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

.

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Monterey, California

THESIS

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ON
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WHILE UNDER HEAT STRESS

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
B.A., University of Oregon, 1967

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Using a serial short term memory task, subjects were
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symbols while breathing either 100 percent oxygen or atmospheric
air with an oxygen mask in a heat stressful environment.
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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 docu-
mented. Grinth $\underline{/}$1965$\underline{/}$ 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. $\underline{/}$1964$\underline{/}$ 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

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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. $\sqrt{1945\_7}$
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

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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. $\underline{/}$1953$\underline{/}$ 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 $\underline{/}$1943$\underline{/}$ 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 $\underline{/}$1961$\underline{/}$ 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 signi-
> ficantly 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

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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] 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]:

> It is well known that after a severe blow
> on the head which has produced temporary uncon-
> sciousness, 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 retrograde amnesia 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 <u>activity</u>--
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 contro-

versy 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 per-

ception 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 recon-

cilable 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 $\underline{/}$ 1956 $\underline{/}$
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 infor-
mation it is better to use complex chunks.

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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_7. The other theory of
loss is that of interference. Welford /1968_7 and Norman
/1969_7 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_7
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_7 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 exten-

sion 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 $\sqrt{1975}\,\_\!\!\!7$ 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
$\sqrt{1974}\,\_\!\!\!7$. 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 $\sqrt{1964}\,\_\!\!\!7$ reports on the primary physiological conseq-

uences 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

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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 posi-

tion.

Mackworth $\sqrt{1946\_7}$ examined the effect of heat stress on

mental performance by comparing activities of trained tele-

graphy operators hearing and recording morse code messages

under varying effective temperatures. From this and related

work, Mackworth $\sqrt{1950\_7}$ 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 $87.5^{\circ}F$ 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 $\sqrt{1970\_7}$

            ...as an empirical sensory index combining
        into a single value the termal effect of temper-
        ature, 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 $\underline{/}$1955$\underline{/}$. McCormick $\underline{/}$1970$\underline{/}$ 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 <u>required evaporation</u> 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 <u>difference</u> between these two values (expressed in Btu per hour) indicates the load that must be reduced or dissipated otherwise. The <u>otherwise</u> 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 $\underline{/}$1965$\underline{/}$ 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.
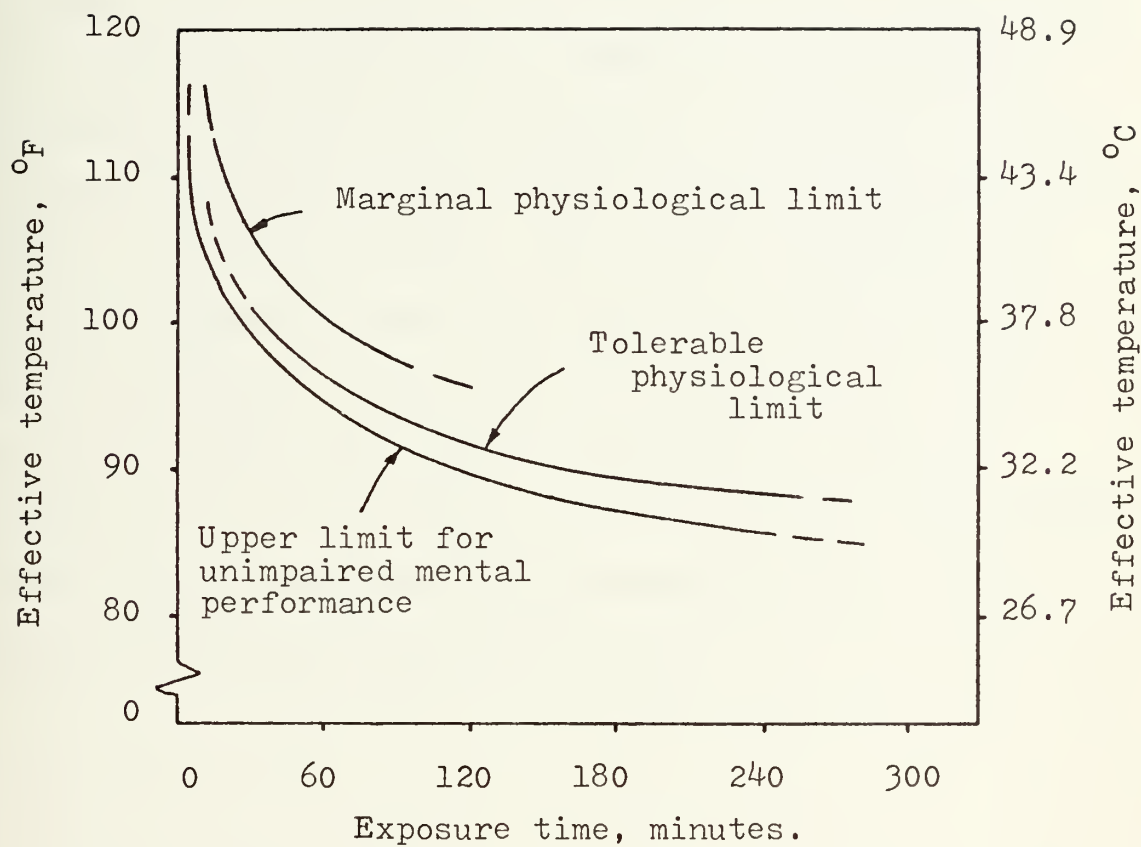
Figure 1. Temperature-duration function of
            mental performance. (Wing, 1965)

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 $\angle$1974$\angle$ and Marsden $\angle$1975$\angle$.

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,
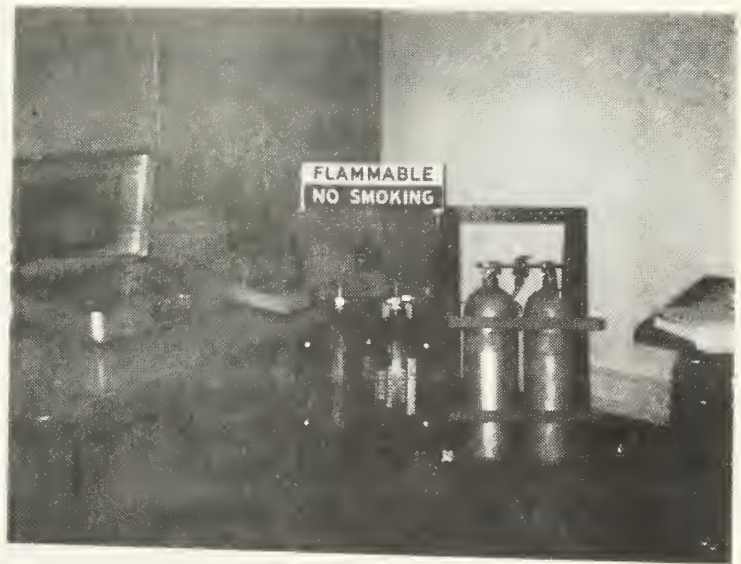   and Temperature measuring devices.

FLAMMABLE
NO SMOKING

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

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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.
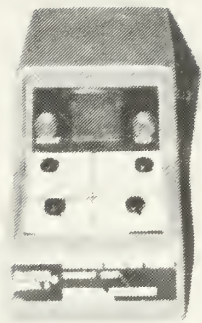
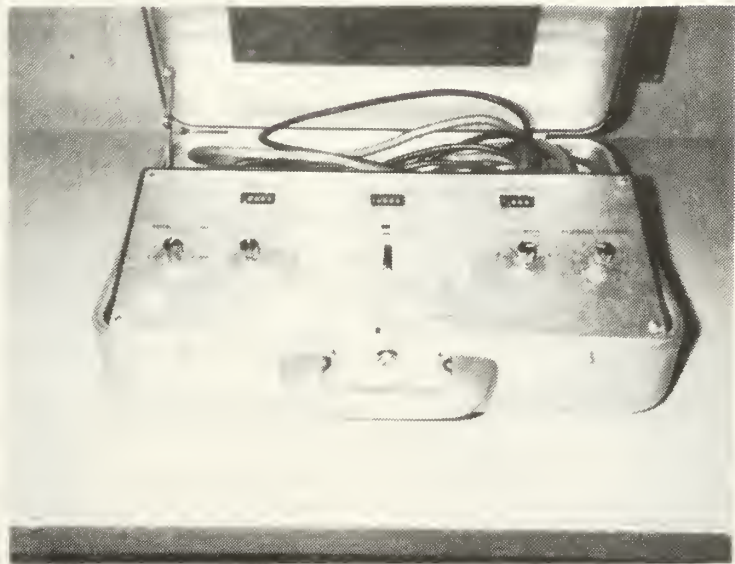Figure 4.   RATER Stimulus-Response Unit.

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 $122^\circ F$ 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 $93^\circ F$. The effective temperature was computed from nomograms as shown in Lee $\sqrt{1964}$. The maximum allowable exposure time in this environment is 23.8 minutes according to the Heat Stress Indes as outlined by Belding and Hatch $\sqrt{1955}$ and refined by Belding as shown in Cralley $\sqrt{1972}$. 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 breathing. 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°F

Globe Temp : t_g = 127°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°F

Globe Temp : t_g = 76°F

Velocity of Air : V = 35 ft/min.

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

t_w = 77.0 E_{max} = 587.5

R = -270.0 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 breath-
ing mixture. After three minutes of exposure, the data collect-
ion 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
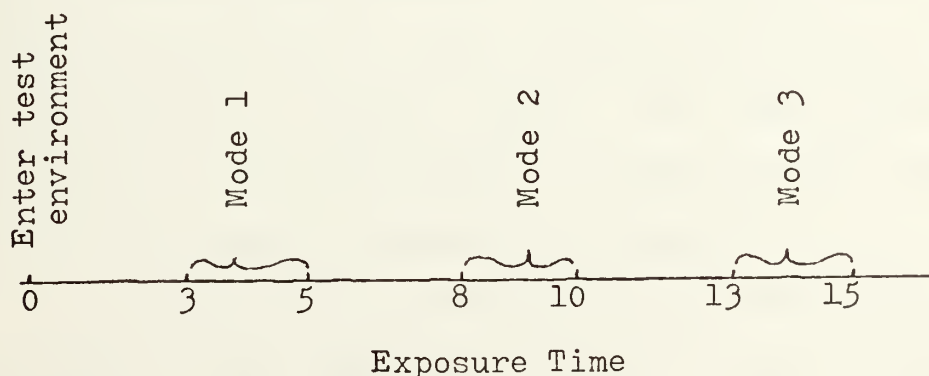to 15 minutes of pure oxygen or air and heat stress.

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), $\underline{/}$Hicks, 1973$\underline{/}$. 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 $93^{o}F$ 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 $\underline{/}$1965$\underline{/}$.
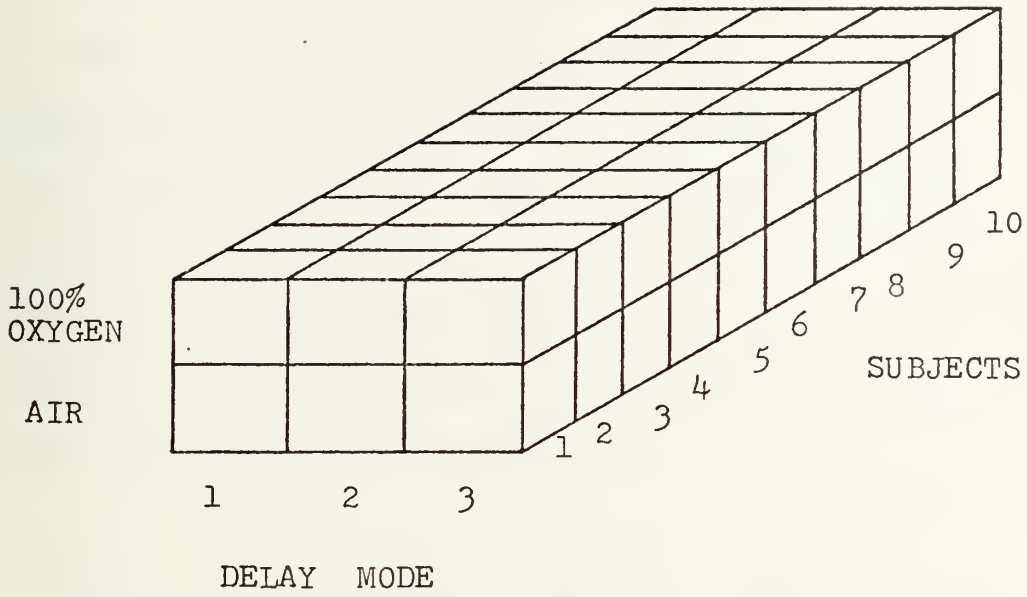
Figure 7. Conceptual Model of the Experiment.

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 (T) $(O_2$ or Air)	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 $\sqrt{1974\_7}$ published results but in agreement with Marsden $\sqrt{1975\_7}$. 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 $\sqrt{1964\_7}$. 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 $\sqrt{1968\_7}$ 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_7 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_7 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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