

AN EXPLORATORY STUDY OF THE PSYCHOLOGICAL EFFECTS OF
INTERMITTENT EXPOSURE TO ELEVATED CARBON DIOXIDE LEVELS

by

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SUMMARY PAGE

THE PROBLEM

To determine whether any remarkable psychological changes occur as a result of intermittent exposure to 3% carbon dioxide for six days.

FINDINGS

There were no significant changes in vigilance, eye-hand coordination or in problem-solving capability. However, benign emotional changes may have occurred during such an exposure, but the experimental design did not allow for the partitioning of the differential effects of confinement, boredom, fatigue, and the effects of an unpalatable diet from the effects of exposure to the gaseous conditions.

APPLICATIONS

The data from this pilot study suggest quite tentatively that the psychological effects of intermittent exposure to 3% carbon dioxide have a very small likelihood of being significant though a more comprehensive experiment is needed to confirm this statement.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9009DA5K - Psychophysiological Effects of Prolonged Exposure to the Environment of the Submarine and Diver. The present report is No. 4 on this Work Unit. The manuscript was approved for publication on 4 December 1970 and designated as Naval Submarine Medical Research Laboratory Report Number 647.

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ABSTRACT

The purpose of this pilot study was to determine whether any remarkable psychological changes occur as a result of intermittent exposure to 3% carbon dioxide for six days. The measures used to detect these effects were: (1) the Response Analysis Tester (RATER) which measures general vigilance; (2) single-digit addition test as a measure of problem-solving ability; (3) letter cancellation as a measure of eye-hand coordination and sequential reaction time; and (4) adjective checklist measures of depression, hostility, anxiety and general maladjustive trends. The data from this pilot study tentatively suggest that some emotional changes may have occurred during the six-day CO₂ exposure period. On the other hand, vigilance, coordination and problem-solving ability probably do not change under the same conditions, although a more carefully controlled study involving a substantial subject sample is needed to demonstrate this fact.

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AN EXPLORATORY STUDY OF THE PSYCHOLOGICAL EFFECTS OF INTERMITTENT EXPOSURE TO ELEVATED CARBON DIOXIDE LEVELS

INTRODUCTION

Although it appears that the revitalized atmosphere of the modern nuclear submarine is considered salubrious by most experts in the field (Ebersole, 1960); nevertheless, the fact that there are characteristically some 200 identified substances in the submarine atmosphere attests to the complexity of the problem (Carhart & Piatt, 1963, p58). In addition to particulate material (aerosols) of various kinds found in the submarine atmosphere, a number of gaseous contaminants have been identified and studied. Of these, the most common is carbon dioxide, produced on the average submarine at the rate of 20 cubic feet/day/man. Yet, there were apparently no debilitating physiological effects of breathing an atmosphere containing approximately 10 mm Hg (1.5%) of CO₂ for a period of 56 days, (Faucett & Newman, 1953). However, the above-mentioned study and other subsequent studies have demonstrated that breathing low concentrations of CO₂ (10 - 20 mm Hg) produces a respiratory acidosis which, in turn, initiates compensatory mechanisms by which the acid-base balance is restored (Schaefer, 1959). Too, the systemic effects of enhanced CO₂ tension are attested by the fact that such divergent functions as adrenalin secretion rate, electrolyte balance and EEG alpha blocking time are affected by elevated concentrations of this gas (Navy Bureau of Medicine and Surgery, 1956, p335 ff).

With regard to the behavioral changes expected in humans exposed to abnormally high levels of CO₂ (1-1 1/2%) it appears that there may be some subtle, but no acute effects, as indicated by performance decrements during simulated "dives," (Faucett & Newman, 1953) and during protracted submerged missions (Weybrew, 1963).

The present study extends this literature in the sense that the maximum concentration of CO₂ was 3%, two to three times the CO₂ levels maintained in the above studies and 100 times the concentration found in the normal ambient atmosphere. Two additional procedural variations were employed in the present study. First, the exposure to a maximum of 3% was intermittent rather than continuous and consisted of eight, fifteen-hour days with nine-hour, air-breathing, rest periods interspersed.

A second procedural variation of this study involved an examination of the effects of a complex biochemical reaction hypothetically resulting from the acidosis produced by breathing CO₂. Briefly, data are now in the literature (Schaefer et al, 1970) to suggest that one possible resultant of prolonged exposure to an acidosis-inducing agent (such as CO₂) in the context of high protein intake may be the production of proline, an amino-acid cleavage-product from the protein molecule. Therefore one of the procedural aspects of this experiment was to restrict the

subject to a diet extremely high in protein but totally devoid of proline. The rationale for this, the major objective of the experiment, was to search for evidence of proline in the urine and feces. This symptom if observed, would then introduce the possibility that long-duration exposure to CO₂ may result in untoward bone erosion processes.¹ Whereas there is no reason to suspect behavioral side effects of these biochemical changes directly, the annoyance and unpleasantness of ingesting this "none-too-palatable" diet need to be mentioned particularly since some of our dependent variables involved sequential measurement of performance, reaction time, and mood.

Some of the data collected as part of this experiment have already been reported. First, there were no significant visual effects of the CO₂ exposure with the possible exception of a slight impairment of night vision sensitivity and green color sensitivity (Weitzman, Kinney & Luria, 1969). Another study (Schaefer, Carey and Dougherty, 1970) demonstrated that intermittent exposure to 3% CO₂ for six days neither results in CO₂ tissue saturation nor in a compensation of the respiratory acidosis. The present paper reports the findings regarding the behavioral effects of the same six day CO₂ exposure period, which was the basis for the two studies cited immediately above. Still other papers presenting other aspects of this collaborative experiment

are in various stages of preparation at the time this manuscript was completed.

METHOD AND PROCEDURE

Procedural Details

This pilot study was carried out with one twenty-four year old medical student, highly motivated and in excellent health. The twelve-day experiment was completed with the subject confined to a recompression chamber (volume approximately 30 cubic meters), used only as a gaseous envelope in this study since the ambient pressure was maintained standard throughout the study. The experimental design was self-controlled, the sequence being three days pre-experimental (air), six days in the experimental (CO₂) condition and three days in the post-experimental or recovery period. Each of the experimental days was fifteen hours in length during which time compressed CO₂ was added to the sealed chamber at a rate sufficient to produce a linear accelerating relationship between CO₂ concentration and time, reaching a maximum of 3% in twelve to fifteen hours. At the termination of each fifteen-hour exposure to CO₂, the chamber was purged with ambient air and the subject allowed to sleep or rest the remaining nine of the twenty-four hour period in weather air.

Measurement Techniques

Single-digit Addition. Eleven, randomly sequenced single-digits in horizontal rows constituted the addition

¹ This rationale holds because this amino acid apparently affects the collagenous matrix that holds dense connective tissue such as bone together.

task. The sessions were two minutes in length, the score for each session being the percentage of erroneous sums.

Letter Cancellation. This technique was designed to measure eye-hand coordination and sequential reaction time. With a time limit of one minute imposed, the subject was instructed to cross out upper case "C's" randomly interspersed in rows of capital O's. Two scores were obtained for every session: (1) an error score consisting of the totality of errors of commission (cancel O's instead of C's) and errors of omission (failure to cancel C's); and (2) an estimated sequential reaction time (in units of seconds $\times 10^{-3}$), obtained by dividing sixty seconds (the timed interval) by the number of cancellation responses made irrespective of accuracy.

Response Analysis Tester (RATER). This approach to measuring discrimination reaction time was described in two previous reports (Parker, 1967 and 1968). The stimuli used in this study were presented in the viewing aperture of RATER and consisted of four geometric shapes; a circle, a cross, a triangle and a diamond. The procedure for presenting the stimuli used in this study was autopaced for the three, one-minute trials making up each session. Two scores were recorded for each session, a median (of three trials) error score and a median total response.

Subjective Ratings. Two adjective checklists were used to collect data pertaining to mood, interests and general adjustment status. Different patterns of adjectives were summed to

produce three scores obtained from the Multiple Affect Adjective Checklist (MAACL, Zuckerman, M. and Lubin, B., 1965). These scores were labelled Depression, Anxiety and Hostility. A fourth score was called Maladjustive Trends, the pattern of adjectives constituting this score having its origin in a factor analysis of items used to evaluate the crew of the Submarine TRITON (Weybrew, 1963).

RESULTS

With data obtained from one subject only, it is impossible to generalize to other populations and conditions. However, for each measure used in this study, an array of approximately thirty measurement sessions (five to ten practice sessions and twenty-four experimental trials) were obtained from the single officer confined to the experimental conditions. Accordingly, since, in most instances each test was administered twice daily; once in the early a.m. and again just before retiring, it was possible to search for accumulative diurnal trends. These trends, if observed, could conceivably be the result of fatigue. Similarly, during the six experimental days when the CO_2 concentration was increased to 3%, the differences between the a.m. and p.m. data for each measure could be indicative of the accumulative effects of elevated carbon dioxide.

Single-digit Addition

Since the subject calculated about the same number of sums (from ten to fifteen) during each of his a.m. and p.m. sessions, it was possible to plot the

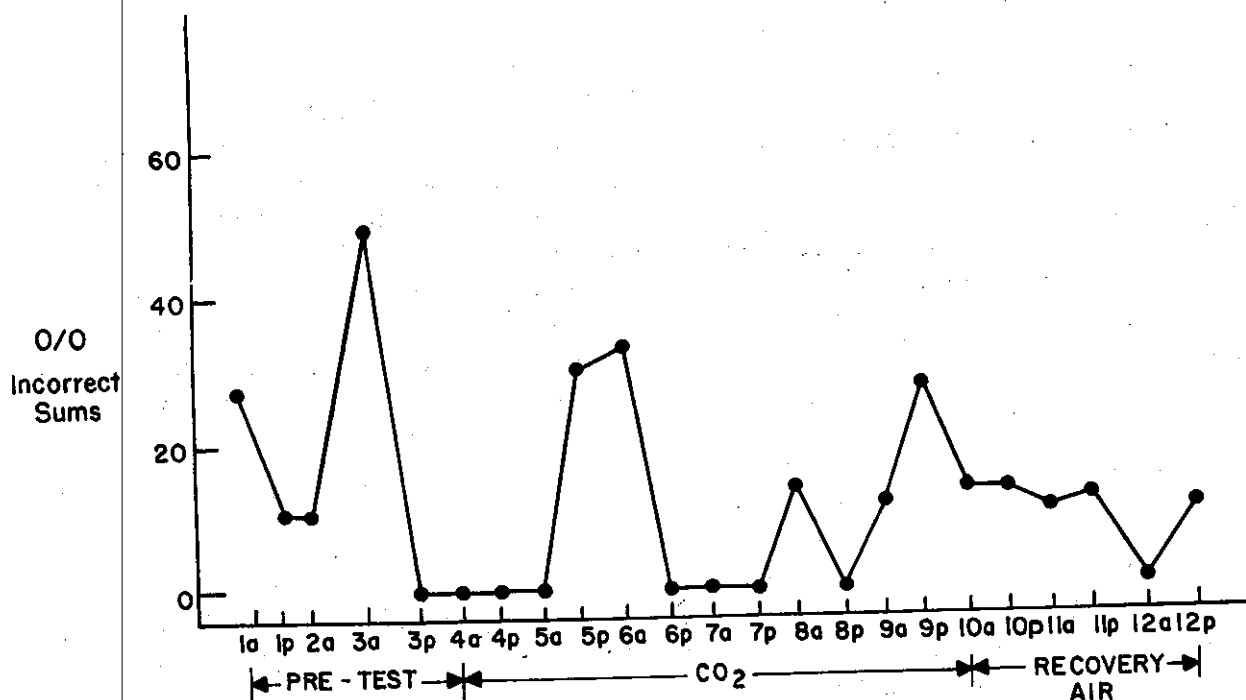


Fig. 1. Percentage Incorrect Sums of Single-digit Addition Problems

proportion of incorrect sums by measurement session.

At the outset, the overall impression is that the accuracy of the subject's single-digit addition is greater during the six-day CO_2 exposure period than for either the pre- or post-experimental control periods (seven out of twelve errorless sessions during a CO_2 period as compared to two out of twelve for the control sessions). The simple Sign Test (Kerlinger, 1965) was used to answer the question as to whether a systematic, directional trend existed in the differences between a.m. and p.m. addition scores. While there are sizeable morning and evening differences (days 5 and 6 for example, Figure 1), nevertheless, the diurnal "increases"

approximately equal the "decreases" resulting in no non-chance daily trends.

Letter Cancellation

The same general method of data analysis was applied to the cancellation data. Figure 2 presents the response time and cancellation accuracy data for each session.

At the outset, the application of the Sign Test failed to demonstrate any non-chance differences in the direction of either error or response time differences between a.m. and p.m. scores. As for differential trends during CO_2 exposure as compared to the pre-experimental and recovery periods, it is to be noted that sequential response

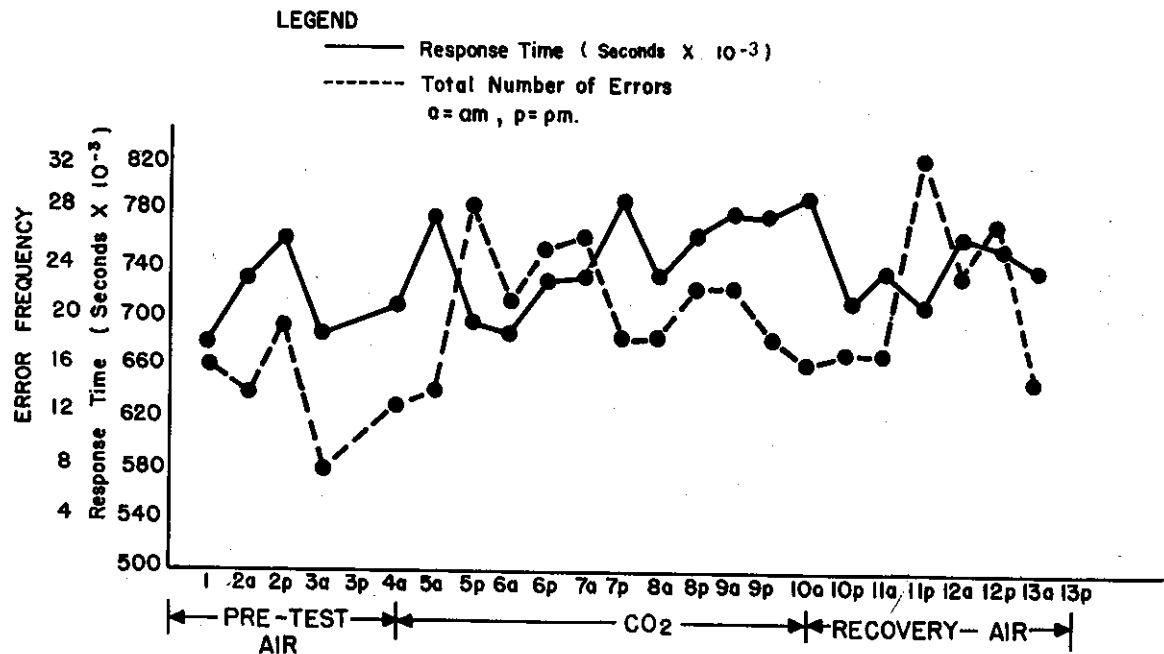


Fig. 2. Sequential Response Time and Letter Cancellation Errors Plotted by Test Session

time slowed the first twenty-four hours of CO₂ exposure* and shortened the next day. From Day 6 to the end of the CO₂ period (Day 10), the trend is toward longer response times with one reversal in that trend between the p.m. measures on Day 7 and the a.m. measures on Day 8. During the recovery period the subject's sequential response time suddenly decreased, levelling off at the one approximate pre-stress control level. The covariant contours of the error curve with the response time curve in Figure 2, tend to be similar, though unexpectedly, in certain measurement sessions, to be in opposite directions. Though the impression is that both response time and cancellation error scores increase during the CO₂ exposure period, there is insufficient data in this study to support

anything but a tentative finding in this regard.

Response Analysis Tester (RATER)

Figure 3 presents the total response and error scores for each measurement session.

It should be obvious that if the lower (broken line) error curve is subtracted from the upper (solid line), it is possible to obtain the correct response frequency per minute. With the subject practiced to a plateau prior to the onset of the experimental period, the locus of median RATER scores* suggests an increase in response frequency during the CO₂ exposure period. However, since the error response curve tends to covary positively with the total

*Scheduling problems did not allow for data collection on evening of Day 1.

*It should be recalled that the score plotted in Fig. 3 was the median score for the three trials per session.

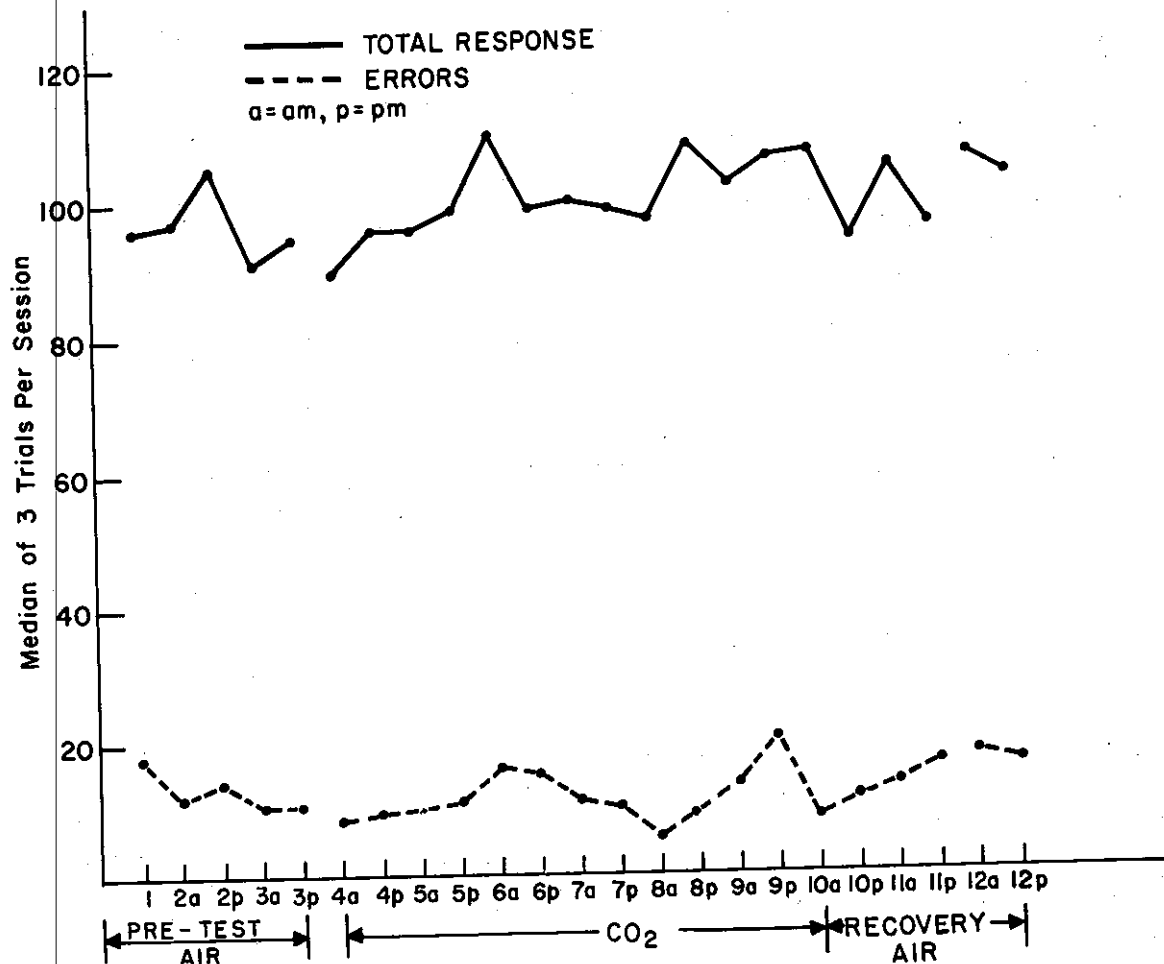


Fig. 3. RATER Scores Plotted by Test Session

response curve, the best guess is that the frequency of correct response remains relatively constant across the pre-test, experimental and recovery periods. Again, application of the median test demonstrated approximately equal numbers of gains as losses when comparing a.m. and p.m. RATER scores.

Subjective Ratings

The Multiple Affect Adjective Check-List (MAACL) has been shown to be a useful "tool" for evaluating the emotional and affective concomitants of stress, of drug therapy and the like (Zuckerman, Lubin, Vogel & Valerius, 1964). The three scores derived from the 132-item

MAACL List, together with the 23-item Maladjustive Trends (MT) score are plotted by measurement session in Figure 4.

Consistent with the findings from the other three measures used in this study, none of the a.m./p.m. differences were disproportionately in one direction. The impression obtained from the line graphs in Figure 4 are: (1) that the MAACL-Hostility index tends to be slightly elevated as compared to the pre-experimental period (except for a drop in hostility on the last day of the CO₂ period); (2) similarly, on the last day of the CO₂ exposure, the MAACL-Depression score drops to the level observed the first two pre-test days but remains raised (as compared to the first two sessions) throughout the experimental and recovery time intervals, and (3) to an extent, the MAACL-

Anxiety and the Maladjustive Trends (MT) scores tend to fluctuate together though the latter score is much more variable from session to session. Like the two other Checklist scores discussed above, the impression is that smoothed curves for these two scores would be slightly raised as compared to the pre-stress period, but not for the recovery period. In short, Anxiety, Hostility, Depression and Maladjustive Trends as measured by the checklist technique all appear to increase during the first five days of the six-day CO₂ exposure period, to revert to the level of the pre-stress control period only to rise again during the first day of recovery period with the subject still in the chamber but breathing a weather air atmosphere. It is quite possible that replication of this pilot study using an appropriate population sample would disclose trends toward changes in

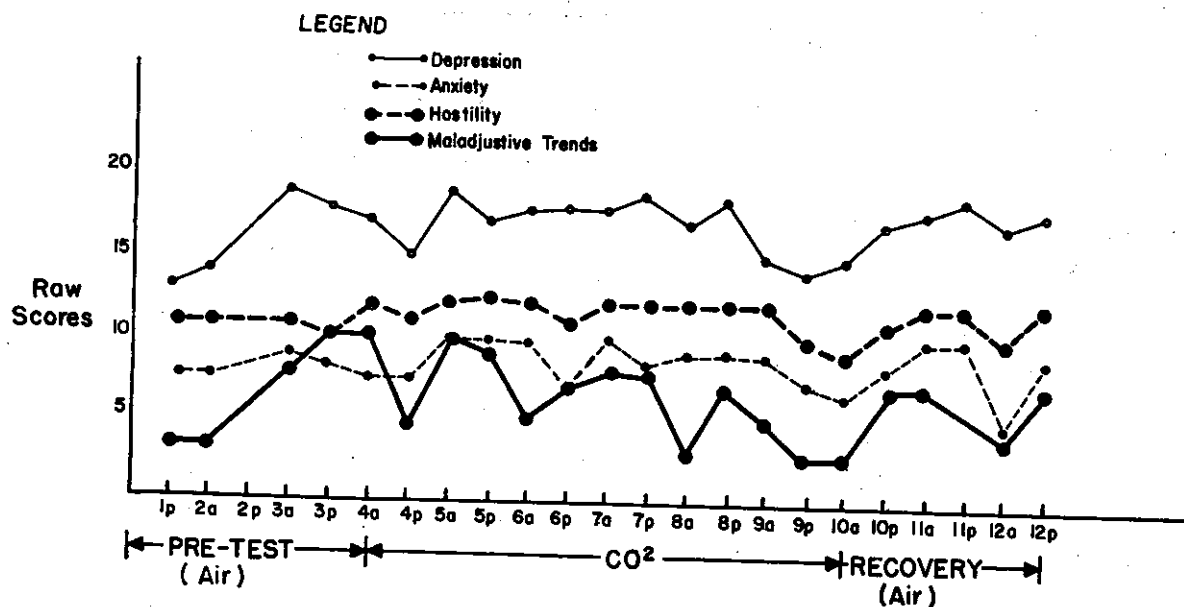


Fig. 4. Adjective Checklist Scores--Plotted Twice Daily

indices of emotionality somewhat as depicted in Fig. 4. At the same time, one would predict from the pilot data in Figures 1, 2 and 3 that only slight (if any) impairment of vigilance, and general performance would occur were this experiment to be repeated on a larger scale.

SUMMARY

A U.S. Navy Medical Corps research intern was confined to a steel recompression chamber for twelve days, six of which involved a daily "build up" of carbon dioxide to 3% with three days, pre-test and three days recovery, providing the control data. Whereas the design of the experiment as a whole involved restricting the subject to a high protein, proline-free diet in order to search for certain biochemical indicators of CO₂ effects, the major focus of this aspect of the study was upon behavioral changes hypothetically resulting from the confinement, the CO₂ exposure and from various annoyances, including the unpleasant diet.

The measures used to detect these effects were: (1) the RATER (Response Analysis Tester) a measure of general vigilance; (2) single-digit addition test as a measure of problem-solving ability; (3) letter-cancellation as a measure of eye-hand coordination and sequential reaction time; and (4) adjective checklist measures of depression, hostility, anxiety and general maladjustive trends.

Whereas a more extensive study is needed to support these conclusions, the data from this pilot study suggested that vigilance, eye-hand coordination,

sequential reaction and problem-solving ability are not remarkably affected by these conditions. On the other hand, the subjective data obtained from the four adjective checklist scores tentatively suggests that some emotional changes may have occurred during the CO₂ exposure period. An experimental design involving adequate population sampling and controls for the effects of confinement, fatigue, boredom and general annoyances is necessary if these highly tentative findings are to be satisfactorily validated.

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13. ABSTRACT

The purpose of this pilot study was to determine whether any remarkable psychological changes occur as a result of intermittent exposure to 3% carbon dioxide for six days. The measures used to detect these effects were: (1) the Response Analysis Tester (RATER) which measures general vigilance; (2) single-digit addition test as a measure of problem-solving ability; (3) letter cancellation as a measure of eye-hand coordination and sequenced reaction time; and (4) adjective checklist measures of depression, hostility, anxiety and general maladjustive trends. The data from this pilot study tentatively suggest that some emotional changes may occur during the six-day CO₂ exposure period. On the other hand, vigilance, coordination and problem-solving ability probably do not change under the same conditions, although a more carefully controlled study involving a substantial subject sample is needed to demonstrate this fact.

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