NAVSEA 1 – Measurement of Nitrogen and Hypercapnic Narcosis Using NASA's MATB-II Software

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INTRODUCTION

Elevated nitrogen partal pressure (PN_2) can decrease cognitive performance by causing narcosis during deep air diving.

Elevated arterial partial pressures of carbon dioxide ($PaCO_2$) and oxygen (PaO_2) may further increase the overall narcotic effect.

The US Navy has need to predict the degree of cognitive performance deficit associated with the narcotic gases a working diver may experience at operationally relevant depths.

Monitoring inspired (P_i) or end-tidal (P_{ET}) CO_2 during a dive is a theoretically practical way for a diver to be warned of impending narcosis.

$P_{ET}CO_2$ is a reasonable surrogate for $PaCO_2$ under resting conditions at the surface and up to moderate elevations (50-55 mmHg) during exercise at depth. *However,* it is unknown whether $P_{ET}CO_2$ can be relied upon to predict PaCO2 at higher levels.

This series of experiments is designed to:

(1) Quantify the effects of elevated $PaCO_2$ and PaO_2 on nitrogen narcosis.

(2) Establish the relationship between $P_{ET}CO_2$ and $PaCO_2$ in the upper range of interest (50-70 mmHg) during immersed rest and hyperbaric exercise.

(3) Use this information to construct an algorithm which can predict $PaCO_2$ from $P_{ET}CO_2$ and correlate this to an "equivalent narcotic depth" for $PaCO_2$ in the working deep sea diver.

HYPOTHESIS

Elevated PN_2, $PaCO_2$ and PO_2 cause decreased cognitive performance with a additive effects. (PN_2 > $PaCO_2$ > PO_2)

$P_{ET}CO_2$ is an accurate estimate of $PaCO_2$ at rest and during exercise at levels exceeding 50 mmHg and depths to 158 fsw.

An algorithm can predict cognitive performance in exercising divers, based on $P_{ET}CO_2$ and the divers' inspired partial pressures of oxygen and nitrogen (P_IO_2 and P_IN_2).

STUDY DESIGN

The Multi-Attribute Task Battery-II (MATB-II) is a NASA developed, computer based flight simulation software designed to evaluate operator cognitive performance and workload during an operationally realistic scenario. *(See Abstract _____)*

8 Pilot subjects were studied during head-out immersion at rest and at 50 watts of output on an exercise cycle ergometer.

$PaCO_2$ and $P_{ET}CO_2$ were measured by arterial blood gas and mass-spectrometry respectively at sea-level and hyperbaric conditions, with and without exercise.

Table 1: Surface Phase Protocol (constant across all protocols)

Experimental Condition	Est time min	Expt stage	Depth (fsw)	P(ATA)	Gas Density at 37°C (g/L)	Work Rate (W)	Inspired PCO2 (mmHg)	PO2 (ATA)	PN2 (ATA)	EAD (fsw)
	60	Subject preparation / Equipment calibration / Gas confirmation								
1	5	1.1	0	1	1.13	-	0	0.2	0.8	0
2	5	1.2	0	1	1.13	-	+	0.2	0.8	0
3	5	1.4	0	1	1.26	-	0	1.0	0	-
4	5	1.3	0	1	1.26	-	+	1.0	0	-
		Begin surface exercise								
5	5	1.5	0	1	1.13	+	0	0.2	0.8	0
6	5	1.6	0	1	1.13	+	+	0.2	0.8	0
7	5	1.8	0	1	1.26	+	0	1.0	0	-
8	5	1.7	0	1	1.26	+	+	1.0	0	-
	60	Rest at surface / Equipment calibration / Gas confirmation								
		Begin Dive Protocol								
	3	Dive to 158.4 fsw on RA								

Subjects will be tested with the MATB-II software during variable experimental conditions in 5 minute time intervals

Table 2: Hyperbaric Phase Protocol (varies between protocols)

Protocol	Subjects	Exercise	Depth (fsw)	Added CO_2	PO_2 (ata)	PN_2 (ata)	EAD (fsw)
A	15	-	122 158	+/-	0.2, 1.3	4.5	158
B	15	+	122 158	+/-	0.2, 1.3	4.5	158
C	10	-	158	+/-	0.2	5.6	200
D	10	+	158	+/-	0.2	5.6	200

Hyperbaric phase varies PO_2, PN_2, PCO_2 and exercise.

Table 3: Breathing gases used

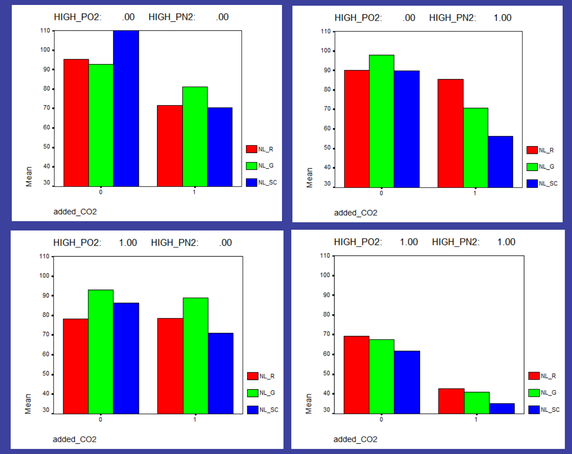
Gas #	Description	O_2 %	CO_2 %	Protocol
1	Surface/158 fsw Air	21.00	0.00	Surface All, Depth A, B
2	Surface Air + CO_2	21.00	7.50	Surace All
3	Surface O_2	100.00	0.00	Surface All
4	Surface O_2 + CO_2	92.50	7.50	Surface All
5	158 fsw 1.22 PO_2 (air) + CO_2	21.00	1.29	Depth A, B
6	122 fsw 0.21 PO_2	4.47	0.00	Depth A, B
7	122 fsw 0.21 PO_2 + CO_2	4.47	1.60	Depth A, B
8	158 fsw 0.21 PO_2	3.62	0.00	Depth C, D
9	158 fsw 0.21 PO_2 + CO_2	3.62	1.29	Depth C, D

Figure 2: Foxtrot chamber - gas switching manifold

RESULTS

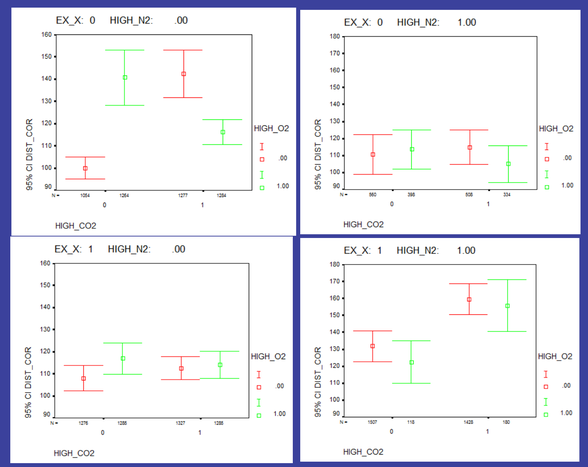
Elevated PN_2 and PCO_2 decreased overall accuracy for the system-monitoring (SYSMON) attention & surveillance tasks by 30% from baseline (P=<0.001).

Accuracy of red and green lights (not significant)
Accuracy of scales: (PCO2: p=0.002, PN2: p=0.03, PO2 p=0.01)



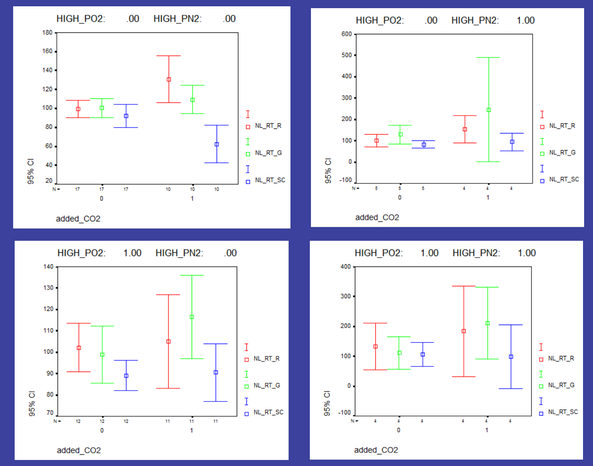
Tracking task (TRACKING) accuracy at low cognitive workload was not consistently affected by elevated PN_2 or PCO_2 but accuracy decreased at high workloads for both narcotic and non-narcotic gases.

Corrected tracking distances by exercise, PN2, PCO2 and PO2:



ANOVA p-values: (exercise p=0.003, PN2 p<0.014, PCO2 p<0.003, PO2 p=0.860.

Reaction time for SYSMON tasks for added PCO2 and PN2:



CONCLUSION

The MATB-II is sensitive enough to detect the cognitive effects of breathing narcotic gases. Preliminary results indicate that ability to multi-task and pay attention to surroundings is affected by narcotic breathing gases. Ability to focus on a single task may be less affected depending on overall task loading.

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Funded by NAVSEA Deep Submergence Biomedical Contract #N0463A-12-C-0001.