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TRACKING PERFORMANCE WITH TWO BREATHING OXYGEN CONCENTRATIONS AFTER HIGH ALTITUDE RAPID DECOMPRESSION

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ABSTRACT

Current military aircraft Liquid Oxygen (LOX) systems supply 99.5% gaseous Aviator's Breathing Oxygen (ABO) to aircrew. Newer Molecular Sieve Oxygen Generation Systems (MSOGS) supply breathing gas concentrations of 93-95% oxygen. This study compared the margin of hypoxia protection afforded by ABO and MSOGS breathing gas after a 5 psi differential rapid decompression (RD) in a hypobaric research chamber. The barometric pressures equivalent to the altitudes of 46,000, 52,000, 56,000, and 60,000 ft were achieved from respective base altitudes in 1-1.5 s decompressions. During each exposure subjects remained at the simulated peak altitude breathing either 100% or 94% O_2 with positive pressure for 60 s, followed by a rapid descent to 40,000 ft. Subjects used the Tactical Life Support System (TLSS) for high altitude protection. Subcritical tracking task performance on the Performance Evaluation Device (PED) provided psychomotor test measures. Overall tracking task performance results showed no differences between the MSOGS breathing oxygen concentration of 94% and ABO. Significant RMS error differences were found between the ground level and base altitude trials compared to peak altitude trials. The high positive breathing pressures occurring at the peak altitudes explained the differences. Considered with the physiologic data, an acceptable degree of hypoxia protection was met with both oxygen concentrations using TLSS at altitudes <60,000 ft for <60 s durations.

INTRODUCTION

In both the US Navy and the US Air Force, there is increasing interest in Molecular Sieve Oxygen Generation Systems (MSOGS) for their logistic and reliability advantages when compared to liquid oxygen supplied aircraft breathing systems. A limitation in the maximum oxygen concentration attainable with MSOGS, however, has motivated USN and USAF development communities to establish laboratory evidence of the acceptability of using reduced breathing oxygen throughout the altitude envelope of current aircraft oxygen systems.

Based upon a fairly well developed theory of respiratory gas exchange at altitude, our team of researchers concluded that there was no reason to expect adverse effects of MSOGS oxygen concentrations at normal cabin pressures. However, after a rapid loss of cabin pressure while flying at emergency ceiling altitudes needed further investigation. Especially, if a reduction of oxygen concentration is expected in the breathing gas supplied to the aircrew. We therefore, incorporated a rapid decompression (RD) profile in our study.

The first phase of research employed the current production oxygen system including: the CRU-73 dilution-demand breathing regulator and it's oxygen delivery/breathing pressure schedule; the MBU 12/P oxygen mask and HGU 55-P helmet. The RD profile was across a 5 psi differential, from 20,000 to 50,000 ft, and remained at peak altitude for 60 s. Results of this phase of research were reported elsewhere (Bomar, et. al, 1988; Holden, et. al, 1987; Nesthus, et. al, 1988; Nesthus and Schiflett, 1989; Wright, et. al, 1988; Wright, et. al, 1990).

During the second phase of study we used a developmental life support system designed to improve high altitude and high acceleration protection. The Tactical Life Support System (TLSS) included a modified CRU-73/TLSS dilution-demand oxygen regulator with an adjusted oxygen delivery and breathing pressure schedule. Also, a TLSS helmet, mask, and counterpressure jerkin-vest

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system was used to allow breathing gas delivery at much higher positive pressures needed for high altitude protection.

Our altitude profile simulated loss of cabin pressure while flying at various potential emergency flight ceilings. The profile incorporated a 5 psi differential RD similar to Phase I research but we included 4 different base-to-peak simulated altitudes seen in Table I.

Both phases of study were conducted in the hypobaric research chambers at the USAF School of Aerospace Medicine (USAFSAM), Brooks AFB, Texas.

Table I: Four base-to-peak, 5 psi differential rapid decompression profile pressures and simulated altitudes.

Pressure (torr)				Altitude (ft)		
Base		Peak		Base		Peak
364.4	-	105.9	=	19,000	-	46,000
340.0	-	79.5	=	20,800	-	52,000
321.3	-	65.7	=	22,000	-	56,000
307.9	-	54.2	=	23,000	-	60,000

METHOD

Our subject population was comprised of 17 chamber-qualified active duty male volunteers from the USAFSAM Altitude Panel. The voluntary fully informed consent of the subjects used in this research was obtained as required by AFR 169-3.

In addition to measuring a number of physiologic parameters, discussed in detail in the Phase I research references, a computer-based unstable tracking task from the Performance Evaluation Device (PED) provided two psychomotor measures (Systems Research Laboratory, 1987). The tracking tasks' instability was based on an algorithm similar to that of the subcritical tracking task (Jex, 1967). RMS offset-from-center error and the number of boundary hits were the primary measures of tracking performance. Subjects were trained to perform the task while inside the chamber environment wearing the TLSS ensemble with most of the physical distractors in place. Sessions with high positive breathing pressures were also included.

Figure 1 shows a generic altitude profile and time line for one experimental RD session.

During a 1 hr 100% O_2 prebreathe for decompression sickness prevention, one performance task warm-up and trials 1 and 2 were conducted. An ear and sinus check and an abdominal gas check were made before holding at the base altitude. Pre-RD physiological recordings and trials 3 and 4 were completed. Prior to the RD, the breathing gas mixture was switched from 100% oxygen to a pre-RD mixture of O_2 representative of the CRU-73's scheduled dilution mixture for each particular base altitude. Subjects breathed this mixture for 2-3 minutes for pulmonary equilibration. The base altitude breathing gas mixture and the peak altitude oxygen condition for each experimental trial was unknown to the subject. After a final "ready" was communicated, the subject was cautioned to breath normally. Then the hypobaric chamber was rapidly decompressed (approximately 1 s) to a simulated peak altitude of either 46,000 ft, 52,000 ft, 56,000 ft, or 60,000 ft. The positive breathing pressure at 46,000 ft, irrespective of the O_2 condition, was 50 mmHg at the mask. Positive breathing pressure at the remaining peak altitudes was 70 mmHg. The subject, initiating the "Peak" performance task trial ten seconds after the RD, remained at that altitude for 50 s more, whereupon the chamber pressure was increased to a 40,000 ft equivalent (141.18 torr). When the subject completed the unstable tracking task a descent to ground level was made. This procedure was repeated for each O_2 condition and peak altitude.

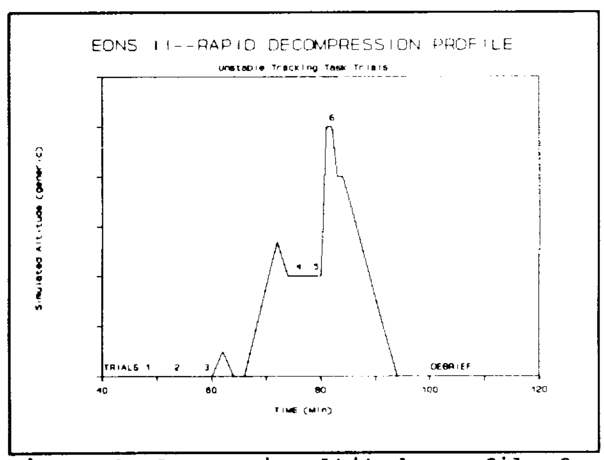

Figure 1: A generic altitude profile for the EONS II rapid decompression study.

A mixed, random and fixed effects design was followed. The fixed effects included: two peak altitude oxygen conditions--100% O_2 and 94% O_2; four peak altitude conditions--46,000, 52,000, 56,000, and 60,000 ft; and three trial levels--Ground, Base, and Peak. Measures analyzed for this report included: Root-Mean-Squared offset from center (RMS) and boundary hits or control losses for unstable tracking performance; and one physiologic parameter, oxyhemoglobin saturation (SaO_2).

RESULTS

Our overall design analysis revealed 3-way interactions (O_2-by-Level-by-Peak Altitude) for RMS tracking error, Boundary Hits (BHITS), and SaO_2. These results were anticipated. Separate analyses for O_2 and Peak Altitude were conducted and resulted in predominant Level effects for RMS error and SaO_2. The former was due primarily to the combined effects of positive breathing pressures delivered at the peak altitudes and potential hypoxia. No positive breathing pressure was delivered at ground and base levels. These results can be seen in Figure 2 for the 100% O_2 condition and in Figure 3 for the 94% O_2 condition.

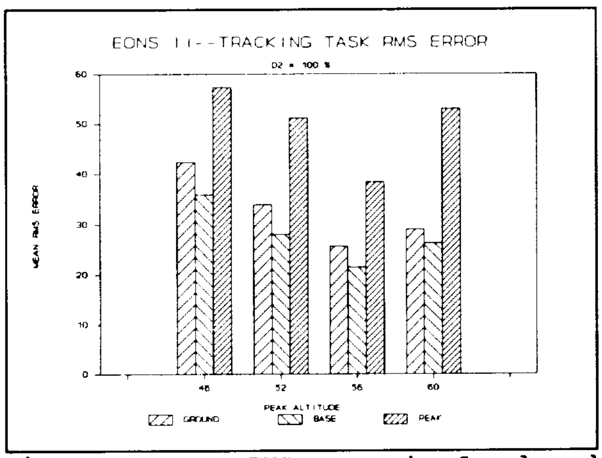

Figure 2: Mean RMS error by Level and Peak Altitude for the 100% O_2 Condition.

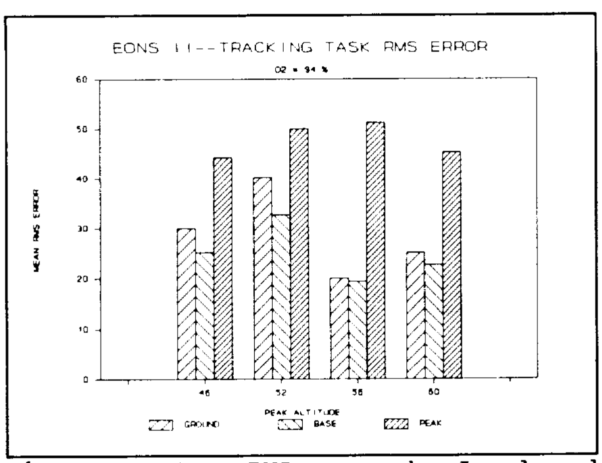

Figure 3: Mean RMS error by Level and Peak Altitude for the 94% O_2 Condition.

The Level effect for SaO_2 was primarily due to high oxyhemoglobin saturations which occured while breathing 100% O_2 during the ground and base level trials (prior to the RD) compared to high altitude desaturations which occured at peak altitudes. This effect is seen in Figure 4.

The Level analysis revealed an O_2-by-Peak Altitude interaction which is clearly seen in Figure 5. Least Square mean t-tests showed that boundary hits for the 94% O_2 condition were greater at 52,000 ft compared to 56,000 or 60,000 ft.

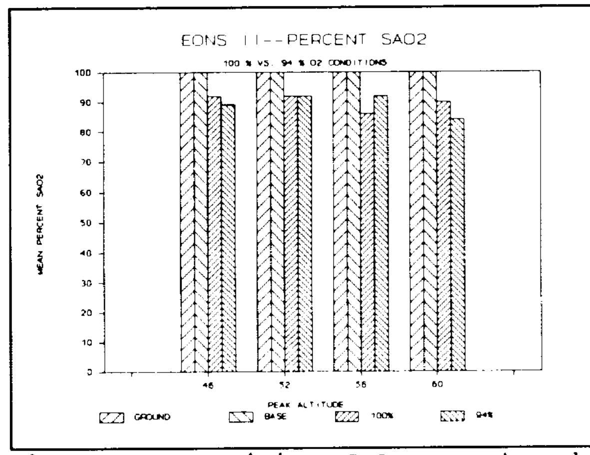

Figure 4: Mean minimum SaO_2 percentage by Level and Peak Altitudes for the 100% and 94% O_2 Conditions.

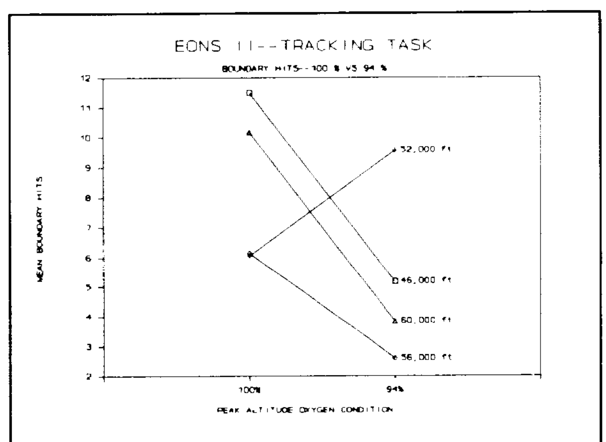

Figure 5: Mean Boundary Hits for O_2 by Peak Altitude interaction

Figures 6 and 7 are examples of additional physiologic data showing 5 s mean $P_{ET}O_2$ values (with +/- standard error) 10 s before and 80 s after RDs to 60,000 ft for the 100% and 94% O_2 conditions, respectively. The figures show a rapid fall in PO_2 at the RD (verticle line in figures) followed by relatively stable values before the descent to 40,000 ft (at time 60 s in figures) as an increase in barometric pressure occurred. The values indicated subjects were exposed to compensatory levels of hypoxia as described in the

USAF Physiological Training Pamphlet (Tables 4-3 and 4-5). Any performance deficit assumed at this level of hypoxia was confounded with the positive breathing pressures at peak altitudes and were probably diminished by the transient exposure (i.e., <60 s). The relatively high SaO_2 values seen in Figure 4 at peak altitudes may also reflect the transient nature of the exposure.

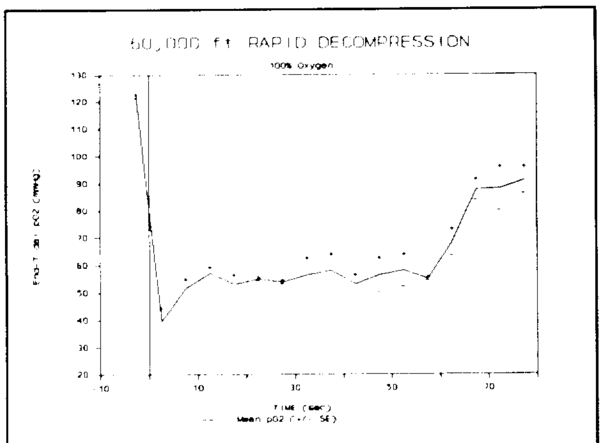

Figure 6: Mean (5 s epoch) End-Tidal pO_2 before and after rapid decompressions to 60,000 ft for the 100% O_2 Condition.

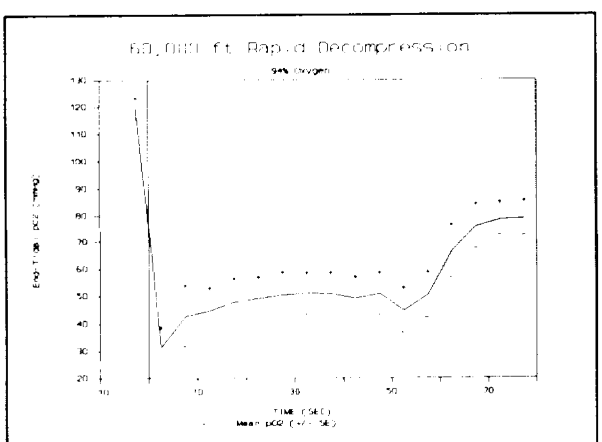

Figure 7: Mean (5 s epoch) End-Tidal pO_2 before and after rapid decompressions to 60,000 ft for the 94% O_2 Condition.

DISCUSSION

We believe decrements found in tracking performance for the Level effect were due primarily to the anticipated effects of high positive breathing pressures delivered to the mask for high altitude protection. Confounded in these data, however, are potential effects due to the transient, compensatory level of hypoxia experienced by the subjects in this phase of research. We feel the increase in RMS error was not of a magnitude which would translate into operational instability.

The O_2-by-Peak Altitude interaction for the boundary hits measure, as displayed in Figure 5, demonstrated the only evidence of a performance decrement with the 94% O_2 condition compared to the 100% O_2 condition. The elevated mean boundary hits found at 52,000 ft for the 94% condition were not fully understood. A thorough investigation of the data and various post-hoc tests did not help us explain this effect. No other performance differences were found between the 100% and 94% conditions.

CONCLUSIONS

We conclude that unstable tracking performance was not appreciably different for the two oxygen conditions compared. The combined effects of positive breathing pressure and possible hypoxia during the peak altitude trials affected unstable tracking performance by increasing RMS error. High breathing pressures were necessary for high altitude protection and were not present during the ground or base level trials. Overall, we believe the TLSS provided an adequate degree of protection against hypoxia for both oxygen conditions for durations less than 60 s at altitudes up to 60,000 ft as were studied in this phase of research.

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