RESTING METABOLIC GAS EXCHANGE WITHIN THE ENCLOSED HOOD OF THE MK10 SUBMARINE ESCAPE AND IMMERSION EQUIPMENT (SEIE) SUIT

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INTRODUCTION

The MK10 SEIE suit is designed to enable free ascent from a stricken submarine. It incorporates an enclosed ascent hood for buoyancy and breathable air during escape. With the introduction of Virginia class submarines into the U.S. submarine fleet mass escape for up to 22 submariners at a time may be possible by pressurizing and flooding the VA lockout trunk. While the CONOPS for VA class submarine mass escape is currently being developed, it is possible that during an actual escape some escapees may not have convenient access to the built-in breathing system and may be required to rebreathe from the hood volume prior to escape. Furthermore, once submariners reach the surface following an escape they may keep the hood zipped up while floating in the SEIE raft to avoid inhaling sea water during high sea states. Prolonged breathing from the enclosed volume of the hood could lead to dangerous levels of hypercapnia and/or hypoxia that may compromise escape or survival.

OBJECTIVES

The aim of the current study is to determine the change in concentration of O_2 and CO_2 over time within the ascent hood in resting partially immersed subjects rebreathing from the hood volume at 1 ATA. Using these data, guidance for the safe time limits to avoid incapacitating hypoxia and/or hypercapnia while rebreathing from the enclosed volume of the MK 10 SEIE suit hood was generated.

METHODS

Subjects

11 U.S. Navy trained divers and 1 submariner.

Age (mean ± SD):	37.8 ± 9.9 yrs,
Height (H):	1.77 ± 0.05 m,
Weight (W):	89.9 ± 9.3 kg.
Body Surface area (S):	2.10 ± 0.13 m^2
Body volume (V):	87.2 ± 10.1 liters
BMI:	28.5 ± 2.2 kg/m^2

Anthropometric data

Body surface area was calculated from height and weight using the method of Mosteller, *N Engl J Med* 317(17):1098 (1987) shown below:

$S\ (m^2) = ([Height\ (cm) \times Weight\ (kg)\ ]/\ 3600\ )^{½}$

Body volume (V) was calculated using the formula described by Sendroy and Collison, *J. Appl. Physol.* 21(1): 167-172 (1966)

$V = S\ (51.44 \times (W/H) + 15.3)$

Where V, S, W, and H are in liters, m^2, kg, and cm respectively

$BMI = Weight\ (kg)/H(m)^2$

Procedures

Rebreathing trials were conducted at 1 ATA while the subjects wore the MK10 SEIE suit with the stole fully inflated and the hood fully closed under the following conditions:

A: While dry and unimmersed (see Fig. 1).
B: Immersed in a water tank with the water level 2 inches above the hood vent.
C: Immersed in a water tank while floating erect.

Each subject completed all of the conditions in a counterbalanced order on a single lab visit. Consecutive trials were conducted once the subject's minute ventilation and end tidal O_2 and CO_2 had returned to baseline. A trial continued for 10 minutes of rebreathing or until FiO_2 reached 13% or $FetCO_2$ exceeded 9%. Minute ventilation was monitored continuously using a K.L Engineering pneumoscan Spirometric module attached to the expired port of a Gentex oxygen mask (see Fig 1). Inspired and end tidal measurements of O_2 and CO_2 were continuously monitored via an MGA 1100 mass spectrometer from a gas sample line connected to the oral nasal mask. The volume of air removed from the hood for sampling was 60 ml/min. Analogue output from the mass spectrometer and spirometric module was passed to a BIOPAC A/D system to permit the CO_2 and O_2 fraction to be continuously displayed on a monitor and stored on computer hard disc for later analysis.

Fig.1: Rebreathing tests with the MK10 SEIE suit while unimmersed (left photo) and while immersed in a water tank (right photo). The right photo also shows the Genetex mask that was worn to permit measurement of metabolic gas exchange.

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Table 1: Group statistics for the inspired and expired O_2 and CO_2 concentrations and minute ventilation ($\dot{V}_E$) measured at the end of each rebreathing trial. (n=12)

	Mean	Min	Max	SD
Unimmersed: Condition A				
PiO_2 (mmHg)	138	128	145	4.8
FiO_2 (%)	18.0	16.5	18.8	0.6
$PetO_2$ (mmHg)	109	101	116	4.5
$FetO_2$ (%)	14.2	13.1	15.0	0.6
$PiCO_2$ (mmHg)	19	15	26	3.4
$FiCO_2$ (%)	2.4	2.0	3.3	0.4
$PetCO_2$ (mmHg)	40	38	42	1.5
$FetCO_2$ (%)	5.2	4.9	5.5	0.2
$\dot{V}_E$ (l, BTPS)	16.5	8.4	29.4	5.4
Immersed: Condition B				
PiO_2 (mmHg)	99	96	100	1.3
FiO_2 (%)	12.9	12.6	13.0	0.1
$PetO_2$ (mmHg)	81	75	88	4.3
$FetO_2$ (%)	10.6	9.8	11.4	0.5
$PiCO_2$ (mmHg)	41	39	44	1.5
$FiCO_2$ (%)	5.4	5.0	5.8	0.2
$PetCO_2$ (mmHg)	49.6	43	52	2.7
$FetCO_2$ (%)	6.4	5.7	6.9	0.3
$\dot{V}_E$ (l, BTPS)	23.8	17.2	32.7	5.0
Immersed: Condition C				
PiO_2 (mmHg)	99	97	100	0.9
FiO_2 (%)	12.9	12.7	13.0	0.1
$PetO_2$ (mmHg)	84	76	99	5.7
$FetO_2$ (%)	11.0	10.0	12.9	0.7
$PiCO_2$ (mmHg)	42	38	45	1.9
$FiCO_2$ (%)	5.4	4.9	5.9	0.3
$PetCO_2$ (mmHg)	51	47	54	2.3
$FetCO_2$ (%)	6.6	6.1	7.1	0.3
V_E (l, BTPS)	26.1	13.9	41.1	7.3

RESULTS

The unimmersed condition (A) continued for the full 10 minutes without reaching any of the abort criteria. During immersion, conditions B and C were terminated due to reaching the FiO_2 limit after 162±29 s and 198±47 s, respectively (mean ± SD). The inspired and expired O_2 and CO_2 concentrations and minute ventilation (V_E) measured at the end of trials A, B and C are given in Table 1. Body volume, weight, and surface area all showed high significant negative Pearson product-moment correlations with test duration (See Table 2).

Table 2: Pearson Product moment correlations between the time taken to reach the 13% FiO_2 limit during the immersion trials and selected anthropometric characteristics (n=12). * $p<0.05$

Variable	Water level 2 inches above the hood vent Condition B	Floating erect Condition C
Height	-0.59*	-0.49
Weight	-0.86*	-0.74*
BSA	-0.86*	-0.74*
Body Vol.	-0.85*	-0.74*
BMI	-0.71*	-0.63*

CONCLUSION

Submariners breathing from the enclosed volume of the SEIE suit hood while partially immersed at 1 ATA will approach unsafe hypoxia levels after 2 to 3 minutes of rebreathing. As the SEIE suit is one-size fits all, larger submariners will reach critical hypoxia levels earlier than submariners of smaller body size. It is thus recommended that if the water level raises beyond the level of the hood vent while the submariner is rebreathing from the enclosed volume of the hood that the duration of rebreathing, if possible, be limited to less than 100 seconds to avoid symptoms of hypoxia. Additional research is needed to provide guidance on safe rebreathing limits at depth and under physically active conditions where hypercapnic rather than hypoxic symptoms are likely to be the limiting factor.