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REPORT NUMBER 556

PERFORMANCE EFFECTS OF INCREASED AMBIENT PRESSURE

I. Helium-Oxygen Saturation and Excursion

Dive to a Simulated Depth of 900 Feet

by

Benjamin B. Weybrew

and

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9009.02

Released by:

Gerald J. Duffner, CAPT MC USN
COMMANDING OFFICER
Naval Submarine Medical Center

1 November 1968

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Depth Simulation Chamber and Environmental Control Complex.

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SUBMARINE MEDICAL RESEARCH LABORATORY

Bureau of Medicine and Surgery, Navy Department

Research Work Unit MF12.524.004-9009.02

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SUMMARY PAGE

THE PROBLEM

To ascertain whether any measurable changes in subjective symptomatology, reaction time, problem-solving ability and form perception occur as the result of helium-oxygen saturation at approximately 10 atmospheres absolute pressure with excursions to 25 and 28 atmospheres.

FINDINGS

While rather vague joint and muscle sensations occurred in both diver subjects during decompression (and periodically during compression), only slight changes in addition, letter-cancellation and form-perception were observed during the "bounce dives" to a simulated depth of 800 and 900 feet of sea water.

APPLICATION

The study provides some indication as to the behavioral effects that may be expected to occur during hyperbaric exposure in helium-oxygen at pressures in excess of 20 atmospheres. This information is relevant to ongoing deep sea exploratory programs such as SEALAB.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Project MF12.524.004-9009—Physiological Effect of Closed Habitat Stressors. The present report is No. 2 on this Work Unit. The manuscript was approved for publication on 1 November 1968, and designated as Submarine Medical Research Laboratory Report No. 556.

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ABSTRACT

Two experienced commercial divers were administered an addition, a letter-cancellation and a form perception test before, at selected intervals, during, and after a simulated helium-oxygen dive to a saturation depth of 600 feet with excursions to 800 and 900 feet (total dive time 143 hours). Apart from vague joint and muscle sensations reported by means of a subjective checklist, the slow descent to 600′ was uneventful. Slightly poorer performance in addition, letter-cancellation and form perception was seen at 800′ as were symptoms resembling the so-called helium tremors. No remarkable changes in the test profiles were observed during the implementation of a conservative (15 minutes/foot) decompression schedule, though obscure knee pains in one diver persisted to the "surface" but with no untoward sequelae. Suggestions are provided for improving experimentation aimed at an assessment of the performance effects of hyperbaric conditions.

PERFORMANCE EFFECTS OF INCREASED AMBIENT PRESSURE

I. Helium-Oxygen Saturation and Excursion Dive to a Simulated Depth of 900 Feet

INTRODUCTION

Thirty years ago, the U.S. Navy published evidence to support the general conclusion that mental efficiency was impaired by exposure to air at 4 atmospheres absolute pressure, approximately the equivalent of 100 feet of sea water (Shilling and Willgrube, 1937). Recently, two studies, one by the U.S. Navy (Kiessling and Maag, 1962) and the other by the Royal Navy (Barnard, Hempleman and Trotter, 1962) tended to confirm the earlier findings. Still more recently (Poulton, Gatton and Carpenter, 1964), based upon data obtained from a sorting test, showed that the average sorting rate significantly decreased at 2, 2½ and 3 atmospheres absolute air pressure (N=34 men with varying amounts of experience in compressed air). Interestingly enough however, upon repeated exposure to 3½ atm absolute air pressure, the same men failed to show this retardation in card sorting, thus suggesting the possibility of some kind of pressure-adaptive processes or effects of practice, or both being involved.

A number of studies conducted in the early and mid-sixties have demonstrated clearly that the narcotizing, toxic effects observed in hyperbaric air are virtually eliminated by substituting an inert gas such as helium for all or most of the nitrogen present in normal air (Bennett and Glass, 1961; Weybrew, Greenwood and Parker, 1964). However, this so-called "protective" effect of the replacement of nitrogen by helium may not hold for dives in excess of 500 feet (Bennett, 1965).

The literature pertaining to the performance effects of hyperbaric exposure has been comprehensively integrated by Bennett (1966). One characteristic common to all or most of these studies is that the subjects typically are exposed to the various gas mixes during so-called "bounce" or excursion dives wherein the ambient pressure is increased rapidly and bottom-time (and consequently decompression time) are kept at a minimum. In contrast, to the bounce-dive technique, the present study involved what has come to be called "saturation" diving. That is, sufficient exposure time is allowed for the subjects to absorb something approaching the theoretically-maximum amount of gas for the particular pressure and gaseous conditions under consideration. Again, theoretically, the saturation-diving concept assumes that gaseous equilibrium with the ambient atmosphere is achieved after a given duration. Thus, decompression schedules are unaffected (in theory) by bottom time in excess of saturation time. Accordingly, for "bounce dives" to 10 atm pressure for example, bottom times might be from 5 minutes to one hour or so while a saturation dive might be of the duration of 4-6 hours to a matter of days, or even weeks.

Whereas the present report for the most part deals with a helium/oxygen saturation dive to 600 feet (with a bounce to 900 feet), it may be well, as background for this study, to present some unpublished data collected during several brief dives (on air) conducted at the Submarine Medical Research Laboratory (SMRL) in the middle sixties.*

PRELIMINARY EXCURSION DIVES ON AIR

Subjects, Measures and Results

The subjects for these dives were either members of the SMRL Research staff or experienced Navy divers. In all cases, the data were analyzed on an individual basis since the subject samples were too small and nonhomogeneous to be meaningfully grouped in any way.

*While the authors participated in the planning and implementation of these dives, major credit for the studies belongs to Mr. Michael Greenwood, Research Psychologist formerly a member of the staff of the Submarine Medical Research Laboratory and to CAPT George F. Bond, MC, USN, the then Officer-in-Charge of the Laboratory.

The measurements taken prior to and during the dives may be described briefly as follows:

Simple Reaction Time

The instrument used for this measurement was a Lafayette Instrument Co., No. 301, the stimulus being a white light. A timer measured reaction time in units of .01 seconds. Each measurement session consisted of eleven stimuli administered at the approximate rate of three per minute. The reaction time computed for each session was the median of the eleven responses.

Two-Hand Coordination

The measurement instrument was the Heinrich Two-Hand Coordination Test. Assumed to measure bilateral coordination, this apparatus consisted of an eccentrically moving target which the subject "tracks" by manipulated horizontal and vertical controlling cranks. The score was the total time (in units of 0.01 minutes) the tracking pointer was in contact with the moving target during a one-minute trial period.

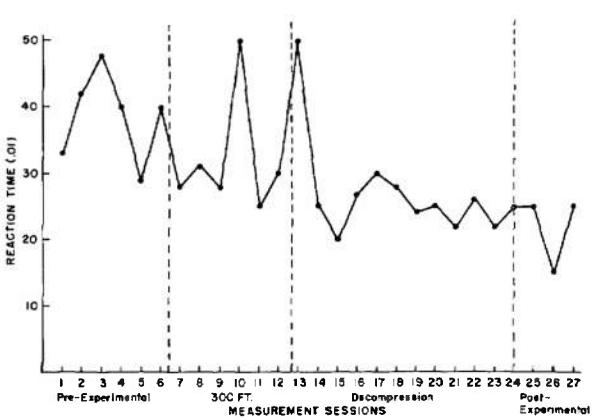

Fig. 1. Simple Reaction Time (Median of eleven trials) During Various Phases of a 300 Foot Dive on Air (N=1).

Spiral Illusion

Based upon what has been called the Archimedes Spiral, this after-image phenomenon occurs when an 8 inch black-white spiral is rotated at a rate of 60 RPM for about 30 seconds and then stopped suddenly. The illusion consists of an **apparent** "swelling" in-and-out in the front-to-back plane, characteristically persisting for 5 seconds to 30 seconds or more following cessation of the rotation. There is some evidence in the literature indicating that psychiatric patients with known brain pathology are less likely to see the after-image or illusion than are controls (London, 1960). The rationale for its use in the hyperbaric studies had to do with the possibility that the duration of the illusion was correlated with the onset, and possibly, the degree of inert gas effect. The "score" used in this study was simply the time (in seconds) that the delusion persisted.

Simple Addition

Problems consisted of 10, single-digit numbers added from left to right as rapidly as possible during a 2-minute trial. The score was percent correct of the problems attempted. Characteristically, well-motivated subjects would try from 5-11 or 12 during a given measurement session of 2 minutes.

The results of these studies, while limited in scope, are nonetheless suggestive. First, the experiment involving a simple reaction time obtained from one subject indicates little, if any, consistent decrements during a brief excursion to 300 feet (Figure 1).

It should be emphasized at the outset that the subject providing the data in Figure 1 had a sufficient amount of practice prior to the dive, to reduce at least the probability of practice effects confounding any changes seen during the experiment. It should be mentioned in passing that a pre-experimental training period was provided for all subjects as a precaution against learning effects for all of the measures.

The subject for the reaction time experiment was a Navy diver in his early thirties with about ten years' diving experience. The schedule for this particular "dive" called for a rapid "descent" to 250 feet allowing about 10 minutes to reach depth from that "point."

Ten minutes were allowed at 300 feet in order to obtain the required data.

In the first place, in view of the fact that the subject had ample learning experience prior to the study, the erratic pre-experimental (control) performance is difficult to explain. (Note median reaction time 0.48 minutes in session three.) The degraded reaction time "scores" midway in the six sessions taken at 300 feet and again as the decompression phase started are believed to be indicative of fluctuating attention rather than symptoms of "slowing" of the CNS processes involved in vision and motor response. This opinion is based upon the observation that five of the six sessions conducted at 300 feet were well below (shorter reaction time) the pre-experimental levels as were all but one of the sessions during the decompression phase. One cannot, however, gainsay the possibility that these two sizable spikes (trials 10 and 13) are symptomatic of gas toxicity.

During the same experiment, the second author acted as a subject, having had extensive training with the Heinrich Two-Hand Coordination Measure* prior to the study.

These results are plotted as percentage of each one-minute trial on target at varying simulated depths.

For this subject, there seems to be little doubt that two-hand coordination as measured by this instrument was adversely affected after approximately 5 minutes at 300 feet, performance dropping from 70% to 25% after the first 3 trials of that depth. While this decrement may be attributable to inert gas (nitrogen) toxicity, one is surprised at the rapidity of recovery between trial 9 (265 feet) and trial 10 (240 feet). It is unfortunate that the recovery curve is disjoined, nevertheless, the data obtained on trial 22 (30 feet) and the continued recovery to control levels as the surface was approached, argue that reversals of any appreciable magnitude were

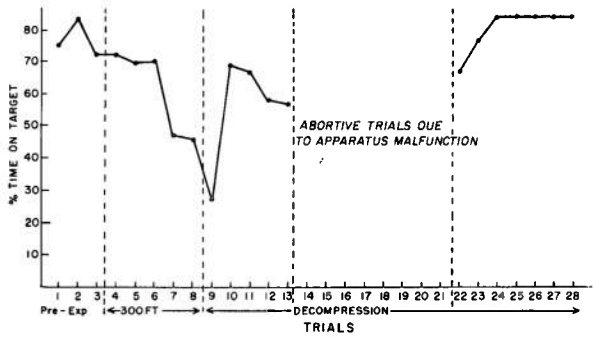

Fig. 2. Tracking Efficiency Per Trial on Heinrich Two-Hand Coordinator During a 300 Foot Simulated Dive on Air (N=1).

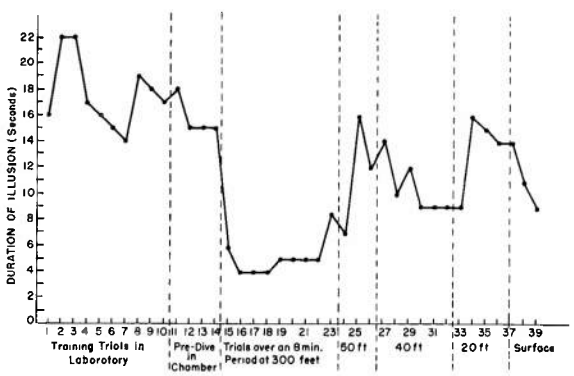

Fig. 3. Duration of Spiral Illusion (seconds) Per Trial for Various Stages of a 300 Foot Dive on Air (N=1).

unlikely during the period of equipment malfunction. In brief, and although one cannot generalize with confidence beyond this one subject involved in this specific simulated dive, two-hand coordination, even in highly pretrained people may be adversely affected by air exposure at this pressure.

The same dive provided yet another measure obtained by means of the Spiral Illusion apparatus. These data are plotted as duration of the illusion (seconds) by trial for one subject.

This subject in his late twenties had had minimal experience in "pressure" work at the time of this experiment. It is important

*At the time of the experiment, the subject was in his mid-thirties and in good health. The amount of real or simulated diving experience was minimal, consisting of 2-3 simulated dives to pressures of 4-5 atmospheres.

to note that the subject had considerable training on the spiral apparatus both in and out of the simulator prior to the dive, thus quite probably negating the likelihood of learning effects being involved.

With these precautions in mind, for this one subject only, duration of the spiral illusion appears to be remarkably reduced at a simulated depth of 300 feet with air as the atmosphere. Moreover, a reversion to control levels is seen soon after decompression started. Whether one can assume that the reduction in the duration of the spiral illusion is indicative of the narcotizing effects of nitrogen (at greatly elevated partial pressure) or diversion of attention or both is problematic at this time. At the same time, the data suggest that perceptual processes such as "spiral" after-images, as measured, may be usefully sensitive indications of the "effects" of hyperbaric air.

One final pilot study completed in the early sixties might be mentioned. The measure of interest in this simulated dive was single-digit addition. The subject was a submarine medical officer in his early thirties. He had completed the Navy Diving Course for Medical Officers and had considerable "skin diving" experience.

This simulated dive had one aspect that differed from most dives, namely it involved a varied descent schedule. This procedure was adopted to shed some light on the often-cited assumption that there may be an element of suggestibility contributing to the severity of what has been called "rapture of the deep" or nitrogen narcosis.* Accordingly, with chamber depth gauges blanked out, a pre-arranged, variable-rate descent schedule was implemented, with the results indicated in Figure 4.

Recalling that an addition session consisted of two minutes with instructions to complete

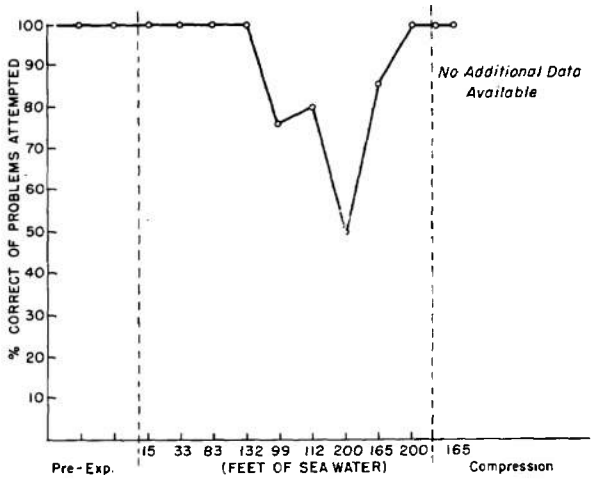

Fig. 4. Percent Correct Addition Problems Plotted Against Simulated Depth (Feet of sea water, N=1).

as many 10-digit problems as possible, it is noteworthy that a drop of 20 percent in accuracy occurred after reaching 132 feet, the decrement occurring after ascent. Control data is lacking of course, to explain this finding, that is identical data obtained from a monotonic descent schedule to 200 feet. The impression is that the graphs would have not been too dissimilar had the brief ascent and redescent to 200 feet been omitted—this impression based upon the assumption that the "pressure effects" had occurred upon reaching 132 feet and the brief (4-5 minutes) ascent/redescent cycle was unsufficient time to "wash out" these effects.

But, difficult to explain, is the apparent recovery during the brief ascent/redescent approximately seven minutes after "bottoming." Unfortunately, only data from two trials were obtained during decompression as the result of the physician-subjects' busy data-collection schedules involving other than psychological variables. Though in no sense conclusive, the study does, it is believed, indicate the possibility that different performance curves would result from variable-descent dives, if knowledge of depth is withheld from the divers. Parenthetically, the difficulties (and dangers) involved in calcu-

*The so-called "martini rule," familiar to most divers is a case in point. That is, 100 feet=intoxication effect of 1 martini, at 200 feet, 2 or three martinis and so on.

lating bottom times for varied-descent dives are recognized and contraindicates any extensive program of this kind.

HELIUM-OXYGEN SATURATION AND EXCURSION "DIVE" TO A SIMULATED DEPTH OF 900 FEET

The brief series of pilot studies completed in the early sixties and summarized above provided some suggestions utilized in planning the present study. For one thing, the data provided clues as to the kinds of processes which may and may not be affected by elevated ambient pressures. For example, it seemed highly probable that well-practiced psychomotor performances will not show decrements in hyperbaric conditions as early as cognitive or problem-solving processes. This is certainly true for air dives and quite possibly true for high-pressure helium dives (Bennett, 1966).

Method and Procedure

Dive Simulation Equipment. This experiment took place at AIRCO's (Air Reduction Company) Advanced Engineering Laboratories at Murray Hill, New Jersey in February of 1968. The experiment was a joint AIRCO/I.U.C. (International Underwater Contractors) effort, the former being responsible for the development and operation of the environmental control system, and the latter for the design of the depth simulation chamber complex itself. The depth simulator consisted of a deck decompression chamber, large enough for six occupants with an entry lock and a PTC (personnel transfer capsule) which could be either "married" to the main chamber or detached as a diving bell. Since the PTC and the main decompression chamber could be pressurized separately, because of its small volume, the PTC was used in the study under discussion for the brief excursion dive from the decompression chamber pressurized to 600 feet to a depth of 800 feet (356.4 pounds per square inch (PSI) relative pressure).

The ambient atmosphere was composed of helium and oxygen, the concentration of the latter being reduced as simulated depth increased so as to maintain its partial pressure somewhat above that found in the atmosphere at sea level pressure. The descent time to 600 feet was three hours and ten minutes.

TABLE 1 - COMPARATIVE BIOGRAPHICAL DATA FOR THE TWO DIVERS

Item of Biographical Information	Diver R. W.	Diver B.W.
1. Age/Racial Background	25/Caucasian	26/Negro
2. Height/Weight	6 feet, 2in./190	6 feet/175
3. Geographical Area where Raised	Brookiyn, New York	Michigan
4. Education	High School Graduate	High School Graduate
5. Present Occupation	Diver, International Underwater Contractors, Inc.	Diver, International Underwater Contractors, Inc.
6. Father's Occupation	Retired, Public Information Officer Conn.-Edison	Foreman, Bendix Aviation Co.
7. Marital Status	Single, lives with brother who is a commercial diver	Married, one child, lives in Queens, New York
8. Aquatic Training and Experience	SCUBA and Sport Diving - 7 years; commercial diving - 10 months	First Class U. S. Navy Diver SCUBA, Mine recovery work 2-1/2 years
9. History of Decompression Sickness	Yes, Bends - early 1968	None
10. Military Experience	U.S.N.R. 2 years - Quartermaster Second Class	U.S.N. - 8 years - Damage Control man, First Class
11. Attitudes towards diving	Likes it as hobby. Reads skindiving books	Doesn't read skindiving books
12. Attitudes toward Scientific Experimentation in connection with diving	"Pioneer effort, fascinating"	"Very important"

Subjects. The subjects consisted of two professional divers employed at I.U.C. Brief, semi-structured interviews were conducted individually with the two divers a few hours prior to the onset of the experiment. Being professional divers, both men were in excellent general health and physical condition. Similarly, the impression resulting from the brief interview was that both men were reasonably well-adjusted (according to most criteria) and were moderately enthused about participating in the experiment. Specific items of biographical data for each of the divers is contained in Table I.

While brief, the background information in Table I serves to indicate the similarity between the two subjects, that is, they are of comparable age and education and are from similar socio-economic situations. It is to be noted that one diver (R.W.) has had about seven years SCUBA. Diver B.W., on the other hand, has had more detailed and varied training in diving technology than has R.W. though his experience (and apparently his interest) in sport diving is somewhat less. The interviewer's impression was that B.W. had made the vocational choice of commercial diving largely because it was a well-paying job showing much less enthusiasm about diving and related activities than his chamber mate (R.W.). When asked, however, both indicated very favorable attitudes regarding the importance of the experiment in which they were about to participate.

Measurement Techniques. Based in some part upon past experience in measuring performance during simulated air dives (see earlier sections of this paper) a battery of tests and measures was compiled with the following constraints in mind: (1) the measures should have acceptable face validity[1] for mature divers; (2) the test administration must be brief and unobtrusive; and finally, (3) the measures used must be sufficiently sensitive to show subtle effects of narcotizing gaseous conditions (pressure and composition). The brief measurement battery in Table II was compiled with these criteria in mind. Appendices A, B, C, and D contain examples of each measure.

TABLE II - MEASUREMENT BATTERY

Measure	Rationale	Description of Measurement Technique	Administration and Scoring Procedures
Addition	Historically, arithmetical computation tasks have been the most sensitive to pressure exposure (Bennett, 1966). Appear to meet all criteria (This paper, p	Fifteen addition problems consisting of 11 digits, adding horizontally by rows.	Time limit 2 minutes. Scores were the percentage of errors of the problems attempted Instructions are to add by rows as rapidly as possible.
Letter Cancellation	Visual discrimination, eye-hand coordination and sequential reaction time are measured by this test.	Upper case "C's" are randomly interspersed with "O's".	Time limit 1 minute. Instructions are to put a line through C's only moving from left to right as fast as possible. Type I errors (crossing out O's rather than C's) and Type II errors (failing to cross out C's) are obtainable. Time per response (in seconds) is obtained by dividing 60 seconds by the number of responses.
Minnesota Paper Form Board Test[a]	This test measures ability to integrate geometrical forms perceptually.	Test figure consisted of from 2-6 polygons (Appendix C). Each of the 5 response alternatives was polygon (or circle) enclosing 2 or more geometric forms.	Six groupings of 3 problems each (equated in terms of difficulty) were obtained from the original test items. The subject is to circle the letter identifying the ONE form that can be made from the test figure. Score for each measurement was the number of problems correct out of the 3 included in the group.

[a] The authors of this test are R. Likert and W. H. Quasha. It is published by Psychological Corporation, New York, NY.

[1]This requirement may seem unduly stressed; however, in the opinion of the authors, measurement techniques which appear to the diver-subject as "childish" will not in most instances generate sufficient cooperation to be useful.

Subjective indicators were also assessed during each measurement session by means of a brief checklist designed for that purpose (Appendix D). The questionnaire responses for each session were rather simply examined as to which symptoms or indicators were (and were not) checked. Of particular note is the open-ended question listed as Item No. 5. Obviously, the intent of this item was to encourage uninhibited expression of the diver's experiences, symptoms and observations as they occurred during the dive.

RESULTS

Prior to the onset of the experiment each of the diver-subjects was subjected to a private orientation interview for the purpose of apprising him of the nature of the tests and observation techniques to be implemented and their relevance for the assessment of the effects of pressure exposure.

Obviously with N=2, statistical tests of significance are unwarranted. At best, all that can be done with data of these kind is to search for trends as a function of depth and other conditions existing throughout the experiment. Accordingly, it is clear from the data in Figure 5 that one subject (R.W.) was both much slower and less accurate at addition than B.W., suggesting that insofar as addition skills are concerned, the two subjects probably represented samples from different populations. During descent to 600 ft, R.W.'s adding speed and accuracy improved[1]; however, in going singly in the PTC on an excursion to 800 feet, he went from 3 errorless, 11-digit sums at 600 ft to 2 out of 3 accuracy at 800 ft. Similarly, diver B.W. showed a noticeable improvement in accuracy and speed of addition during the descent to 600 ft.[2]

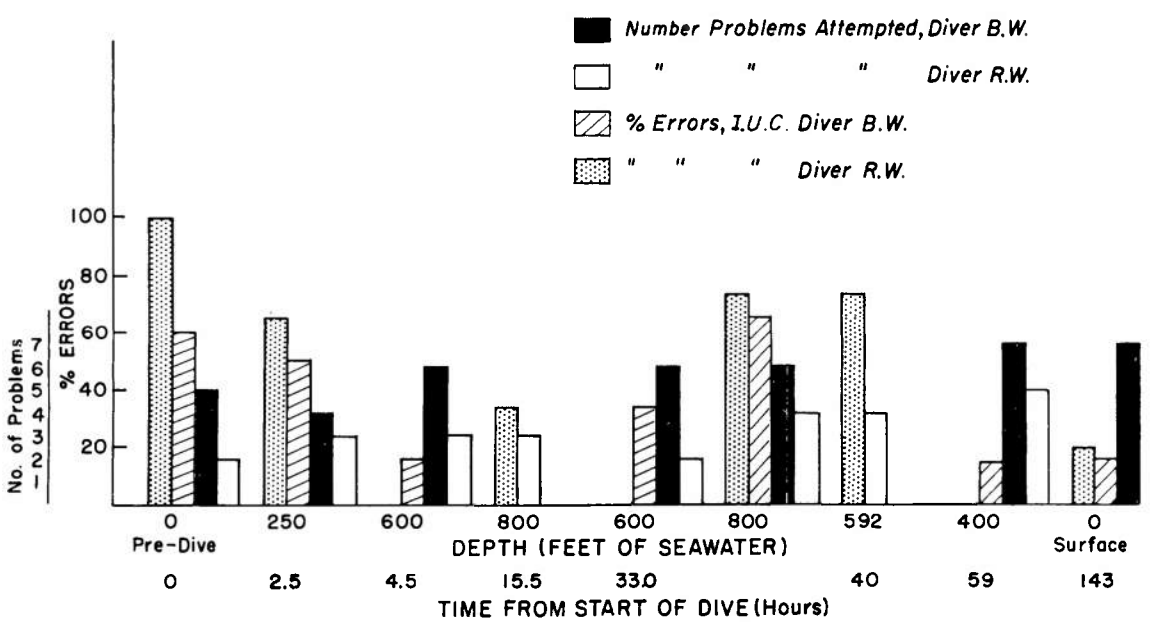

Fig. 5. Single Digit Addition.

Addition Task

As indicated in Table II, the single-digit addition problems were scored as percentage errors calculated from the number of problems attempted at each session. Figure 5 contains these data in bar graph form.

1. To be noted is the fact that these data were obtained at 600 feet after 6-7 hours' bed rest.
2. Because of some suspected changes in pulmonary function indices, B.W. was not allowed to make the first 800 foot "bounce" dive.

It is to be noted in Figure 5, that both divers, after a night's rest, showed a decrease in adding accuracy in going from 600 ft to 800 ft in the main chamber. Again, though very few problems were involved for the man making his second excursion to 800 ft (R.W.), similar results were seen, namely, two out of two correct sums at 600 ft but only one out of four sums at 800. During ascent, both speed and accuracy of adding improved for both men.

In short, there is no indication whatsoever that with a slow descent profile to 600 feet and saturation at that depth that problem-solving capability, at least as indicated by single-digit addition, is adversely affected. However, there is some slight indication that rapid excursion to 800 feet from a saturation depth of 600 feet may result in less accurate arithmetical performance (addition). However, much more data are needed to examine this possibility more thoroughly.

Letter Cancellation

It may be recalled (Table II) that time per response (in seconds) and two kinds of errors constituted the scores for the letter cancellation task. However, since errors of omission (failing to cross out a "C") occurred so infrequently, both types of errors were included as the error score. These data are plotted in Figure 6.

Again, it is well to note at the outset the differences between the two divers insofar as their performance on the cancellation task is concerned. Subject R.W. responded very slowly, his mean number of responses for the nine measurement sessions being 51 as compared to 77 for B.W. In contrast, however, R.W. made few errors (5 errorless sessions) as compared to B.W.

As for trends in the data as a function of pressure exposure, it is seen that descent to 250 feet coincided with a slight lengthening of response time for both men, an increase which had disappeared when the data were first collected at 600 feet. Possibly indicative of learning is the fact that one diver (B.W.) showed a progressive improvement in response time during the descent.

R.W.'s solo excursion to 800 feet at about fifteen hours "time-into-dive" showed a slight slowing from 1.22″ at 600′ to 1.30″ at 800′ as well as a slight decrease cancellation accuracy (from 0% to 2.2% errors). Approximately 21 hours later, both divers made an excursion to 800 ft. with an accompanying slowing in cancellation speed for R.W. but with errors either at 600 or 800 feet. On the other hand, B.W. performed at the same rate but showed a slight increase in errors, from 4% at 600 ft. to 9.5% at 800. As was the

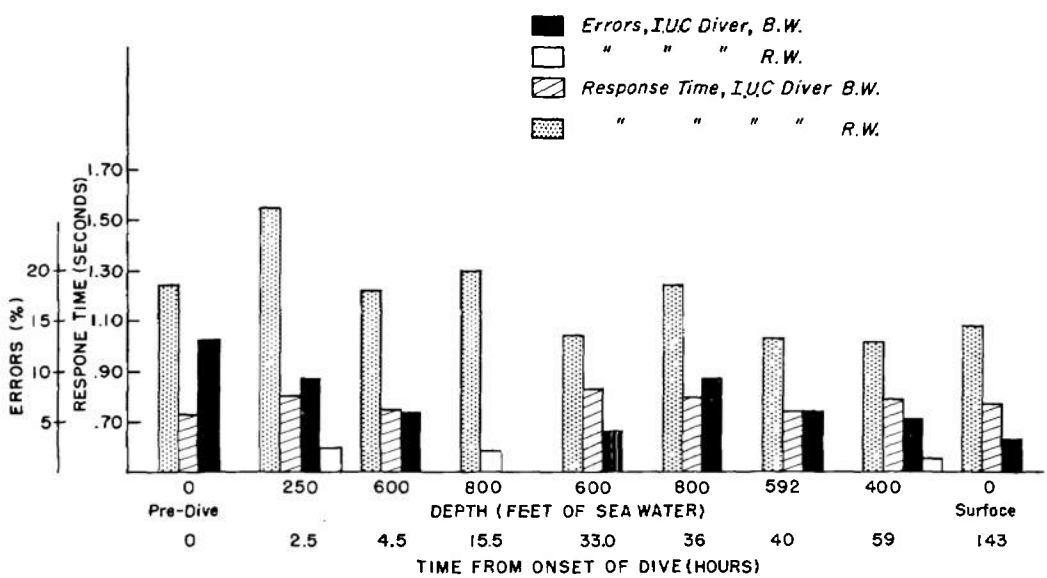

Fig. 6. Letter Cancellation.

case with the addition task, the cancellation rate and accuracy remained relatively stable at approximately the pre-experimental level during the ascent to the "surface."

Minnesota Paper Form Board Items

Appendix C and Table II describes the procedure for administering the abridged version of the Minnesota Paper Form Board. Unfortunately, the process of equating the problems for difficulty provided only 15 problems, which were divided into five groups of three problems each. The number of problems correct (out of 3) for each session is presented in Figure 7.

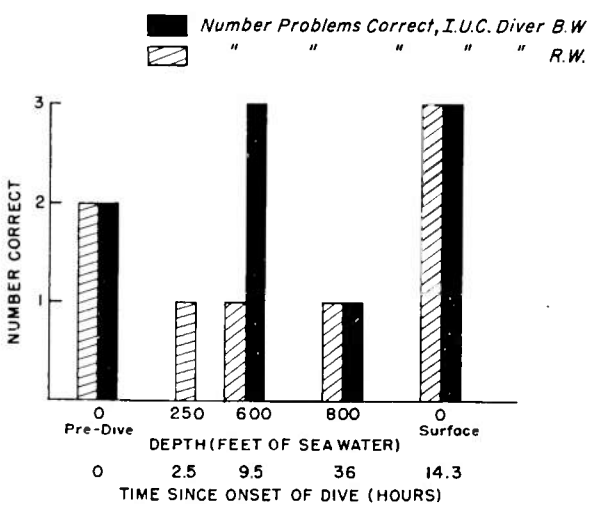

Fig. 7. Minnesota Paper Formboard Problems.

Assuming the items from the Minnesota Paper Form Board measure some kind of spatial abilities, it may be that the data collected at 250 feet (1 problem correct for B.W., none for R.W.) and one problem correct for each diver at 800 feet, are suggestive of some interference effects involving form perception. However, it is obvious that a more detailed study is needed to examine this possibility more critically.

Subjective Indicators

It is to be noted that historically, most, if not all, of the now sizable number of investigations into the effects of increased ambient pressures and/or exotic gaseous mixtures upon human subjects have depended upon subjective symptomatology as the one most valid class of indices of the effects under surveillance, (Bennett, 1966). Self-rating scales, diaries or adjective checklists have been used as "tools" to collect data of this kind in a systematic manner. In the present study the subjective data were obtained by the use of a checklist and open-ended diary-type questionnaire. These data are presented in Table III.

It is to be noted that with a relatively flat descent profile in a helium/oxygen mix results in few if any untoward subjective signs. However, upon "bottoming" both men reported vague joint and muscle aches, looseness and stiffness. Possibly noteworthy, is the fact that these indicators are reported after 7-9 hours' sleep so that one might be inclined to discount fatigue effects as contributing to the joint and muscle symptoms.

One of the indicators reported by R.W. during his solo dive in the PTC to 800 feet namely, the trembling may be symptomatic of what has been called "helium tremors" characteristically reported during helium dives involving steep descent profiles but according to one researcher* apparently not reported for flatter profiles. In this context, it is interesting to note that in repeating the dive (i.e., roughly equivalent descent rates) to 800 feet about 15 hours later (this time in the main chamber) R.W. reported seeing dense gas movement but no trembling. On this "bounce" however, B.W. did report slight trembling of fingers as well as the "loose joint" feeling reported earlier. In passing, it is noted that the "solo" bounce by R.W. to 900 feet was uneventful from the standpoint of symptoms.

*Personal communication from CAPT R. D. Workman, MC, USN

TABLE III - SUBJECTIVE INDICES

Bottom Time (Hours)	Depth (Feet sea water equivalent)	Indicators Reported		Sleep Habits				Spontaneous Comments	
		DIVER R. W.	DIVER B. W.	DIVER R. W.		DIVER B. W.		DIVER R. W.	DIVER B. W.
				Hours	Quality Good?	Hours	Quality Good?		
Pre-Dive	0	Satisfied, inefficient	Good; happy	7	Yes	6	Yes		
2.5	250	Good, tired, feel cold.	Good, satisfied	7	Yes	6	Yes		
3.0	400	- - - - - -	Good, satisfied, dry mouth, feet cold			6	Yes		
9.5	600	Tired	Good, satisfied, headache	9	Yes	7	No	Very humid, warm, tired feeling, slight trembling lower arms, like overworked muscle	Joints feel very loose, shoulder, etc., have to be more careful how I move.
15.5	600	Good, satisfied; muscle aches	Good; satisfied	9	Yes	7	No	Stiffness in joints; dull ache when light pressure or strain applied, really not muscle ache; freedom of movement seems hampered by pressure	Joints loose, light pain center of back after riding bicycle; pain went away in 2 minutes

TABLE III - SUBJECTIVE INDICES (Continued) Page 3

Bottom Time (Hours)	Depth (Feet sea water equivalent)	Indicators Reported		Sleep Habits				Spontaneous Comments	
		DIVER R. W.	DIVER B. W.	DIVER R. W.		DIVER B. W.		DIVER R. W.	DIVER B. W.
				Hours	Quality Good?	Hours	Quality Good?		
36.3	900	Tired, satisfied		4-6	No	8	Yes	A little nervous, try not to be---- think I'm not, but I am	
40	592	Satisfied, muscle aches	Good, satisfied, happy	4-6	No	8	Yes	Slight muscle pain, comes and goes, feel it in the joints; we laughed today, maybe it is because we are on the way up-tensions gone. Humidity depressing. Muggy.	"Wish I had a cold beer"
59	400	Good, bored, muscle aches	Tired, wish I were not here; satisfied; happy, bored; muscle aches	5	Yes	7	No	Sleep broken, but don't feel tired; little bored now but tests, change CO_2 cannister breaks monotony; constantly retuning my guitar; neither of us have had a bowel movement, some gas; we sweat constantly. Could 90% of body waste be removed this way?	Joints have a slight ache. knee, etc.

TABLE III - SUBJECTIVE INDICES (Continued) Page 2

Bottom Time (Hours)	Depth (Feet sea water equivalent)	Indicators Reported		Sleep Habits				Spontaneous Comments	
		DIVER R. W.	DIVER B. W.	DIVER R. W.		DIVER B. W.		DIVER R. W.	DIVER B. W.
				Hours	Quality Good?	Hours	Quality Good?		
15.5	800	Good; satisfied, irritable; lightheaded, muscle aches		9	Yes			Not nervous, am trembling, seem clear and levelheaded, slight pain in back; trembling stopped after a minute or so; time on written tests seems longer or I am getting better.	
33	600	Good, satisfied	Good, satisfied	4-6	No	8	Yes	Notice irritability; lack of communication bothers me. woke up several times, but felt refreshed each time like I had slept all night.	Joints feel as loose this morning as yesterday
36	800	Good; blurred vision	Good, satisfied, dry mouth some difficulty in breathing	4-6	No	8	Yes	Vision not actually blurred but can see the helium atmosphere while running chamber down, gas floats around like heat moves on a hot summer day.	Joints again feel loose; slight trembling in finger after reaching 800; could have been change in temperature

TABLE III - SUBJECTIVE INDICES (Continued)

Page 4

Bottom Time (Hours)	Depth (Feet sea water equivalent)	Indicators Reported		Sleep Habits				Spontaneous Comments	
		DIVER R. W.	DIVER B. W.	DIVER R. W.		DIVER B. W.		DIVER R. W.	DIVER B. W.
				Hours	Quality Good?	Hours	Quality Good?		
83	240	Good, satisfied, happy; bored, irritable	Tired; wish I were not here; bored; satisfied, irritable muscle aches	5	--	6	No	Getting a little boring now; read the same magazine twice, including advertisements	Knee joints ache; believe it's bends
107	190	Tired, discouraged, bored; irritable	Tired; wish I were not here; satisfied, bored; irritable, muscle aches	5	Yes	5	No		Another poor night's sleep; this morning joints feel OK. Started moving around and the pain came back. On hot towel treatments which really relieves the pain. I really never had bends but damaged knees
116	120	Tired; satisfied, discouraged, bored; irritable	Good, tired; wish I were not here; bored; satisfied; muscles ache	5	Yes	4	No	Heartburn (mint cookies for breakfast and pizza for lunch). Tired of ham and swiss cheese. Griping helps ease my irritation. In one more day, I can go out and scream and holler.	Joints in knees ache

TABLE III - SUBJECTIVE INDICES (Continued)

Page 5

Bottom Time (Hours)	Depth (Feet sea water equivalent)	Indicators Reported		Sleep Habits				Spontaneous Comments	
		DIVER R. W.	DIVER B. W.	DIVER R. W.		DIVER B. W.		DIVER R. W.	DIVER B. W.
				Hours	Quality Good?	Hours	Quality Good?		
143	0 Surface	Good, satisfied, happy		4-1/2	--			"On surface now, don't think there has been any noticeable physical change from beginning to end."	"Feel just fine except for knees".

Decompression from saturation depth of 800 feet was started at approximately 37 hours total dive time, the initial "ascent" rate being 15 minutes per foot. It is noted (Table II) that slight muscle and joint pain was mentioned by R.W. at 592′ and for B.W. at 400′. Noteworthy perhaps is the fact that R.W.'s poorly localized symptoms had disappeared before reaching 240′ while, in contrast, B.W.'s more specific knee pains persisted to 190 feet at which point a recompression treatment schedule was introduced. Upon recompression to 210′ (2 hours) and subsequent continuance of the 15 min/ft decompression schedule, some muscle and knee joint symptoms were still reported at 120 feet, the final data obtained prior to collection of the control data at the surface. The control indicates that R.W. was asymptomatic but, at the same time, B.W.'s knee pains, while somewhat alleviated by hot packs, nonetheless, were still there in some degree.

SUMMARY AND DISCUSSION

There are at least four somewhat overlapping explanations for depth (air) narcosis. Apparently the most enduring theory is that the behavioral changes result from the high partial pressure nitrogen, which in turn, results in hypoventilation. (Behnke and Yarbrough, 1939; Case and Haldane, 1941; Bennett and Glass, 1961). Another explanation is that increased breathing resistance reduces CO_2 elimination, thus causing a "carbon dioxide euphoria" (Bean, 1950). A third notion is that compressed air intoxication results from the combined effect of increased partial pressure of three gases: nitrogen, oxygen, and carbon dioxide (Shilling and Willgrube, 1937; Hesser, 1963). Other investigators, (Frankenhauser, Graff-Lonnevig and Hesser, 1963) have proposed as an explanation, an oxygen carbon dioxide synergistic effect. The mechanism for this effect is held by the theory to be the retardation of CO_2 removal from the cells by the elevated oxygen tension, 1.5 — 2.5 atm. O_2 at four or more atmospheres (absolute) being cited by the authors as an example of what was meant by "elevated" oxygen partial pressure. Finally, some of the earliest investigators have proposed that some of the hyperbaric symptoms at least may be manifestation of anxiety (End, 1938; Shilling and Willigrube, 1937).

The apparent protective effect from pressure narcosis resulting from the replacement of nitrogen with helium, has been known or suspected for more than forty years (Sayers and Yant, 1926; Behnke and Yarbrough, 1939). Yet, there is evidence in the existing literature (e.g. Bennett, 1965) that there may be narcotic-like effects with helium-oxygen at extreme pressures, for example in excess of 15 atmospheres. The present study, while involving only two subjects, nonetheless, provided an opportunity to observe and test human subjects in a helium-oxygen atmosphere at extreme pressures, namely in the 18 to 27 atmosphere range.

A paper-and-test battery designed to measure addition skills, sequential reaction time, eye-hand coordination, form perception, and subjective symptomatology, was administered before and after the experiment and repeatedly at selected intervals during the chamber-simulated dive to 900 feet. Possible trends noted in the data may be summarized as follows:

There were no remarkable changes in any of the measures obtained during the relatively slow descent to a simulated depth of 600 feet. In fact, speed of letter cancellation; addition accuracy, and, in one subject, form perception accuracy, all improved this phase of the experiment. The interpretation of this finding however is ambiguous, since a period 6-7 hours sleep had intervened the control and 600′ measurement session, thus raising the possibility of confounding fatigue effects (Figures 5, 6 and 7). Following the same period of sleep and some 6 hours after reaching 600 feet, it may be significant that vague symptoms of "muscle trembling" and "loose joints" were reported by both divers. The fact that symptoms of this kind were not reported at 400′ on the way down, together with the fact that they were reported some 6 hours after reaching 600 feet, reduce the likelihood that the symptoms were indicative of what have come to be called "helium tremors."

The assumption that the absence of typical tremors resulted from the flatness of the descent profile, received some empirical support by the appearance of finger tremors during the 800′ "bounce" from 600. It should be noted that both divers reported some benign symptoms suggestive of tremors during their initial excursion to 800′. However, the one diver, (RW), who made two 800′ bounce dives (20 hours apart), did not show the symptoms during the second dive even though the descent profiles were comparable. No conclusion, of course, can be reached on the basis of such sparse data; however, one thinks of apprehension during the first experience (but not the second) being a contributing factor to the tremors. Too, the notion of some adaptation processes being involved would also seem to be a possibility.

The data obtained during the 800′ dives were examined closely for any semblance of gas narcosis symptoms (Figures 5, 6 and 7). Whereas at 800′ (from saturation at 600′), one subject (RW) showed a slight slowing of response time (Cancellation) and in both men, a depreciation in addition and form perception accuracy, the data are too sparse to argue that these findings were indicative of hyperbaric effects. They are, nonetheless, suggestive.

In a sense, the subjective data may be more to the point of the experiment, since, insofar as decompression sickness is concerned, subjective reports of pain and discomfort continue to be the most reliable or at least the most relied upon, class of indicators. It has already been noted that both divers reported joint stiffness, and vague muscle symptoms upon bottoming at 600′. Moreover, the fact that these vague symptoms persisted after 4 — 6 hours sleep reduces the likelihood that fatigue may have been confounding the symptom "picture." Since compression and not decompression is involved here, one needs other than the usual gas-expansion notion to explain these findings. One thinks of "pockets" of gas in joints and muscles that compress as well as decompress at different rates resulting in "bending" of tissue with consequent stimulation of pain receptors in the anatomical area involved.

It may be well to note that data taken from R.W. just prior to the onset of the 800′ "bounce" from 600′ (15.5 hours into the experiment) contained the report of "joint stiffness, and dull ache." At 800′, a short time later, no mention of joint stiffness was made though slight back pain was reported. It is tempting to think of a therapeutic effect of the "descent" from 600′ to 800′ for R.W. Contraindicating this possibility, however, is the fact that for B.W., the loose joint symptoms (as he described them) were unaffected by an identical excursion dive a day later.

As for decompression, it is noted that R.W. reported muscle aches after 8 feet decompression from the 600′ saturation depth. Moreover, both divers reported muscle aches at 400 feet. Also, at this depth (400 feet), the first indication of BW's knee pain is noted, which had worsened considerably when checklists were made out at 240 feet (Table II). Noted also is the fact that R.W. at this "depth" reported no pain, although he reported being bored and irritated. At 189 feet recompression-treatment (to 210′) with intermittent O_2 (1.4 atm. partial pressure) administered to B.W. by mask was initiated. However, the subjective data collected about 6 hours after the decompression schedule was resumed, continued to show R.W. asymptomatic and B.W. with muscle aches and knee pain, though reportedly of less severity. Whereas, upon surfacing some slight muscle and knee pain persisted for R.W., the results of the terminal medical examination argued that the slight knee pain probably was not symptomatic of bends but was related to a muscular accident at depth" (Kinsey, 1968). The fact that B.W.'s knee symptoms had disappeared within a week following the "dive" further corroborated the "other-than-bends" diagnosis.

A cursory examination of the pertinent literature, e.g. Bennett's (1966) review, provides considerable support to the general contention held by some that possibly the most remarkable finding in studies of this kind is that individual differences in terms of

response to variations in hyperbaric conditions are sizable and reasonably consistent. This seems to be so for most measurement and observational techniques. This study was no exception inasmuch as sizable differential change patterns were observed for both divers for all the measurements taken.

Therefore, assuming that the quality of the adjustment of men to hyperbaric conditions varies markedly from one person to another, then several implications for future research in this area seem obvious. First, one implication has to do with the relevance of programs designed to carefully screen each hyperbaric subject with respect to certain (largely unspecified) medical and psychological criteria. The very real need for programs of this kind appears to have already been recognized (Kinsey, 1968). A second implication has to do with typical experimental designs used in diving research. Specifically, what is the nature of a sample, for example, of reaction time scores from 30 subjects "pooled" from 15 experiments involving 2 men for each dive. The calculation of means and variances from samples of this kind apparently makes the unlikely assumption that the small samples are drawn randomly from the same population. The difficulty in replicating a series of dives in terms of the diving profile, gas mixes and so on is only one of the limitations of this practice.

Too, future experimentation along the lines of this paper might, to an advantage, benefit from the use of control group designs rather than control session designs which use each subject as his own control. The advisability of the former over the latter design is increased when measures are used which are greatly affected by practice. With a self-control design, it is difficult to ascertain how one is to partial out the effects of gaseous composition and density from the effects of learning, confinement, heat, humidity, and so on. This limitation certainly holds for the present study. Although one of the criteria for inclusion in the measurement battery was that practice effects are minimal, it is nonetheless difficult to explain the improved addition and cancellation scores during descent as other than learning effects. Unfortunately, the busy pre-dive schedule of the two diver subjects did not allow sufficient pre-experimental practice for the learning to reach a stable plateau.

In short, while only suggestive at best, the test data failed to indicate any significant changes in psychomotor, cognitive and effective processes "tapped" by the tests. The cause of the poorly localized muscle and joint sensations, more conspicuous in one subject than the other, during decompression and paradoxically during compression, remain problematical.

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APPENDIX A
ADDITION PROBLEMS

Instructions: Each row of numbers is an addition problem. Add from left to right as fast as you can and put the sum in the blank on the right. Work rapidly for ___ minutes. You are not necessarily expected to finish all of the problems. Please note the time then start.

8	9	2	4	6	8	3	3	0	3	4
8	1	1	8	2	1	9	4	3	7	5
8	9	9	1	1	2	2	2	8	2	1
9	6	9	6	2	5	6	2	1	7	7
1	3	4	9	4	2	6	6	4	2	2
8	9	9	8	7	8	9	6	1	9	6
6	4	2	3	3	6	3	6	4	4	0
4	6	4	7	2	9	5	7	0	9	2
1	1	5	1	5	4	9	1	5	6	4
8	6	3	6	4	6	4	7	3	3	7
2	5	3	9	1	6	9	5	1	5	0
9	9	4	3	5	6	6	9	5	9	3
6	8	3	4	2	9	9	4	9	5	2
1	2	5	2	7	9	4	6	7	7	8
9	3	6	6	3	6	4	9	5	8	8

APPENDIX B
CANCELLATION TEST

Group

Series 30
Time____

Instructions: Below are listed a series of capital O's with capital C's interspersed. The task is to work from left to right making a mark through each C. Work as fast as you can for 1 minute. You are not necessarily expected to finish. However, should you finish, please record on the sheet exactly the time taken.

OOOOOOOOCCOOOOOOOCCCOOOOOCOOCOOOOOCOCOOO

OCOOCOOOOOOOOOOOOCOOOOOOOOCOOCOOCOOOOO

OOCOOOOOOOOCOCOOOOCOCOOOOCOOOOOOOOOOCOOO

OOOOCOOOOOOOOOOOOOOOOCOOOOOOOOOOOOCOOOOO

OOOOOOOOOOCOOOOOOCOOOCOOOOOOOOOOOOOOOOCO

OCOOOOCOOOCCOOOOOCOOCOOOOOOOOOOOOCOCOOOO

OOOOOOOOOOCOOOOOCOCCOOOOOOOOOOOOOOOOOOOC

OOOOOOOOOCOOOCOOOOOOOOOOOOOOOOOOOOOOOOOO

OCCOOOOCOOOCCOOCOOCOOOOOOOOCCOOOCOOOOOOO

OOOOOOOOCOOOOOOOOOOOOOOOCOOOOOOOOOOCOOOO

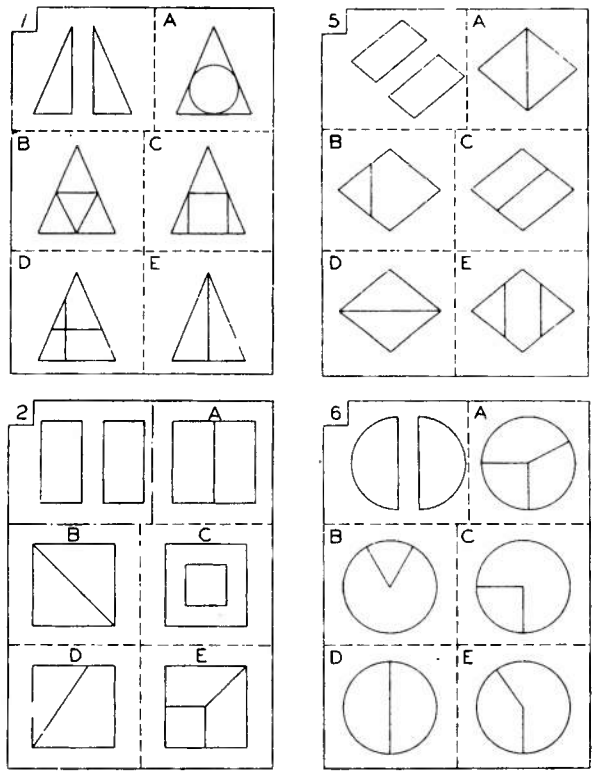
COOCCOOOOOOOOOOOOCCCOOOOCCOCOOOOOOOOOOOO

OOOOOOOOCCOOOOOCOOOOOOOOOCOOCOOOOOOCOOOO

OOOOOOOOCOOOOCCOOOOOOOOCOCOCOOOOCOOOOOOO

OOOOCOOOCOOCOOOOOOOOOCOOOOOOOOOOOOOOOOOO

APPENDIX C
SAMPLE OF MINNESOTA PAPER FORM BOARD TEST ITEMS



APPENDIX D
DEEP DIVING QUESTIONNAIRE

DEEP DIVING QUESTIONNAIRE

This check sheet is designed to help determine your feelings and physical condition during a series of dives. You can be of great help by answering the following short questions as accurately as you can. Please do not try to recall how you responsed previously, but check those responses which describe you best at the time you are completing the form.

NAME_____DATE_____TIME_____DEPTH_____ft

1. How do you feel right now? (Check all that apply at this time.)

_____ 1.1 Good	_____ 1.5 Satisfied	_____ 1.8 Inefficient
_____ 1.2 Tired	_____ 1.6 Happy	_____ 1.9 Disinterested
_____ 1.3 Exhausted	_____ 1.7 Discouraged	_____ 1.10 Irritable
_____ 1.4 Wish I were not here		

2. Do you have any of the following? (Check all that apply at this time.)

_____ 2.1 Headache	_____ 2.7 Lightheaded
_____ 2.2 Nausea	_____ 2.8 Muscle Aches
_____ 2.3 Dizziness	_____ 2.9 Ringing in ears
_____ 2.4 Cramps	_____ 2.10 Dry mouth
_____ 2.5 Blurred vision	_____ 2.11 Numbness
_____ 2.6 Itching	_____ 2.12 Feel cold

3. Which of the following best describes your breathing? (Check all that apply at this time.)

_____ 3.1 No Difficulty	_____ 3.5 Can't get enough air
_____ 3.2 Some difficulty in breathing	_____ 3.6 Painful breathing
_____ 3.3 Great difficulty in breathing	_____ 3.7 Can't breathe through nose
_____ 3.4 Shortness of breath	

4. About your sleeping habits:

_____ 4.1 Estimate hours of sleep in past twenty-four hours (to nearest half hour)

_____ 4.2 Was the quality of sleep fair to good ? (Yes/No)

5. Is there anything not covered in the above questions which you would like to tell us ? If so, please write your answer on the back of this sheet.

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13. ABSTRACT

Two experienced commercial divers were administered an addition, a letter-cancellation and a form perception test before, at selected intervals, during, and after a simulated helium-oxygen dive to a saturation depth of 600 feet with excursions to 800 and 900 feet (total dive time 143 hours). Apart from vague joint and muscle sensations reported by means of a subjective checklist, the slow descent to 600 feet was uneventful. Slightly poorer performance in addition, letter-cancellation and form perception was seen at 800 feet as were symptoms resembling the so-called helium tremors. No remarkable changes in the test profiles were observed during the implementation of a conservative (15 minute/foot) decompression schedule, though obscure knee pains in one diver persisted to the "surface" but with no untoward sequelae. Suggestions for improving experimentation aimed at an assessment of the performance effects of hyperbaric conditions are provided.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Hyperbaric Exposure						
Decompression Sickness						