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THE EFFECT OF BREATHING 100 PERCENT OXYGEN ON SHORT-TERM MEMORY OF MILITARY OFFICERS WHILE UNDER HEAT STRESS

Robert Louis Krubsack

Naval Postgraduate School
Monterey, California

September 1975

NAVAL POSTGRADUATE SCHOOL

Monterey, California

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by

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The Effect of Breathing 100 Percent Oxygen
on
Short-Term Memory of Military Officers
While Under Heat Stress

by

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Lieutenant, United States Navy
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ABSTRACT

Using a serial short term memory task, subjects were required to respond to symbols presented one-back, two-back, and three-back from a randomly presented list of four different symbols while breathing either 100 percent oxygen or atmospheric air with an oxygen mask in a heat stressful environment. The purpose of the experiment was to determine if breathing 100 percent oxygen had any effect on the short term memory of a subject under heat stress. Analysis of the data collected from 10 subjects under heat stress indicated breathing pure oxygen had no effect in the 15 minute period on short term memory.

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I. THE PROBLEM

The lack of oxygen associated with high altitudes and the associated physiological effects are well known and documented. Grinth /̲1965/̲ divides the symptomatology into zones of altitude above sea level with the level up to 10,000 feet producing no noticeable changes due to oxygen deficiency. In the zone from ten to fourteen thousand feet, the body attempts to compensate with increased respiration and heartbeat. It may take as long as an hour for this compensation to be fully apparent. The same compensation onsets in 20 minutes or less in the next zone which has a defined top at 15,000 feet. Between 15,000 feet and 20,000 feet, the compensation mechanism breaks down. The symptoms which result are headaches, giddiness, breathing difficulties and loss of sight. Above 20,000 feet the symptoms become severe with eventual physical and mental incapacitation and death occurring in a period of time depending on altitude. Some visual effects are documented in the first level up to 10,000 feet. Perdriel, et al. /̲1964/̲ showed visual acuity is effected at the upper portion of this zone where the scotopic threshold is influenced by anoxemia, (the lack of oxygen). These night vision variations have been shown to be caused by disturbances in the integration of lumious sensations by the cortex or the subcortical centers rather than in the eye itself. Such a circumstance can be corrected in less than 2 minutes by inhalation of oxygen according to Perdriel.

The U. S. military forces have characteristically supplied 100 percent oxygen to all aviators in aircraft that operate at high altitudes to alleviate the problem. Standard operating procedures dictate the wearing of the oxygen mask and breathing 100 percent oxygen for the duration of all flights in tactical aircraft.

A. PURE OXYGEN RESEARCH

Such a solution could have adverse effects since the breathing of 100 percent oxygen has been reported to be detrimental in some instances. Comroe, et al. [1945] reported on the toxicity of 100 percent oxygen when breathed for 24 hours by normal men. Many of his subjects displayed a symptom called substernal distress. The symptom

> ....was characterized as a substernal ache which often became sharp and severe during inspiration. The sensations were described as follows: 'felt as though I had been smoking excessively,' 'as though breathing raw, cold air,' 'as though I had just run a race to the point of exhaustion,' 'felt like bronchitis.' The symptoms were quite similar to those of mild 'chokes.' The substernal distress was noted at an average time of fourteen hours after the start of the oxygen, the range being from four hours to twenty-two.

This symptom did not develop when the individuals were tested at a simulated altitude of 18,000 feet thus confirming it was the "the presence of high tensions of oxygen (in excess of 50 percent oxygen at sea level) which is required to produce the symptoms mentioned." The author concluded that oxygen in its pure state is a drug and must be handled as such in any clinical treatment situation but that it is probably safe for short periods of use.

Lambertsen, et al. [1953] did further experimentation to try to establish the physiological reasons for oxygen toxicity. Their work was conducted at 3.5 atmospheres and 1 atmosphere as a control. This was based on the prior demonstration by Bert [1943] that convulsions could be produced by prolonged inhalation of oxygen at pressures greater than 1 atmosphere. Lambertsen reports significant decrease in cerebral blood flow (15 percent) due to cerebral vasoconstriction with no change in cerebral oxygen consumption after one hour of breathing oxygen at 1 atmosphere. A similar but more significant (25 percent) decrease was demonstrated at 3.5 atmospheres. But the physiological reasons were left unexplained as he reported:

> Our findings indicate that gross retention of carbon dioxide in brain tissue and intense constriction of the cerebral blood vessels can be excluded as important contributing causes of oxygen poisoning in man. A direct effect of oxygen on nerve cells remains the most likely explanation.

Womack [1961] noted considerable difference of opinion among practitioners of aviation medicine when treating certain medical problems involving the breathing of oxygen. Through a search of the literature, he cited different research projects including Lambertsen's and recommended a mixture of only 35 to 50 percent oxygen. This mixture was recommended because of the uncertainty of 100 percent oxygen in such cases.

Bills [1937] had already recommended such a ratio of oxygen. It was demonstrated in his research that a mixture of 50 percent oxygen, 3 percent carbon dioxide and 47 percent air was an optimal combination to facilitate subjects doing mental work. Bills also found "the breathing of pure oxygen by subjects fatigued from continuous mental work causes some recovery in performance."

Dunn [1962] confirmed Bills' findings in his research of psychomotor functioning while breathing varying partial pressures of oxygen and nitrogen. His research attempt was

> To examine the proposition that gaseous nitrogen produces some degree of narcosis under normal or reduced pressures. 70 subjects were tested on a multidimensional pursuit task while breathing various oxygen-nitrogen mixtures. The partial pressure of nitrogen was reduced in two ways: (1) by increasing the oxygen percentage in the mixture while maintaining constant total pressure, or (2) by decreasing the total pressure while maintaining a constant partial pressure of oxygen. There were no significant changes in performance that could be regarded as correlated with the nitrogen variable. However, increments in the partial pressure of oxygen lessened significantly the rate and magnitude of performance decrement, as noted by previous investigators.

More extensive psychomotor testing was performed by Scow, et al. [1950] in which both immediate and accumulative effects of breathing pure oxygen at an altitude of 35,000 feet and sea level were compared. Four different types of psychomotor tests were used over a period of five weeks in an effort to determine some evidence bearing on the subject of "pilots fatigue." They concluded breating 100 percent oxygen at 35,000 feet "was not associated with a decrease in psychomotor performance and no evidence of the accumulative effects of such exposure was detected."

Psychomotor functioning is thus unaffected by breathing 100 percent oxygen except that fatigue is forestalled. This is an advantage of using a higher percentage mixture. Another area of research has been the effects of 100 percent oxygen on vision. The effects of a lack of oxygen has already been presented but the use of 100 percent must be also included.

Beehler, et al. [1963] subjected mature mongrel dogs to 90 and 100 percent oxygen in a confined chamber at one atmosphere of pressure. Profound eye damage resulted in the animals' eyes in no more than 48 hours exposure. Beehler did not attempt to apply this result to humans as the dog retina differs from the human retina in several respects.

Another approach to the visual aspect of breathing 100 percent oxygen was taken by Miller [1958]. After a carefully controlled experiment, his findings were summarized:

> Analysis of the oxygen data revealed no significant depression or constriction of the central field and no sector defects; the size of the blind spot also remained essentially the same as that of the control study. A lack of significant alterations of the more peripheral isopters indicated no decreased sensitivity in this region. Central acuity was unchanged, and peripheral acuity of the 100 percent oxygen-test run at both five degrees and ten degrees did not differ significantly from that measured during the air-test run. Vision tested in several regions from zero to sixty degrees suffered no apparent decrement as a result of the breathing of 100 percent oxygen at atmospheric pressure for a period of over four hours.

The preceding examples of research have been cited to show there is considerable disagreement in exactly what effects 100 percent oxygen have on the physiology of man. The toxicity does not seem to present a problem provided the environment is at one atmosphere or less. However, Poulton /̄1974_7 introduced yet another aspect to the pure oxygen controversy with his research. He found a progressive deterioration in short-term memory while breathing 100 percent oxygen at normal atmospheric pressure in as little as 8 minutes. His experiment was prompted by reports of British submarine escape procedures not working well because the man would forget

> where he was in his overlearned escape procedure. He omitted some crucial detail or he carried out the correct actions but in the wrong order. It seemed possible that breathing pure oxygen may increase the chances of a failure of short-term memory.

A discussion of short-term memory is in order at this point.

B. SHORT TERM MEMORY

The subject of short term memory has been addressed by Welford /̄1968_7:

> It is well known that after a severe blow on the head which has produced temporary unconsciousness, the patient's memory for events prior to the blow is disturbed. At first he may be unable to remember anything that happened during a substantial time before the accident, except perhaps in a fragmentary or disordered manner. This period gradually shrinks, the more distant memories usually returning before the more recent. There remains, however, a short period of a few seconds or minutes which is permanently lost. Similar <u>retrograde amnesia</u> effects have been found using other agents producing violent assaults on the brain, such as electro-convulsive therapy (ECT).

> Facts such as these have led to the view that learning is a two-stage process. The material being learnt is conceived as held for a few seconds in a short-term 'store' consisting of some kind of brain activity--self-regenerating circuits of neurones analogous to the dynamic memory stores of some early computers have been suggested [Hebb, 1949]. This short-term retention is regarded as providing an opportunity for a more enduring memory trace to be built up.

Welford goes on to state "There has been considerable controversy as to whether short and long-term retention are stages of a single process or whether they imply two separate memory stores in the brain." He presents clinical studies which support the latter view.

Yet another aspect to this controversy was introduced by Broadbent [1971] and others that argued for a three stage system. The three stages are a buffer store, short term memory and a long term memory store. The buffer store was seen by Broadbent as a stage immediately after sensual perception where a presented item will enter, "but unless some further process (known as coding) takes place within the first second or so, the item will be lost." This position is reconcilable to a two stage system in that the buffer store and short term memory can be seen as synonymous to immediate memory [Norman, 1969].

For purposes of this study, the summary introduction of Fitts and Posner [1967] will serve as a definition:

> After a stimulus has been received and processed, there is a period of time during which it requires the attention of the subject if it is to be preserved. This time varies,

> depending upon the complexity of the stimulus. If a single item is presented, no further attention may be required for relatively permanent storage. If the number of items exceeds the memory span even very active rehearsal will not be sufficient to preserve them, since some of them will be lost during the rehearsal process. Short-term memory is defined as a system which loses information rapidly in the absence of sustained attention. Contrast the effect of distraction on the ability to recall your own phone number with its effect on you when you look up a new number, you forget the new number but retain your own. Short-term memory involves about the first sixty seconds after presentation of a new stimulus. After that time, either the items are lost or they are transferred to a long-term memory system.

Areas in this statement which need elaboration are memory span and the means by which items are lost from short term memory.

Memory span is also well explained in Fitts and Posner:

> The type as well as the amount of material affects the capacity for short-term memory. For example, the memory span for letters is 7 items, while the memory span for simple words is 5 items. The number of letters retainable when they are grouped into words is increased several fold. Similarly, subjects can remember eleven binary digits and eight decimal digits, though eleven binary digits can be represented by only four decimal digits. George Miller [1956] pointed out that man shows relatively better retention of complex items such as words than simple items such as letters. Thus, the number of letters retained increases if the subject can find simple words which tie together a number of unrelated letters. Miller proposed that the limitation on human memory be thought of in terms of number of chunks, or meaningful units. The memory span is longer for simple chunks than for complex chunks. Simple chunks, however, convey less information than complex chunks. To convey maximum information it is better to use complex chunks.

The maintenance of the items in the memory span depends on some form of rehearsal in all theories of short-term memory. How items are lost from short-term memory is in much debate. Some researchers support the decay theory which proposes the material is lost from short-term memory as a function of time [Brown, 1958]. The other theory of loss is that of interference. Welford [1968] and Norman [1969] both cite opposing viewpoints to the decay theory and postulate basically that items are lost due to some type of interference to the rehearsal process. Murdock [1961] and others add to this controversy with statements such as: "thus, taken as a whole, the present experiments do not provide unambiguous support for either a decay theory or an interference theory of forgetting."

Due to the nature of this study, another aspect of memory must be investigated. Sequential short-term memory was defined by Poulton [1963] as that process which is used to repeat or record information shortly after it is received. An example of such a process is dictation. Such a task involves continuous presentations and retrival. Fitts and Posner take a somewhat wider view of the process and point out that "these tasks require a combination of short-and long-term memory." But the long-term memory is principally used for the portrayal of the information in the written or spoken form. These authors report:

> Two general methods for studying these processes have been used. The first method, called the running memory span, involves the presentation of a string of unrelated items without any fixed end point. The subject either is required to recall the part of the series immediately before the experimentor stops or is provided with a cue as to which items out of the series to recall. The second method involves the use of skilled tasks such as typing or reading in which the subject's response naturally lags behind his acquisition of new information.

Poulton used the first method in research with breathing 100 percent oxygen. The task used consisted of a moving paper tape under a perpendicular slot. As the tape moved, a small portion of track on the tape would appear to move from side to side in the slot with varying frequency and amplitude. The average frequency was a reversal every 2.3 seconds with the side to side distance never exceeding 4.5 centimeters. The subject then watched the track in the slot and noted the positions at which it reversed direction. These positions were then recorded by the subject in delay modes which ranged from 0 to 3. Zero delay was a very simple task were the subject immediately recorded the noted position. Delay mode one was more difficult in that the subject had to wait until the track reversed again and then record the noted position of the previous reversal. Delay modes 2 and 3 were an extension of this process with mode 3 the most difficult task. The subject had to keep in his memory the position of three previous reversals at all times while he recorded the position which had occurred three times before the one he was presently noting. According to Poulton

> the task was selected because it provides a very precise measure of short-term forgetting under conditions which range from easy to extremely difficult. It is, therefore, likely to be sensitive to relatively small changes in efficiency.

Poulton concludes,

> the results indicate that, when a sufficiently sensitive task is used, breathing pure oxygen at normal atmospheric pressure for as little as 8 minutes is found to produce a progressive reliable deterioration in short-term memory.

Based on Poulton's work, Marsden [1975] performed a similar experiment in which the Response Analysis Tester built by General Dynamics Convair Division was used as the task device. This device will be described later in the present study. Marsden's subjects breathed oxygen or air as they performed the task in a lag condition of 1, 2, or 3 as in Poulton's experiment. Marsden reports,

> ...the results indicated no decrement in short-term memory while breathing 100 percent oxygen in the present experiment. The result is contrary to results obtained by Poulton [1974]. The explanation for this difference is not easy to interpret.

It is possible the subjects of Poulton's experiment were under heat stress as well as breathing oxygen.

C. HEAT STRESS

Lee [1964] reports on the primary physiological consequences of heat:

> The first corrective action initiated by the heat-regulating centers to meet an imbalance toward the hot side is dilatation of the skin blood vessels by means of sympathetic nerve impulses. Skin temperature is raised and heat

> loss by conduction and radiation promoted, or any heat gain through these channels decreased. This reaction may be facilitated by reduction of sympathetic impulses to the adrenal medulla and thus limitation of the outflow of its thermogenic and blood-vessel-constricting hormones.

One of the secondary consequences of the physiological response is a disturbance of the nervous system. According to Lee, this is due to any inadequacy of the peripheral vascular system affecting the cerebral cortex because of its great sensitivity to the oxygen supply and its gravitational position.

Mackworth [1946] examined the effect of heat stress on mental performance by comparing activities of trained telegraphy operators hearing and recording morse code messages under varying effective temperatures. From this and related work, Mackworth [1950] proposed the concept of a critical region on the atomspheric temperature scale above which most men will not work effectively. An example of this region is an effective temperature of 83° to 87.5°F for an acclimatized man dressed in shorts.

Effective Temperature (ET) is one of the composite indexes of environmental factors which affect man's sense of heat. It is defined by the ASHRAE handbook of fundamentals as reported in McCormick [1970]

> ...as an empirical sensory index combining into a single value the termal effect of temperature, humidity, and movement of air upon the human body.

Another composite index of environmental factors is the heat stress index. This index was developed by Belding and Hatch [1955]. McCormick [1970] describes the modified version:

> The index expresses the heat load in terms of the amount of perspiration that must be evaporated to maintain heat balance; this is referred to as E_{req} (the *required evaporation* heat loss). In turn, it is possible to determine the maximum heat that can be lost through evaporation E_{max}, from assumptions of body size, weight, and temperature and by taking into account water-vapor pressure of the environment and air velocity. While the details of these derivations will not be repeated, the *difference* between these two values (expressed in Btu per hour) indicates the load that must be reduced or dissipated otherwise. The *otherwise* can take various forms, such as further reduction of convection or radiation sources, reduction of task demands by reducing physical requirements or by rest pauses, and by proper clothing.

Both the effective temperature and the heat stress index will be used in the present study.

A generalized pattern of the temperature-duration function as related to mental performances was developed by Wing [1965] on the basis of a thorough analysis of the results of 15 previous studies. The lowest temperature at which a statistically significant performance decrement occurred was identified in each of the studies. Since the different studies were performed for varing endurances, Wing was able to construct a curve that represents the upper limit for unimpaired mental performance. This curve, shown in Figure 1, was compared to earlier studies of tolerable and marginal physiological limits which proved it to have a similar shape at the expected lower threshold.

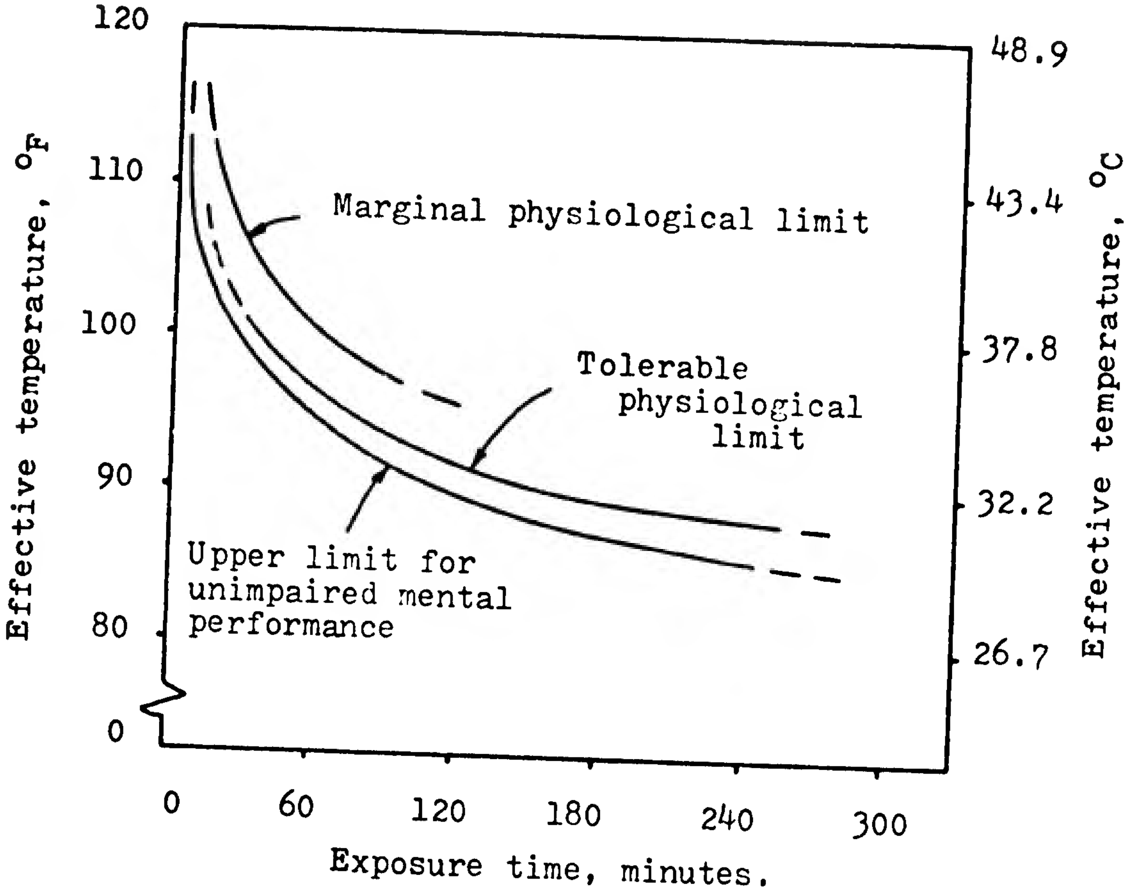

Figure 1. Temperature-duration function of mental performance. (Wing, 1965)

D. THE PRESENT PURPOSE

An excessive amount of heat induced into the cockpit can accompany high performance aircraft emergencies. This situation can put the pilot into an immediate heat stressful environment. Under such circumstances, the pilot must rely on memory to perform the necessary emergency procedures while breathing 100 percent oxygen. The present experiment was therefore designed to test the hypothesis that there is no effect (decrement) in performance of subjects on a serial short-term memory task caused by progressive effects of breathing 100 percent oxygen in a heat stressful environment. The methods and procedures were similar to those used by Poulton [1974] and Marsden [1975].

II. METHOD

The experiment used to test the hypothesis was constructed using a known serial short-term memory task device. This device will be described in the apparatus section of this study. Each subject participated in the experiment under two conditions: that is he performed the task breathing oxygen one time and air another time. In this way he was his own control.

A. SUBJECTS

The subjects for the experiment were 10 male students from the Naval Postgraduate School. All subjects were volunteers and were not compensated for their participation. They ranged in age from 28 to 34 years.

B. APPARATUS AND STIMULI

The experiment was conducted in the facilities of the Man-Machine System Design Laboratory at the Naval Postgraduate School.

1. Breathing Apparatus

Standard NAVY equipment was used for the breathing apparatus. The mask was a pressure breathing oxygen mask MS 22001-6, manufactured by the Sierra Engineering Company. Two sizes of mask, medium and large, were used to facilitate the subjects. The mask was held in place to the face of the subject with standard fittings on the cup of the mask which in turn attached to a typical flight crew helmet worn by the subject. Both the standard ear phones in the helmet and the lip microphone in the mask were electronically wired for sound allowing the subject to be in constant communication with the experimenter. This equipment is shown in Figure 2.

The mask was supplied with compressed air or oxygen from a regulator attached to the supply tanks. The regulator was an automatic positive pressure diluter demand type manufactured by Bendix Aviation Corporation. The regulator, which has a setting for diluted or 100 percent oxygen, was set to 100 percent for the duration of the experiment. The corresponding tank valve was opened to supply either oxygen or normal air to the regulator and thus to the subject. The oxygen equipment set up is shown in Figure 3.

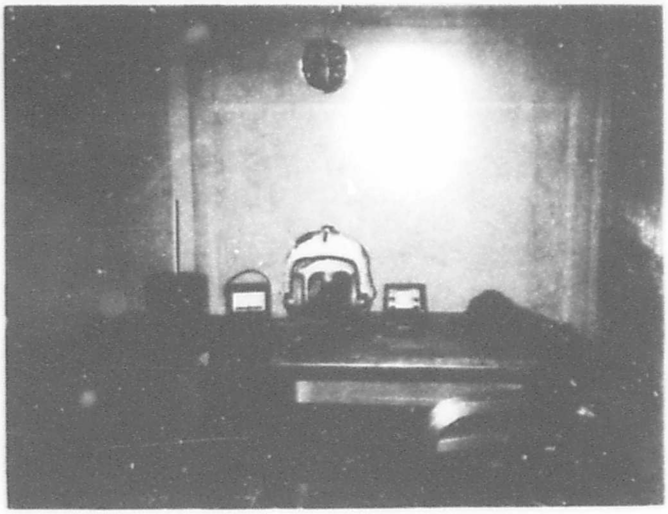

Figure 2. Oxygen Mask, Helmet, RATER, and Temperature measuring devices.

Figure 3. Oxygen Regulator, Supply Tanks, and RATER Control Unit.

2. Stimuli and Response Apparatus

The miniaturized Response Analysis Tester (RATER), Model 3, was used as the experimental device to display the visual stimuli and collect the response data. This device is designed and built as a psychomotor testing instrument by General Dynamics Convair Division. Its purpose is to provide reliable measurement of response speed and accuracy and short-term memory performance with patterned or colored stimuli. The patterned stimuli were used in this experiment. The device consists of two units, the stimulus-response unit and the control unit. The stimulus-response unit (Figure 4) which is placed in front of the subject has four keys and a small viewing screen. The subjects basic task was to respond to one of four possible stimuli presented on the viewing screen by pressing the corresponding key. In this experiment, a card indicating the correct response key was placed on the key panel and remained there throughout the testing. The four stimuli used were a plus sign, a circle, a triangle, and a diamond. All stimuli are white colored with a dark background when projected on the small viewing screen.

Three delay modes of the basic task were used in the experiment. In delay mode one, the first symbol was presented for one-and-one-half seconds. The subject does not respond until the next symbol appears. Since the experiment was selfpaced, the next symbol was displayed for an indefinite period of time until the correct response to the first symbol was made. When the correct response was made, the present symbol would dim momentarily indicating a correct response and then the next symbol would automatically appear. An incorrect response caused no action on the viewing screen. This repetative sequence continues for the duration of the mode test period.

Delay mode 2 was similar to delay one except that the subject viewed two symbols for the fixed time period of one-and-one-half seconds before making a response while the third symbol was displayed. He was to respond to the first symbol while the third was displayed and then to the second symbol while the fourth was displayed and so on. He thus was always to respond to two symbols back from the present one on display. This sequence continued for a two minute period.

Delay mode three was again similar to modes one and two except that the subject was to respond to symbols three back from the one presently displayed. This was the most difficult mode used in the present experiment.

Two counters on the control unit (Figure 5) keep a running account of the subjects' total responses and his correct responses.

Figure 4. RATER Stimulus-Response Unit.

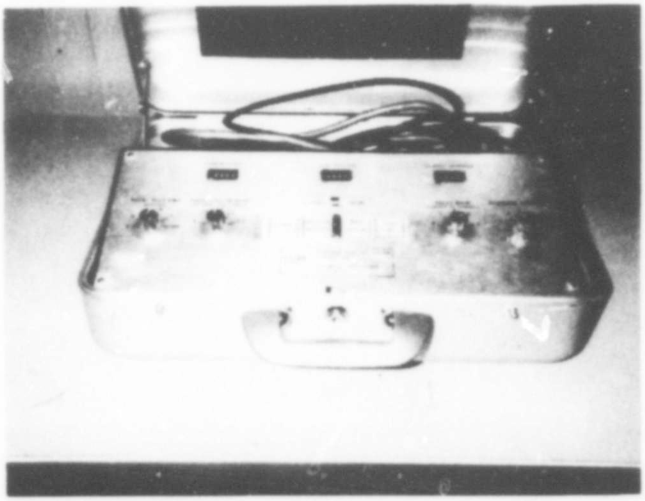

Figure 5. RATER Control Unit.

3. Heat Stress Environment

The experiment was conducted in a Controlled Acoustical Environments chamber manufactured by the Industrial Acoustics Company of Bronx, New York. A dry bulb temperature of 122°F was used with a relative humidity of 20 percent and an air velocity of less than 35 feet per minute to achieve the effective temperature of 93°F. The effective temperature was computed from nomograms as shown in Lee [1964]. The maximum allowable exposure time in this environment is 23.8 minutes according to the Heat Stress Indes as outlined by Belding and Hatch [1955] and refined by Belding as shown in Cralley [1972]. Each subject was actually exposed for 15 minutes. The minimum recovery time was computed for outside the heat environment in the laboratory with the subject sitting at ease. This was found to be 15.5 minutes. The above two calculations are shown in Table 1.

C. PROCEDURE

All subjects were told the purpose of the experiment was to determine if breathing pure oxygen would have an effect on short-term memory while under heat stress. They were all familiar with the operation of the RATER device. They were not told which treatment (air or oxygen) they would receive during each test session. Judging from the comments made by subjects during the data collection, none could ascertain which of the gases (pure oxygen or compressed air) they were breatning. Half of the subjects breathed air on their first

HEAT STRESS INDEX CALCULATIONS

1.) Maximum Exposure Time:

Metabolic Load : $M = 410$ (light hand work) (Cralley, 1972)

Dry Bulb Temp : $t_a = 122^{o}F$

Globe Temp : $t_g = 127^{o}F$

Velocity of Air : $V = 35$ ft/min.

Water Vapor Pressure of Air : $P_a = 19$ mm.Hg.

$t_w = t_g + 0.13V^{0.5}(t_g - t_a) = 130.8$

$R = 15(t_w - 95) = 537.7$

$C = 0.65V^{0.6}(t_a - 95) = 147.7$

$E_{max} = 2.4V^{0.6}(42 - P_a) = 466.0$ BTU's per Hour

$E_{req} = M + R + C = 1095.4$ BTU's per Hour

$$\text{Heat Stress Index} = \frac{E_{req}}{E_{max}} \times 100 = 235$$

$$\text{Maximum Exposure Time} = \frac{250 \times 60}{E_{req} - E_{max}} = \underline{23.8 \text{ minutes}}$$

$$\text{Heat Stored} = E_{req} - E_{max} \times \text{Time Exposed} = 157 \text{ BTU's}$$

2.) Minimum Recovery Time (in area separated from heat stress environment where subjects recovered).

Metabolic Load: $M = 360$ (sitting at ease) (Cralley, 1972)

Dry Bulb Temp : $t_a = 75^{o}F$

Globe Temp : $t_g = 76^{o}F$

Velocity of Air : $V = 35$ ft/mim.

Water Vapor Pressure of Air: $P_a = 13$ mm. Hg.

$t_w = 77.0$ $\quad E_{max} = 587.5$

$R = -270.0$ $\quad E_{req} = -19.4$

$C = -109.4$

HSI = 3.3 : less than 100 therefore a cooling situation.

$$\text{Minimum Recovery Time} = \frac{\text{Heat Stored} \times 60}{E_{max} - E_{req}} = \underline{15.5 \text{ min.}}$$

Table I. HSI Calculations

trial; half breathed pure oxygen. Six of the subjects were also familiar with the type oxygen mask used in the experiment. Those that were not familiar with the mask had at least received gas drill training using the service filter-type gas mask.

1. Experiment Trial

The subject was instructed as to the sequence that would be followed during the test session. He was then fitted with the helmet and mask taken into the test heat chamber. The timing commenced with the exposure to the heat and breathing mixture. After three minutes of exposure, the data collection began with the subject participating in a delay mode one operation of the RATER for 2 minutes. A three minute rest period was followed by 2 minutes of delay mode 2 operation. The final three minute rest period was followed by the most difficult delay mode three operation of the RATER. This time sequence is shown in Figure 6. The subjects were thus exposed to 15 minutes of pure oxygen or air and heat stress.

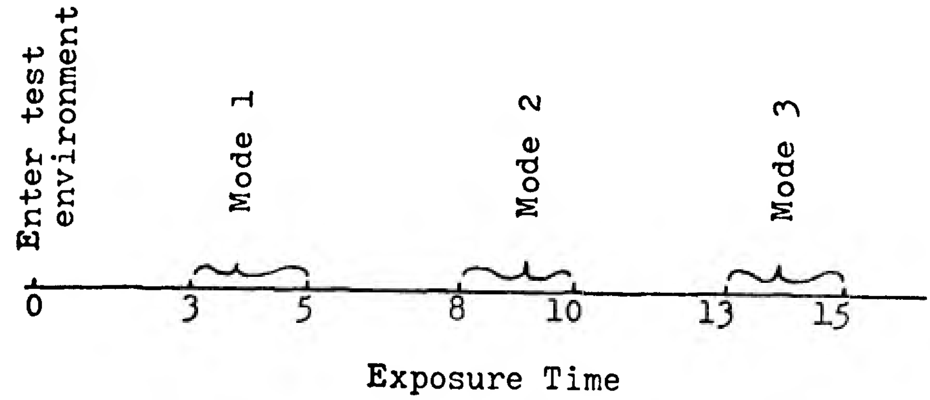

Figure 6. Test Sequence

Performance of the delay conditions was fixed with delay condition one, two, and three performed successively. This was done to allow the subject to respond to the oxygen. All subjects participated in both treatments (air or oxygen) on the same day with at least the minimum heat stress index recovery time between test sessions. It was hoped same day tests would minimize all variables other than the dependent variable.

At the completion of each delay mode test, the total responses and the correct responses of the subject were recorded by the experimenter.

D. DESIGN

The dependent variable for this study was the percent correct score of each delay mode test by each subject under oxygen and air. The percent correct score is derived by dividing the total number of responses by the number of correct responses. This percentage was used because a measure of subject accuracy was desired. The resulting scores were analysed according to a three-way factorial analysis of variance (ANOVA), [Hicks, 1973]. The three factors were the treatment (air or pure oxygen), the delay mode, and the subjects. A conceptual model is displayed in Figure 7.

An effective temperature of 93°F was used for the experiment. This temperature for the exposure time is below the critical value to cause any performance decrement in its own right as shown by Wing [1965].

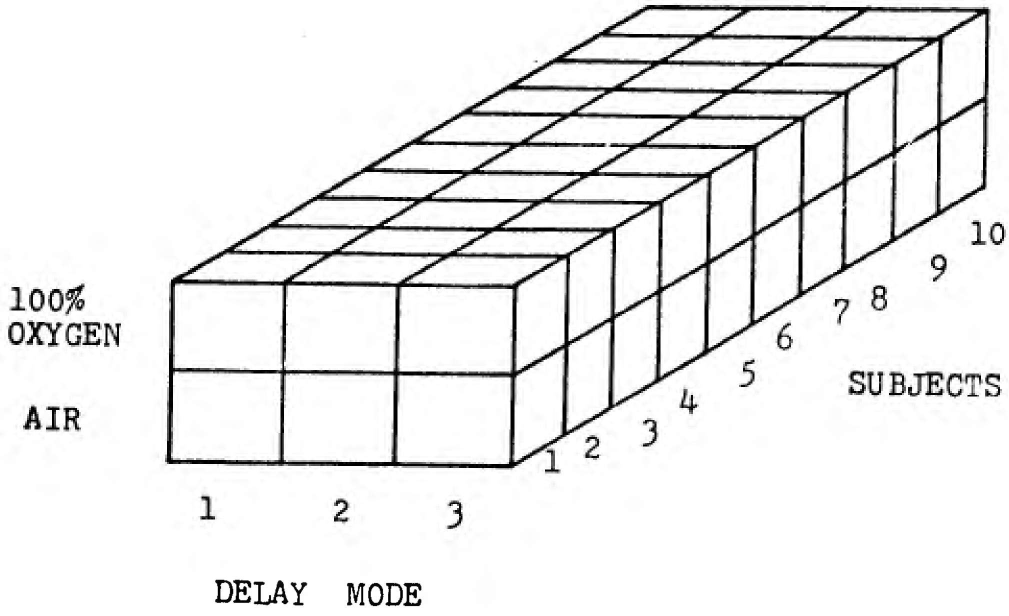

Figure 7. Conceptual Model of the Experiment.

III. RESULTS

The results indicate no significant difference between breathing 100 percent oxygen or breathing air for a period of 15 minutes in a heat stress environment. This statistical result is shown in the ANOVA Table (Table II). The delay modes are significantly different as shown in the same Table. Table III gives the means and standard deviations of the data collected in the experiment.

Source	d.f.	S.S.	M.S.	F	
Treatment (O_2 or Air) (T)	1	.735	.735	.664	
Subjects (S)	9	137.8			
Delay Mode (D)	2	1399.3	699.63	188.58	prob <.001
T x S	9	9.96			
T x D	2	.84	.42	.147	
D x S	18	66.8			
Error	18	51.5			
	59	1666.7			

Table II. Results of ANOVA on percent Correct Responses

	DELAY MODE 1		DELAY MODE 2		DELAY MODE 3	
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
OXYGEN	178.8	44.22	157.1	51.89	149.5	54.96
AIR	179.7	47.00	157.2	53.47	153.1	63.12

Mean and Standard Deviation of Total Responses

	DELAY MODE 1		DELAY MODE 2		DELAY MODE 3	
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
OXYGEN	166.6	42.39	112.2	36.22	81.4	27.78
AIR	166.3	41.37	113.3	34.46	85.5	30.99

Mean and Standard Deviation of Correct Responses

	DELAY MODE 1		DELAY MODE 2		DELAY MODE 3	
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
OXYGEN	93.13	5.05	72.19	9.96	54.90	6.64
AIR	92.97	4.93	72.73	8.83	56.56	5.12

Mean and Standard Deviation of Percent Correct
Scores used for ANOVA

Table III. Mean and Standard Deviation of Data

IV. DISCUSSION

The present experiment showed no decrement in short-term memory to be caused by breathing pure oxygen in a heat stress environment. This is in disagreement with Poulton's [1974] published results but in agreement with Marsden [1975]. Marsden felt "a possible explanation may be that Poulton's discussion of test results with subjects influenced their performances." This remains as a possibility, however, it is a matter of contention.

The task differences must next be considered. Poulton used a tracking type task where a quantitative amount of difference could be measured on each response recording. The RATER does not allow for such data collection but it does meet other criteria as set forth by Poulton [1964]. That is, in the delay mode three operation the average performance is in the 50 percent correct spectrum.

The RATER does prove to be a reliable serial short-term memory task when compared to other work in this field. Welford [1968] reports that Kay performed the original experiment on this kind of task in 1953. Kay's experiment required subjects to press a key in response to a light. The correct response could be delayed by the experimenter so that it was separated from the stimulus light by a variable number of stimuli. This was a forced paced task with 1.5 seconds between stimuli. He found that correct responses fell from

95% at one back delay to 67% at two back delay and were down to 47% at the 3 back delay mode. Mackworth and Mackworth [1959] provided yet another experiment to substantiate this claim. Their device used a spotlighting on a particular object in a display. The spotlighted object then changed every three seconds thus forming another type of forced paced task. Their percent correct scores were 97 for one back, 77 for two back, and 53 for three back. These percentages favorably agree with the present results and those demonstrated by Marsden's subjects.

Marsden's overall percent correct means and standard deviations are shown in Table IV. These values, when compared to the data of the present study with a standard T test, [Dixon, 1969] are found to have no significant difference at an alpha value of .05. This leads the author to believe the heat stress value used in the experiment did in fact have no effect on its own accord.

	DELAY MODE 1		DELAY MODE 2		DELAY MODE 3	
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
OXYGEN	94.59	6.40	74.37	14.15	56.11	11.89
AIR	94.20	7.42	75.12	14.03	57.83	10.49

Table IV. Mean and Standard Deviation of Percent Correct Responses from Marsden's Experiment.

The results of the present experiment thus agree with those of Marsden. It is felt that there seems to be little cause for alarm concerning the toxic effects of breathing pure oxygen under heat stress in this type of experiment for the lengths of time considered.

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