NAVSEA – Hypercapnia: Cognitive Effects and Monitoring

Year 2: Sensitivity, Reliability and Context Sensitive PO_2 Findings

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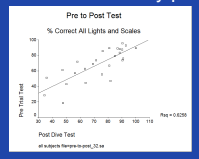
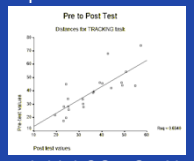
Introduction:

This NAVSEA project is tasked to develop an algorithm to predict equivalent narcotic depth based on breathing gas inspired partial pressures. NASA's MATB-II flight simulator was chosen as the cognitive testing platform. The Multi-attribute task battery-II (MATB-II) is a suite of NASA-developed, computer-based, flight simulation software tests designed to evaluate operator performance and workload during operationally realistic scenarios. Here we present data from year 2 of the project showing: 1) pre-to-post trial score correlations 2) the protective effects of O_2 on CO_2 induced cognitive impairment at normobaric pressure and 3) the adverse effects of hyperbaric O_2 on CO_2 induced cognitive impairment in a scenario modeling CO_2 scrubber failure during a working dive.

Methods:

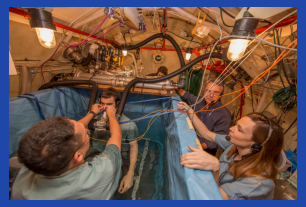
After institutional approval and informed consent, as of 3/15/15, 28 subjects' baseline MATB-II scores (1 ATA air at rest) were compared to those recorded while breathing varying hyperbaric partial pressures of CO_2, N_2 and O_2 at rest and exercise. Inspired partial pressures tested were: (a) PiCO2=0 and 0.075 ATA (7.5 kPa), (b) PiO2=0.21 ATA (21.3 kPa), 1.0 ATA (101.3 kPa) and 1.22 ATA (123 kPa), and (c) PiN2=0.79 ATA (80.0 kpa), 4.6 ATA (465 kPa) and 5.6 ATA (567.3 kPa). TRACKING scores were controlled for recent video game experience, exercise and pre-test hypercapnic ventilatory response (HCVR). The effects learning and breathing gas sequence were assessed by pre-to-post test correlations.

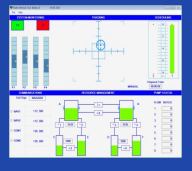




Results:

Arterial CO_2 and O_2 (for TRACKING task), and end-tidal CO_2, O_2, N_2 and their interactions (for SYSMON tasks) were significant predictors of performance by linear regression and repeated measures ANOVA respectively. The TRACKING and SCALES tasks were most sensitive. Pre-to-post test scores were well correlated (TRACKING Rsq= 0.59, SYSMON Rsq= 0.63, p<.01 two-tailed, Pearson). Preliminary data reveal a low to moderate narcosis signal for 4.5 to 5.6ATA N_2 and a strong narcosis / cognitive impairment signal for 0.075ATA CO_2. Quantifying the effect of O_2, however, is complicated in that it appears to affect cognition depending on its context.





Surface Oxygen effect: performance improved (Figure 1)

On the surface the study confirms the findings of Gill and Vann where O_2 appears to counteract CO_2 associated cognitive impairment. When compared to stages where subjects breathed either room air or 100% O_2, added CO_2 caused a 17 to 31% performance decrement both at rest and exercise (p<.001 ANOVA with Tukey's HSD post-hoc correction). However, post-hoc analysis showed significantly better performance during stages with higher PiO_2s where only a 7-12% decrement was observed.

Dive Oxygen effect: performance impaired (Figure 2)

During both normocarbic and hypercarbic dives when PiN_2 was held constant at 4.5ATA a higher PiO_2 (1.2ATA) was associated with a 15 (normocarbia) to 85% (hypercarbia) performance decrement (p<.001) when compared to a normoxic PiO_2 (0.21ATA). Moreover, the higher PiO_2 (1.2ATA) was associated a 50% failure rate for completion of these test stages compared to normoxia. Six of the 12 exercise protocol subjects experienced potentially serious cognitive impairment while breathing added CO_2 with elevated PiO_2 and PiN_2 at depth. Affected subjects continued to fly the simulator, but entered a state of verbal unresponsiveness requiring physical intervention by the in-pool safety staff.

Elevated PiN_2 alone at 4.5 ATA did not significantly impair TRACKING performance (p=.366), however, additional data is forthcoming. Data from other MATB-II tasks (SYSMON, COMM and RESMAN) involving attention, memory and strategy show the expected N_2 narcosis effect.

Conclusions:

According to the Meyer-Overton theory of anesthetic potency, O_2 should cause cognitive impairment when breathed at hyperbaric pressures. Prior investigators have noted mixed effects; however, this may be because oxygen is a substrate for cellular respiration, a potent vasoconstrictor, and is CNS toxic at 1.6 ATA. Accordingly a partial pressure below 1.6 ATA may be insufficient to detect a measurable narcotic effect. Additional subjects and gas partial pressures should be tested to confirm these preliminary findings. Incipient CNS O_2 toxicity secondary to CO_2-mediated release of protective O_2 cerebral vasoconstriction will need to be distinguished from narcosis.

***Figure 1** shows the mean TRACKING distances (± 95% CI) for immersed surface conditions. Performance impairment from 0.075ATA CO_2 was reversed by increased PiO_2=.925. (higher scores are worse)*

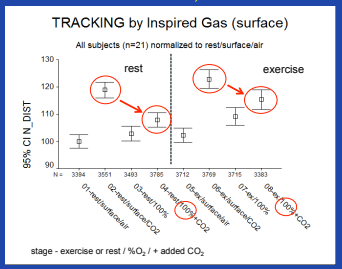
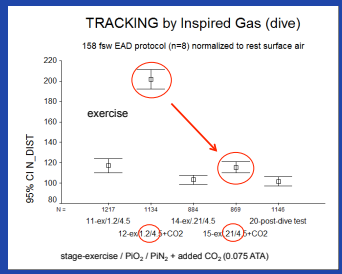


***Figure 2** shows the severe impairment of TRACKING performance during 0.075ATA CO_2 challenge at 158 feet seawater while breathing a PiO_2=1.2ATA that was improved by switching to PiO_2=0.21ATA.*



Gill M, Natoli MJ, Vacchiano C, MacLeod DB, Ikeda K, Qin M, Pollock NW, Moon RE, Pieper C, and Vann RD. Effects of elevated oxygen and carbon dioxide partial pressures on respiratory function and cognitive performance. Journal of applied physiology 117: 406-412, 2014

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