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**A Test
of the American Safety Flight Systems, Inc.
Prebreather/Portable Oxygen System**

By

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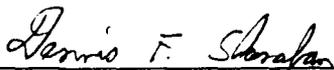
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) In response to a request from the Aviation Life Support Equipment Product Manager (ALSE-PM) of the Aviation Systems Command (AVSCOM), the U.S. Army Aeromedical Research Laboratory (USAARL) conducted an investigation and evaluation of the Prebreather/Portable Oxygen System (P/POS) manufactured by American Safety Flight Systems, Inc. A test of the P/POS was conducted in the hypobaric chamber at the U.S. Army School of Aviation Medicine. Four crews of four subjects each and one crew of three (the last crew had only three because one subject had a middle ear infection) prebreathed 100 percent chamber oxygen for 30 minutes. Then they switched to the P/POS while the chamber was depressurized to 18,000 feet MSL at a rate of 500 fpm. They remained at this altitude pressure until they reduced the P/POS pressure from 1800 psi to 200 psi. Following this, the chamber was repressurized to sea level at a rate of 4000 fpm. Mission durations, percent oxygen saturation and cognitive performance were measured for each subject. The average mission duration was 2 hr 28 min with a standard deviation of 13.9					
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min. If the P/POS pressure had been allowed to drop to 50 psi the projected average mission duration for a crew of four would have been 2 hr 42 min (assuming minimal workload). All subjects were well oxygenated during the entire chamber session as demonstrated by percent saturation readings which rose from 97 percent to 99 percent during prebreathing and remained at 99 percent while subjects breathed from the P/POS. Cognitive performance data suggested no serious decrements in subjects' mental abilities during the chamber session.

The study indicated the P/POS will meet the needs of all helicopter missions for the Army that do not require prebreathing. Missions to altitudes which require prebreathing are extremely rare, but could be accomplished with the addition of a second system connected to the dilution port.

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Table of Contents

	Page
List of tables.....	2
List of illustrations.....	2
Introduction.....	2
Statement of the problem.....	3
Background.....	3
Military significance.....	4
Objectives.....	4
Materials and methods.....	4
Subjects.....	4
Apparatus.....	4
Procedure.....	6
Training.....	6
Logical reasoning.....	7
Digit recall.....	7
Serial addition/subtraction.....	7
Four-choice reaction time.....	7
Altitude chamber.....	8
Results.....	9
Discussion and conclusion.....	14
References.....	16

List of tables

Table No.

1. Crew mission durations (hrs:min) for each of five altitude chamber sessions.....	9
2. Estimates of system duration (hrs:min) for crews of various sizes (assuming minimal workload).....	10
3. System durations (hrs:min) required to support aircraft fuel endurance times.....	10

List of illustrations

1. The American Safety Flight Systems prebreather/portable oxygen system (P/POS) with hoses and Airox VIII regulator.....	5
2. Mean RT for correct responses as a function of session on the logical reasoning subtest.....	12
3. Percent correct as a function of session on the digit recall subtest.....	12
4. Mean RT for correct responses as a function of session on the serial addition/subtraction subtest.....	13
5. Percent correct as a function of session on the serial addition/subtraction subtest.....	14

Introduction

Statement of the problem

In response to a request from the Aviation Life Support Equipment Product Manager (ALSE-PM) of the Aviation Systems Command (AVSCOM), the U.S. Army Aeromedical Research Laboratory (USAARL) conducted an investigation and evaluation of the Prebreather/Portable Oxygen System (P/POS) manufactured by American Safety Flight Systems, Inc. This system was being offered as a helicopter oxygen system (HOS) to satisfy the need of forces which operate helicopters (OH-58, UH-1, UH-60, and CH-47) at high altitudes and at night when supplemental oxygen is needed.

AVSCOM supported development of a HOS manufactured by the Carleton Group of MOOG, Inc., and subsequently type classified the device which they were proposing to purchase under contract during the 1989 fiscal year. The American Safety Flight Systems P/POS was available at half the price of the type classified system. However, information regarding the acceptability of the P/POS from a medical perspective was needed by the ALSE-PM prior to any procurement decision.

Background

Army helicopter aircrews associated with aviation units involved in support of search and rescue operations or military mountain operations frequently are required to fly at altitudes in excess of 10,000 feet above mean sea level (MSL). These flights cannot be conducted without the use of supplemental oxygen. Army Regulation (AR) 95-1 (Department of the Army, 1988) states that aircraft crews in unpressurized aircraft will use oxygen on flights above 10,000 feet pressure altitude for more than 1 hour, and on flights above 12,000 feet pressure altitude for more than 30 minutes. Aircraft crews and all other occupants are required to use oxygen on flights above 14,000 feet pressure altitude for any period of time. Flights above 18,000 feet pressure altitude require oxygen prebreathing by all aircrewmembers for 30 minutes at ground level with continued oxygen use while proceeding to altitude.

Originally, helicopter oxygen systems were locally manufactured, but they were considered unacceptable for medical and flight safety reasons. Later, commercially developed systems were acquired through the normal acquisition cycle, and these have been type classified (Redington, Fannin, and Anderson, 1982). The HOS by MOOG, Inc. was developed in this manner, yet its cost is not competitive with the P/POS which had not been type classified.

Military significance

The military could reduce expenditures substantially by purchasing the American Safety Flight Systems, Inc. P/POS. While the P/POS had not been type classified, a predecessor had been approved by the U.S. Air Force as a portable bailout oxygen system for use during high altitude high opening/high altitude low opening parachute operations. However, prior to any procurement decision, it was necessary to obtain test data on the P/POS comparable to the hypobaric chamber data obtained during developmental test II and operational test II for the HOS.

Objectives

The objectives of the present evaluation effort were to: 1) determine if the P/POS would adequately oxygenate human subjects at a pressure altitude of 18,000 feet, and 2) determine the length of time the system would support four users.

Methods and materials

Subjects

Twenty male military personnel on flight status (8 officers, 5 warrant officer candidates, and 6 enlisted) were recruited from the Fort Rucker area as subjects. Ages ranged from 20 to 48 with a mean of 28.84 years. All subjects were screened by a flight surgeon prior to participation in the study. Subjects also were given a class on altitude physiology, symptoms of decompression sickness and performance of a valsalva prior to entering the hypobaric chamber. Five groups of four subjects each were recruited for each of five hypobaric chamber sessions. However, one subject in one group was eliminated due to an inner ear infection. Thus, a total of nineteen subjects participated in the research project.

Apparatus

Testing was performed in a standard Guardite hypobaric chamber (Model 20M331). This is the same model used by the majority of physiological training units in the United States.

The American Safety Flight Systems, Inc. P/POS (P/N 7920171-1) was provided by the manufacturer (see Figure 1). The system is a self-contained, small profile, six position, 100 percent oxygen portable prebreather for use between 8,000 and 35,000 feet. The system was charged to 1800 pounds per square inch

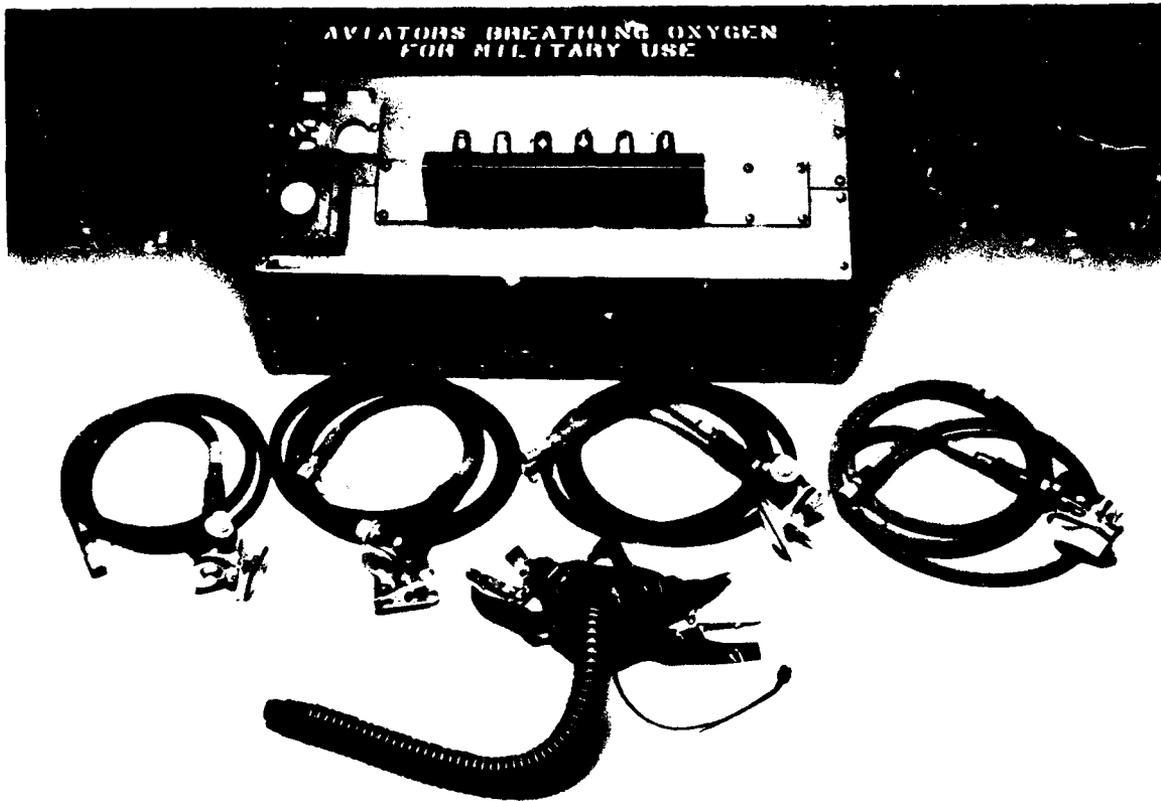


Figure 1. The American Safety Flight Systems prebreather/portable oxygen system (P/POS) with hoses and Airox VIII regulator.

(psi) with commercially procured medical breathing oxygen. The oxygen was tested onsite in accordance with Army policy for 100 percent purity with an Ohmeda 5100 oxygen monitor. The system was slowly charged to 1800+ psi and allowed to cool. This procedure was performed at least three times before each test. After the final cooling period, the system was bled down to 1800 psi gauge pressure.

Oxygen was delivered via Airox VIII regulators through CRU-60/P oxygen mask-to-regulator connectors to either MBU-5/P or MBU-12/P oxygen masks. Type of mask was determined by fit and comfort for each individual. Twelve subjects used the MBU-5/P and seven used the MBU-12/P.

Selected subtests from the Walter Reed performance assessment battery (PAB) were administered to each subject in order to assess cognitive changes which might occur as a result of an insufficient supply of oxygen. The equipment for PAB testing consisted of a Paravant RHC-88 ruggedized, handheld computer for each subject. These devices were book-sized PC-compatible computers which had been ruggedized to meet the specifications of MIL-STD 810-D. Each unit weighed four pounds, and featured a high contrast graphics LCD display with backlight

capabilities, color-coded alphanumeric response keys, and a rechargeable NiCad battery pack for powering the unit.

Baseline hemoglobin oxygen saturation levels were assessed for each subject on ambient air using a Spectramed Pulsat Monitor (Model SP1470). The device measured percent oxygen saturation of the blood by the method of reflectance oximetry using a small finger cuff which was attached to each subject's index finger.

Procedure

Training

Each subject received six training sessions on the PAB subtests prior to testing. Subjects arrived at the laboratory at their appointed times for training on the PAB. All members of an hypobaric chamber group received their PAB training sessions at the same time except for one subject in the third chamber group who was not available at the group's scheduled time. A separate training session was arranged at this subject's duty station. All other training sessions were performed in a well-lighted room while each subject was seated at one of four test stations which were separated by partitions.

All six training sessions were conducted the same day. Each session lasted approximately 15 minutes, and sessions were separated by 10 minute rest periods. The battery consisted of the following subtests which were administered in the same order every session: 1) logical reasoning, 2) digit recall, 3) serial addition/subtraction, and 4) four-choice serial reaction time.

At the beginning of each training session, subjects were seated at a test station and were allowed to familiarize themselves with the ruggedized, handheld computers. They were assigned a subject number which corresponded to a number on their assigned computer, and they were told to use the same device during their hypobaric chamber session.

Training sessions were administered by an enlisted member of the Crew Stress and Workload Branch staff. The test administrator read a prepared script while the subjects viewed copies of the instructions and diagrams of the LCD display for each task. Following the instructions for a particular subtest, the subjects performed the first training session for that subtest. The instructions for the next subtest were read, and then the subjects performed that subtest. Feedback was provided at the end of each subtest. Following the first training session, instructions were not read unless a subject asked a

specific question. The same procedure was followed for each of the five hypobaric chamber groups.

Logical reasoning. The logical reasoning subtest consisted of the presentation of the letter pair "AB" or "BA" with a statement describing the order of the two letters. The subject was required to determine as quickly and as accurately as possible whether the statement accurately described the letter positions. The sentence describing the letter pair could be formed using either "follows" or "precedes" as the root verb, worded in either the active or passive voice and worded either positively or negatively.

Digit recall. The digit recall subtest consisted of the presentation of a string of eight digits selected randomly with replacement (i.e., a digit could appear more than once in the same string). This string was presented for 1 sec followed by a 3 sec blank retention interval. Following the retention interval, seven of the original eight digits were presented again in a different order. The subject's task was to enter the missing digit as quickly as possible.

Serial addition/subtraction. In the serial addition/subtraction subtest, the subject viewed the sequential presentation of two single digit numbers and a "+" or a "-" sign. Following the presentation, the subject was prompted for a response by the presentation of a question mark. The subject's task was to perform the indicated computation and enter a response as quickly and as accurately as possible. If the result of the computation was less than 0, the subject was instructed to add 10 to the result and enter the sum. If the result was greater than 9, the subject was instructed to subtract 10 from the result and enter the difference. Thus, the required response was always an integer between 0 and 9, inclusive.

Four-choice reaction time. In the four-choice reaction time (RT) subtest, the subject viewed a display of four boxes arranged in a square on the LCD screen. One of the four boxes would appear darkened. The numeric keys 1, 3, 7, and 9 were colored red, and the subject was instructed that these four keys corresponded to the four boxes on the screen. The subject's task was to press the key corresponding to the darkened box as quickly as possible. Once a response was entered, the darkened box was removed and would reappear at random in one of the four boxes.

Following training, each group was scheduled for their hypobaric chamber session. Most chamber sessions occurred the day after training. However, because of time constraints, two of the groups received training in the morning on the day of their afternoon chamber session.

Altitude chamber

The subjects reported to the hypobaric chamber at their scheduled time. Prior to the test session, subjects were instructed in altitude physiology, chamber function, and valsalva technique; and a flight surgeon performed a medical screen. Four subjects at a time entered the chamber, were fitted with an oxygen mask, and took the first of their PAB test sessions. Then baseline hemoglobin saturation levels were recorded from each subject while they breathed ambient air.

Subjects then were connected to the P/POS, and the Airox VIII regulator diluter port was connected to the chamber's oxygen system. With the P/POS turned off, the subjects prebreathed 100 percent oxygen for 30 minutes from the chamber's oxygen system for the purpose of denitrogenation. During the denitrogenation period, the chamber was depressurized to the equivalent of 5,000 feet MSL at 3,000 feet per minute (fpm) and then returned to sea level at 4,000 fpm to check subjects for sinus and/or Eustachian tube blockage.

Prior to being disconnected from the chamber oxygen system at the end of the denitrogenation period, hemoglobin saturation on 100 percent oxygen was recorded from each subject. Then subjects were disconnected from the chamber oxygen system and connected to the P/POS. Timing of the system's duration began at this point.

The chamber was depressurized to the equivalent of 18,000 feet MSL at 500 fpm while the subjects breathed on the P/POS. Thus, the ascent took 36 minutes. During the ascent, a second PAB was administered, and subsequent PAB sessions were administered every 40 minutes for the duration of the test. Two or three sessions were administered at altitude depending on the amount of time required to consume the supply of oxygen. All but one of the groups received three PAB sessions at altitude. Prior to each PAB session, hemoglobin saturation levels were recorded from each subject. When subjects were not being tested, they were allowed to relax, read, or talk with the chamber technician until pressure in the P/POS reached 200 psi.

Once 200 psi was reached, the duration measurement (i.e., duration of the P/POS oxygen supply) was terminated, and the chamber was repressurized to sea level at 4000 fpm (4.5 minutes to reach sea level). Subjects remained on oxygen until the chamber was completely repressurized. Then subjects were removed from oxygen and a final PAB session was administered on ambient air. Thus, measures were taken five or six times during the testing session depending on the rate of oxygen consumption. Following the final PAB session, subjects were checked by the flight surgeon and released.

Results

Mean mission duration for the five chamber sessions was 2 hours 28 minutes with a standard deviation of 13.9 minutes. The duration for the fifth chamber session was measured on three subjects and then calculated for four subjects. The durations for each mission are summarized in Table 1 along with calculations projecting durations for missions in which the system is depleted to 50 psi instead of 200 psi because the system can safely be depleted to 50 psi during actual missions.

Table 2 contains estimates of how long the system would support various crew sizes assuming minimal workload calculated on the basis of the experimental data. The independent evaluation plan (IEP) for the HOS required system durations to support the aircraft fuel endurance times contained in Table 3 (from Meeks, Van Loo, and Morris, 1984). Comparison of Tables 2 and 3 indicates the ability of the P/POS to support the various aircraft fuel endurances.

Table 1.

Crew mission durations (hrs:min) for
each of five altitude chamber sessions

Flight	# in crew	1800-200 psi	1800-50 psi**
1	4	2:32	2:46
2	4	2:06	2:18
3	4	2:44	2:59
4	4	2:32	2:46
5	4*	2:27	2:41
Mean		2:28	2:42
S.D.		+/-13.9	+/-15.9

* Measured for 3 subjects and calculated for 4 subjects.

** Calculated for the case when the system is depleted to 50 psi instead of 200 psi as measured.

Table 2.

Estimates of system duration
(hrs:min) for crews of various sizes
(assuming minimal workload)

# in crew	1800 - 200 psi	1800 - 50 psi
1	9:52	10:48
2	4:56	5:24
3	3:17	3:36
4	2:28	2:42

Table 3.

System durations (hrs:min) required
to support aircraft fuel endurance times

Aircraft	Crew	Endurance
OH-58	2	2:30
UH-1	3	2:15
UH-60	3	2:30
CH-47*	8	3:30**

* Uses 2 P/POS
** With external fuel

Percent oxygen saturation data suggested that all subjects were well oxygenated during the entire chamber session. Oxygen saturation rose from a mean of 97 percent to a mean of 99 percent initially and then remained at a mean of 99 percent as subjects breathed oxygen from the P/POS.

Data from both the training and chamber PAB sessions were analyzed using a one-way repeated measures analysis of variance (ANOVA). The following two measures were analyzed for each of the four subtests administered: mean reaction time (RT) for correct responses and percent correct. The percent correct measure was transformed to a proportion and then transformed using the arcsine square root ($2 \cdot \text{asin}(\sqrt{\%/100})$) transformation recommended by Winer (1971).

To determine stability of performance, analyses of variance were conducted across the six training sessions. For those measures with a significant session main effect, contrasts were used to determine the trial at which stability was reached. Results indicated the subjects reached stable performance levels on each of the measures in each of the subtests within the first four sessions with the exception of mean RT for correct responses in the serial addition/subtraction subtest. For this measure, stable performance was not reached before the final session. However, analyses were conducted to compare the final training session to the first altitude chamber PAB session for each measure on each subtest. None of these differences were significant.

The effects of hypoxia on the performance of psychological tests have been well-documented in the literature (see Tune, 1964 for a review). To determine the ability of the P/POS to provide an adequate supply of oxygen, analyses of variance were performed on data from the PAB sessions conducted during each altitude chamber session. Data from all five groups were combined for these analyses. Because one group completed only two PAB sessions at altitude in the chamber, only two of the three PAB sessions which were performed at altitude by the remaining groups were used in the analyses. One subject's data from the altitude chamber session was lost due to equipment malfunction; thus, the analyses were based on data from 18 subjects.

Results of the analysis for the logical reasoning subtest revealed a significant session main effect for the mean RT for correct responses ($F(4,68)=5.12, p=.0011$). The session main effect for transformed percent correct was not significant. Contrasts for the session main effect for the mean RT for correct responses indicated that mean correct RTs during session 2 were significantly longer than for any of the other sessions (see Figure 2). While statistically significant, the session 2 mean (during ascent to 18,000 ft pressure altitude) increased by only 697 ms over the first session mean (prior to prebreathing) and proceeded to decrease after session 2.

Analysis of performance on the digit recall subtest indicated no significant session main effect for the mean RT for correct responses. However, percent correct did reveal a significant session main effect ($F(4,68)=2.63, p=.0419$). Contrasts for the session main effect for percent correct indicated that accuracy on sessions 2 and 4 was greater than that on session 5 (see Figure 3). Accuracy dropped 14 percent from session 2 (during ascent) to session 5 (following return to ground level pressure), while it dropped 19 percent from session 4 (approximately 50 minutes at 18,000 ft pressure altitude) to session 5.

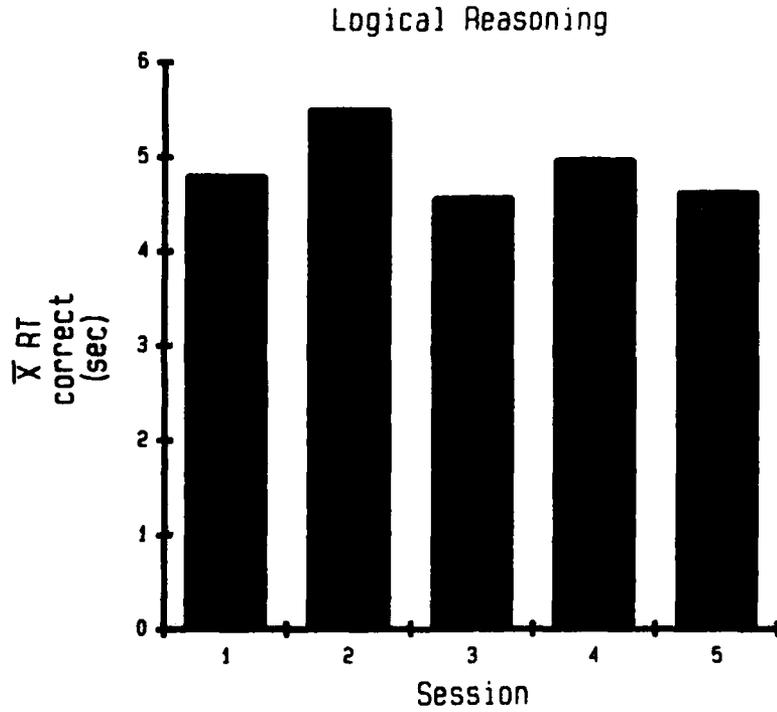


Figure 2. Mean RT for correct responses as a function of session on the logical reasoning subtest.

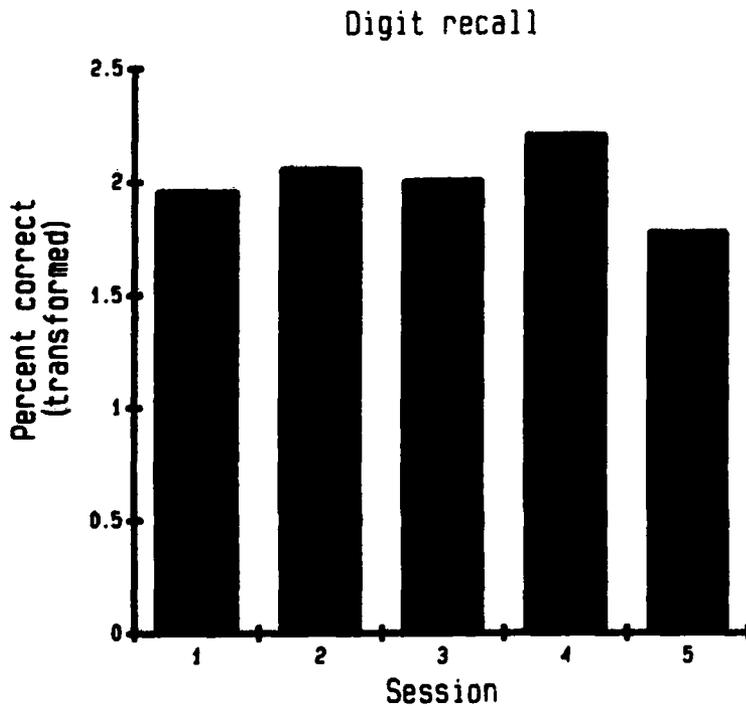


Figure 3. Percent correct as a function of session on the digit recall subtest.

Results of the analysis for the serial addition/subtraction subtest indicated a session main effect for both mean RT for correct responses ($F(4,68)=3.44, p=.0127$) and percent correct ($F(4,68)=3.59, p=.0103$). Contrasts for the session main effect for mean RT for correct responses indicated that mean RT increased significantly from session 1 to session 4. Mean RT also decreased significantly from session 2 to session 5 and from session 4 to session 5 (see Figure 4). Mean RT increased by 169 ms from session 1 to session 4. It decreased by 192 ms from session 2 to session 5 and by 241 ms from session 4 to session 5. Contrasts for the session main effect for percent correct indicated that performance at the first two sessions at altitude (sessions 2 and 3) was degraded compared to both the pretest (session 1) and the posttest (session 5). Accuracy dropped by 6 percent from session 1 to session 2, but was only 4 percent lower than pretest levels by session 3 (approximately 10 minutes at 18,000 ft pressure altitude). Performance at the posttest improved by 8 percent relative to session 2, and improved 5 percent relative to session 3 (see Figure 5).

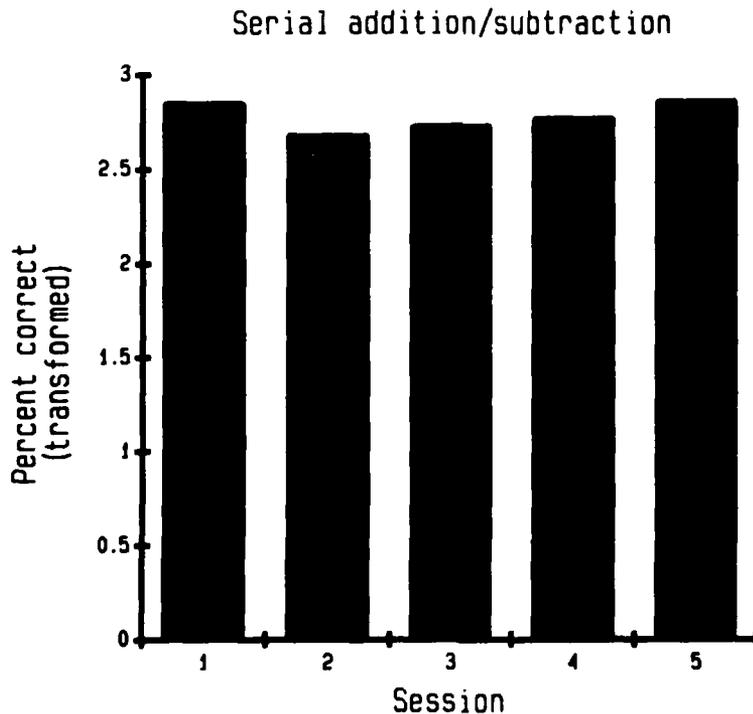


Figure 4. Mean RT for correct responses as a function of session on the serial addition/subtraction subtest.

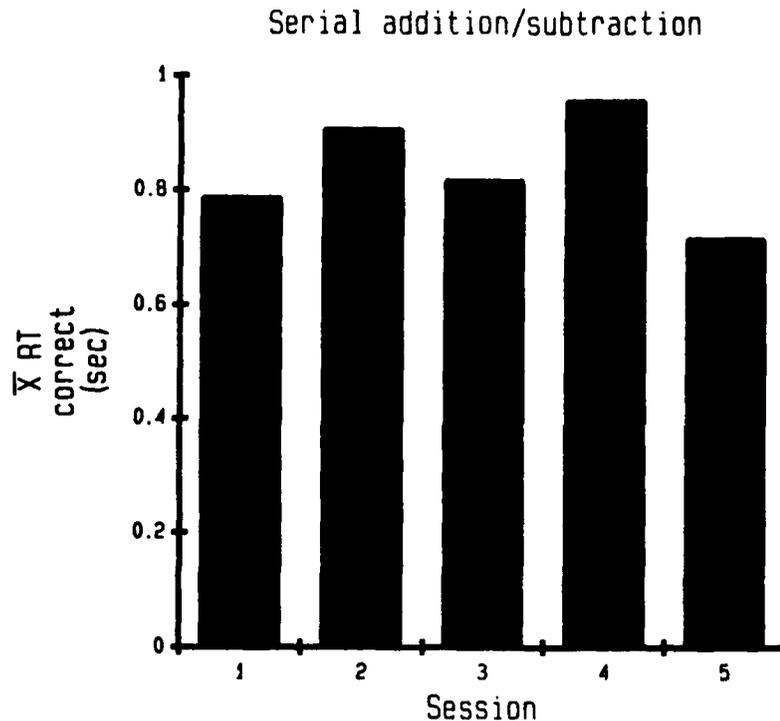


Figure 5. Percent correct as a function of session on the serial addition/subtraction subtest.

Finally, results of the analysis for the four-choice RT subtest indicated there was no significant change across sessions for either the mean RT for correct responses or percent correct.

Discussion and conclusion

The results, taken as a whole, suggest that all the subjects were well oxygenated during their chamber sessions. Oxygen saturation measures were of an acceptable level for adequate oxygenation. The subjects all appeared to be functioning well during their chamber sessions, and results of the PAB suggest their mental abilities were not adversely affected. Two of the subtests, four-choice RT and digit recall, showed either no change or improvement during sessions at altitude while subjects breathed off the P/POS. While the logical reasoning and serial addition/subtraction subtests did show some increase in mean RT for correct responses, these increases were small. While accuracy was affected on the serial addition/subtraction subtest, again the magnitude of the effect was minimal (less than 10 percent in every case). Furthermore, there was no concomitant effect on accuracy for the logical reasoning subtest.

In some instances, the consistency of the groups' performance along with the fairly large sample size contributed to the statistical significance of differences which were of little operational significance. For example, in the logical reasoning subtest, RTs for correct responses increased a little over half a second which was statistically significant. Yet, increases of this magnitude are likely not to be critical when flying at altitudes which require the use of oxygen. Decreases in accuracy of the magnitude observed in the serial addition/subtraction subtest are worthy of concern considering the implications they have for flying duties which involve rapid computation and vigilance, but this was the only subtest on which such decrements in performance were observed. It would be premature to conclude that the decrement in performance on this task was a result of inadequate oxygen supply when no other task demonstrated a similar effect and the oxygen saturation data suggest adequate oxygenation of subjects.

The American Safety Flight Systems, Inc. P/POS using the Airox VIII regulators will supply sufficient oxygen provided work rates are minimal (the same as during the Carleton-MOOG HOS test). Use of diluter demand regulators would increase times somewhat, but if the crew has minute volumes as high as those measured by Pettyjohn et al., (1977) while wearing night vision goggles, neither system would provide adequate oxygen for the required durations. Yet, the P/POS meets or surpasses the requirements of the IEP, and will meet the needs of all Army helicopter missions that do not require prebreathing. Helicopter missions to altitudes that require prebreathing (18,000 feet MSL) are extremely rare. However, one could obtain 100 percent oxygen for prebreathers by the addition of a second system connected to the dilution port.

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