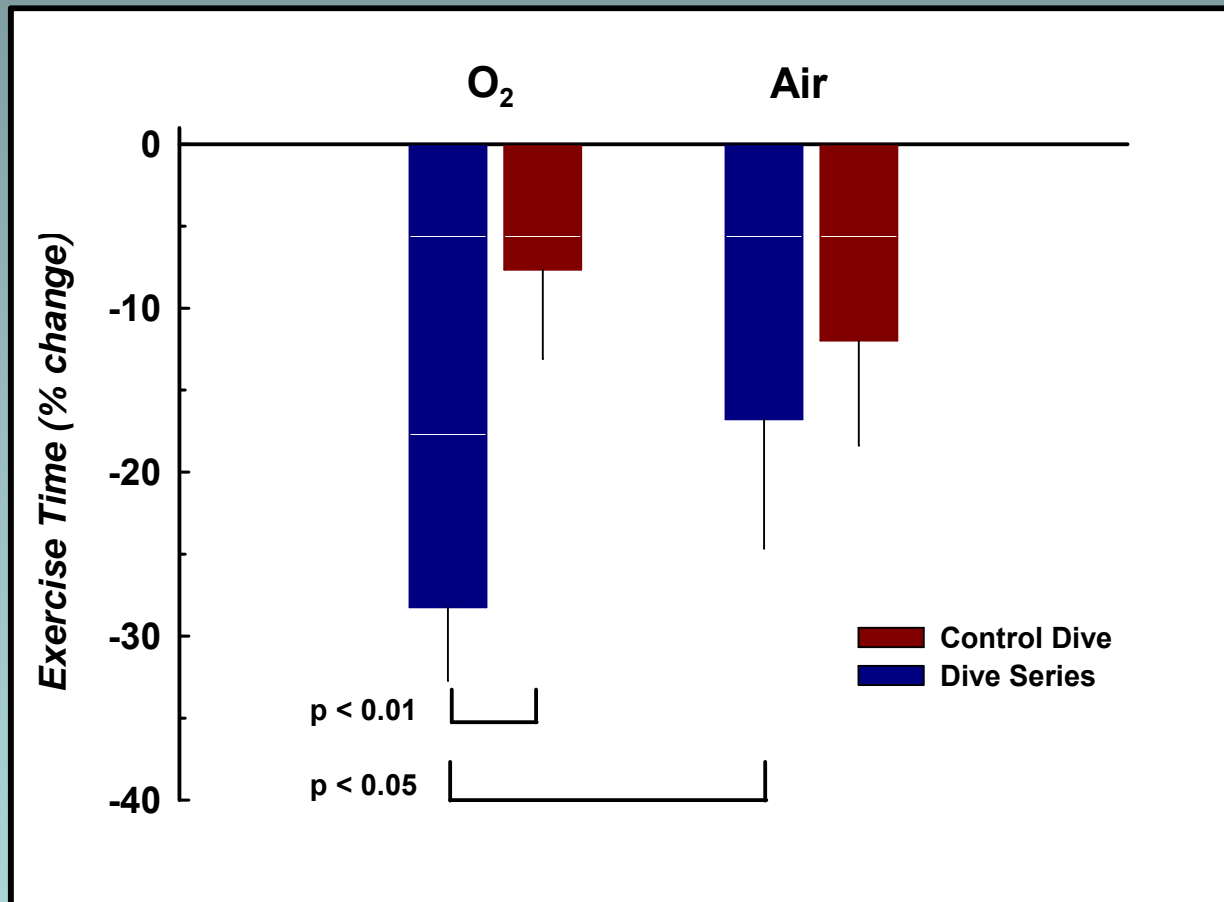


gas \* dive – p=0.018

Delayed effect of O<sub>2</sub> on static handgrip strength?



# Dynamic Exercise Tolerance



## 100% O<sub>2</sub> Dives

- Pulmonary symptoms: 38%
- Correlation  $\Delta$  exercise time vs  $\Delta$  FVC =  $p=0.005$
- $\Delta$  pulmonary function: 50%

## Air Dives

- Pulmonary symptoms: 14%
- $\Delta$  pulmonary function: 57%

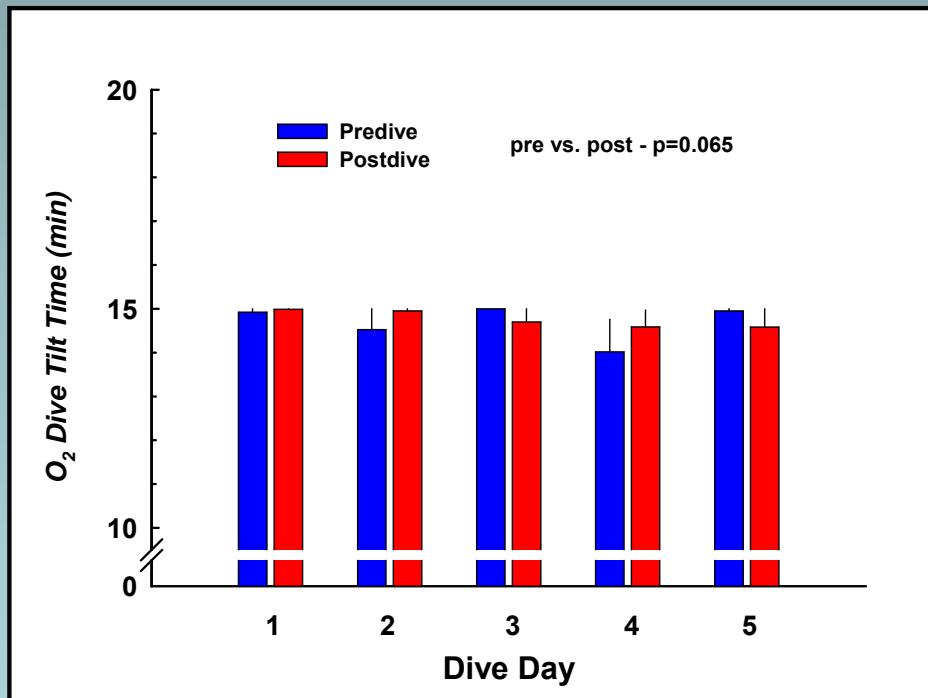




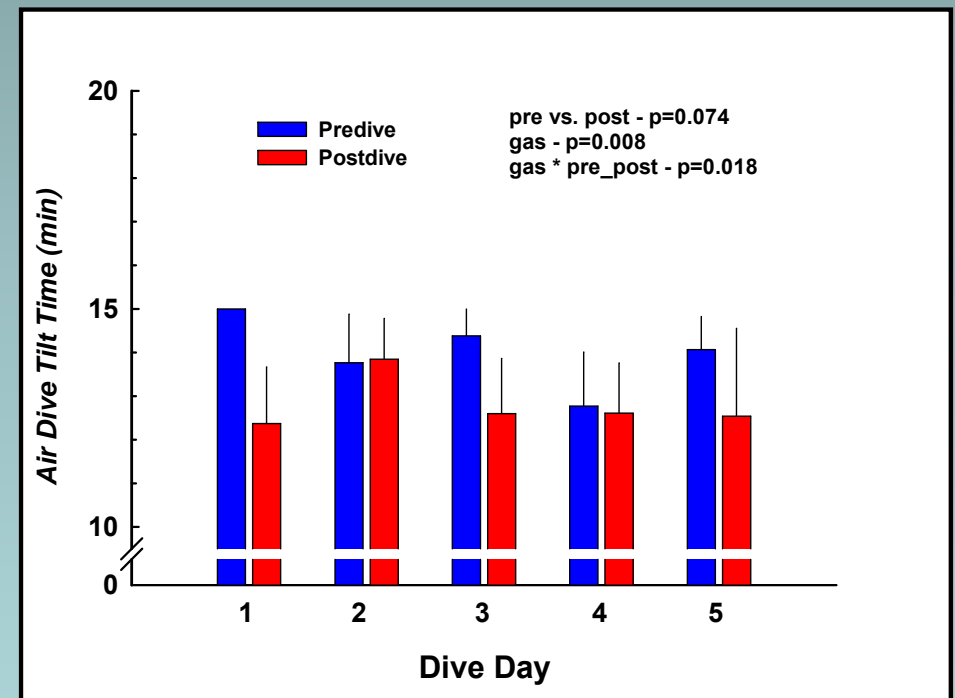
# Orthostatic Tolerance



## 100% O<sub>2</sub> Dives



## Air Dives

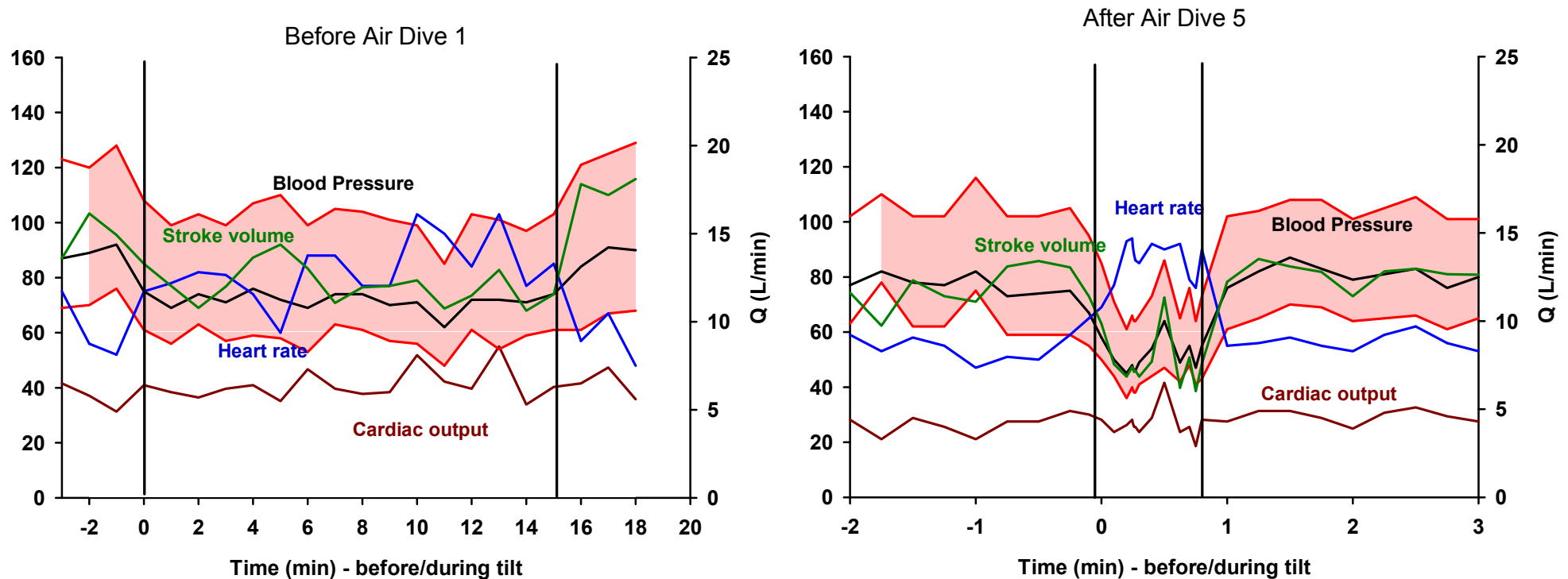




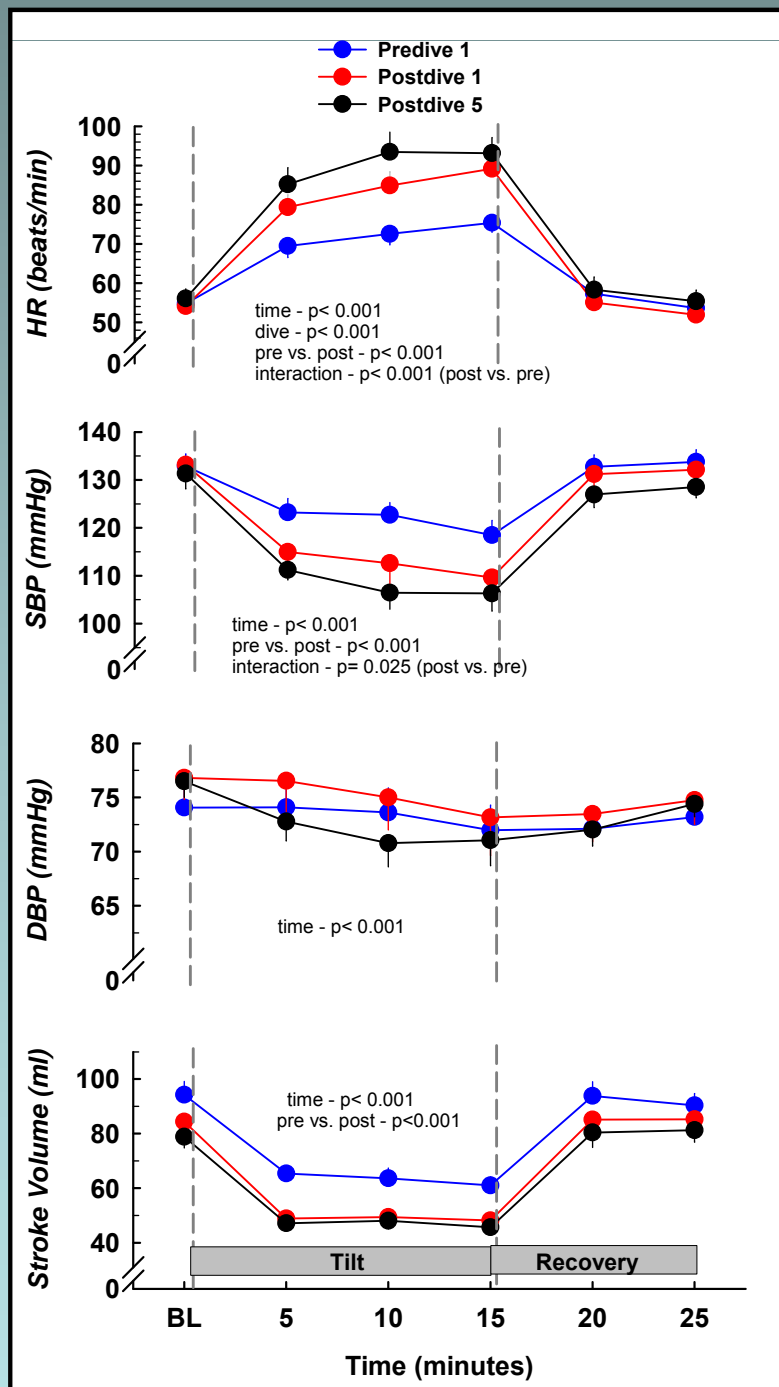
# Orthostatic Intolerance



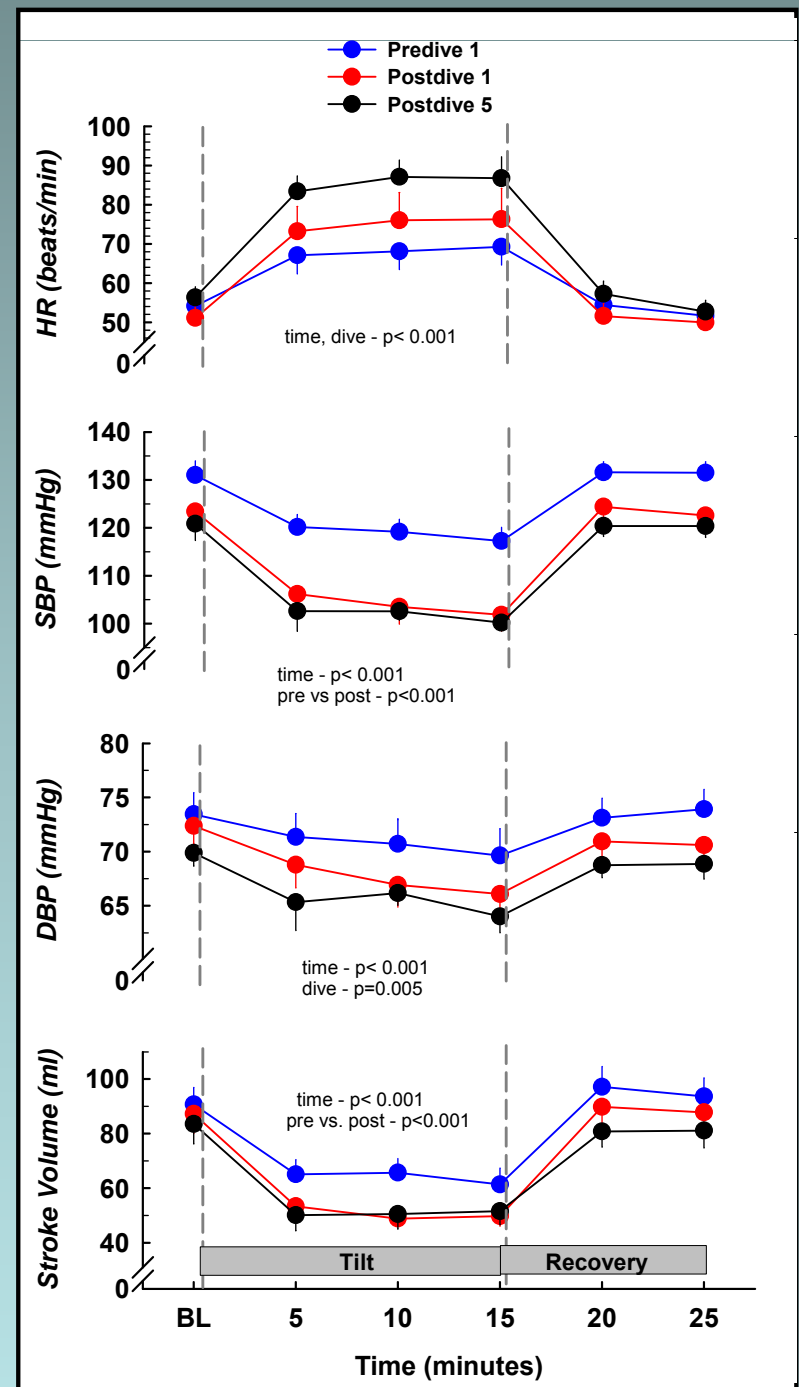
## Example of Orthostatic Intolerance Following Air Dives



## 100% O<sub>2</sub> Dives



## Air Dives





# Autonomic Function



100% O<sub>2</sub> Dives – SNS/PNS ratio of PDM

Dive 1

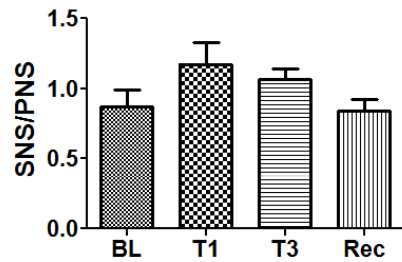
Dive 2

Dive 3

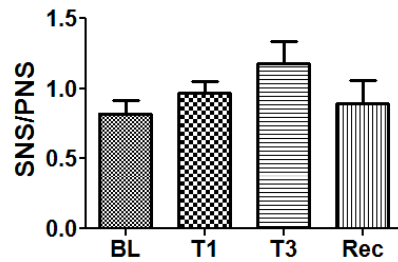
Dive 4

Dive 5

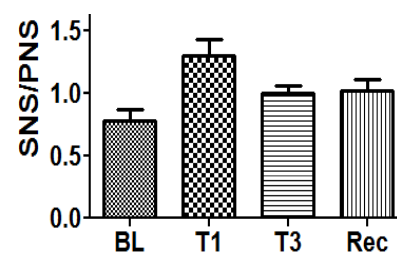
Predive



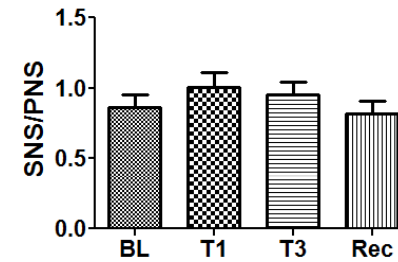
P=0.146



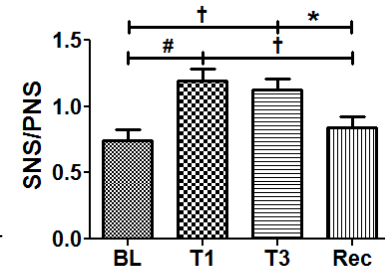
P=0.218



P=0.0503

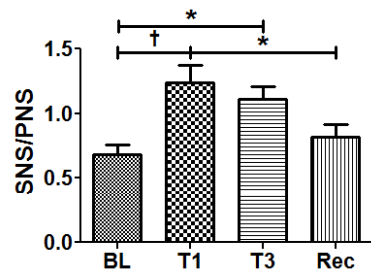


P=0.569

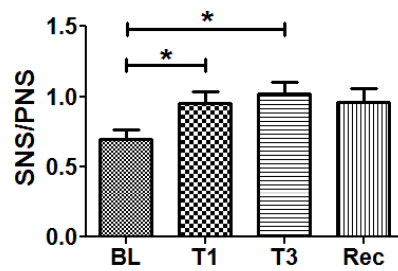


P=0.002

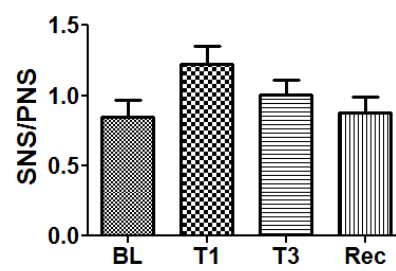
Postdive



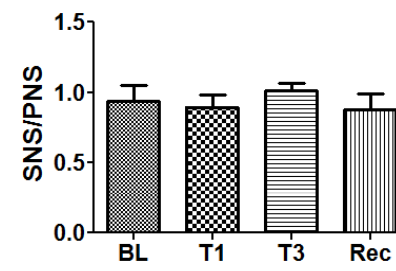
P=0.006



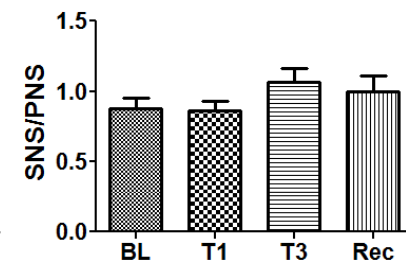
P=0.047



P=0.241



P=0.719



P=0.095



# Autonomic Function



## Air Dives - SNS/PNS ratio of PDM

Dive 1

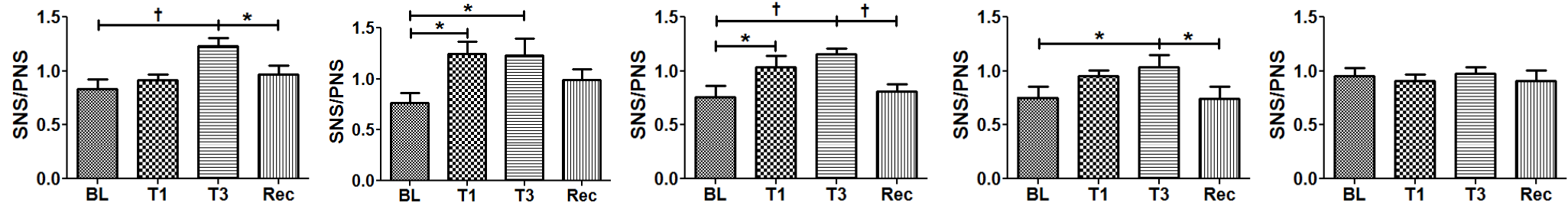
Dive 2

Dive 3

Dive 4

Dive 5

Predive



P=0.013

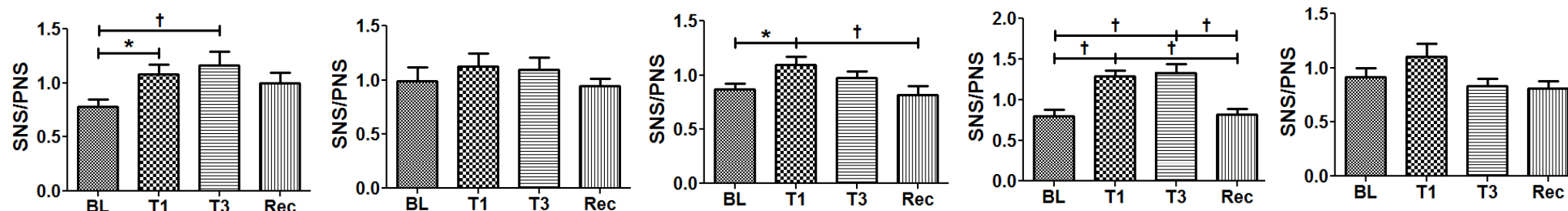
P=0.038

P=0.004

P=0.033

P=0.840

Postdive



P=0.026

P=0.664

P=0.033

P<0.001

P=0.096



# Conclusions



- Following a single dive, static and dynamic exercise functions remain intact, independent of breathing media.
- With repeated dives, dynamic and isometric exercise performance are reduced more following O<sub>2</sub> than air dives.
- Repeated O<sub>2</sub> or air dives adversely affect blood pressure regulation and orthostatic tolerance.
- However, breathing O<sub>2</sub> during repeated dives may provide partial protection to the more marked orthostatic intolerance observed after repeated air dives.





# Acknowledgements



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MULLET Personnel

HM1 Hill

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