NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 793

SHALLOW HABITAT AIR DIVE SERIES (SHAD I and II):
The Effects on Visual Performance and Physiology

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4306.02-3114.04

Released by:

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Officer in Charge
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SUMMARY PAGE

THE PROBLEM

To measure visual performance, physiology, and EEG during shallow habitat diving as part of this Laboratory's investigation of the safe depths at which man can live while breathing air.

FINDINGS

There were no decrements in visual performance tests at either 50 ft or 60 ft; nor was there any indication of malfunction in the EEG. Retinal veins and arteries were constricted as is found with high partial pressures of O_2. Changes occurred in the visual evoked response only during excursions from the saturated depth.

APPLICATION

Since the tests employed cover all the major, known visual symptoms of oxygen toxicity, the data indicate that man can live under water at 50 to 60 ft breathing air for as long as thirty days.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit M4306.02-3114. The present report is Number 4 on this work unit. It was submitted for review on 20 August 1974, approved for publication on 2 October 1974 and designated as NavSubMedRschLab Report No. 793.

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ABSTRACT

In order to determine the safe depths at which divers can live while breathing air, a battery of medical, physiological, and performance tests were administered to subjects who lived for a month in the NavSubMedRschLab pressure chamber at 50 ft and at 60 ft.

The tests included a number of measures of visual physiology and visual performance, since many of the symptoms of oxygen toxicity involve the visual system. The results showed no decrements in visual acuity or in the size of the field of view at either 50 ft or 60 ft. There were no abnormal changes in the EEG during saturation, and the only changes in the visual evoked response occurred during excursions from the saturated depth. Both retinal arteries and veins were constricted, as is commonly found with high partial pressures of oxygen.

SHALLOW HABITAT AIR DIVE SERIES (SHAD I and II):

The Effects on Visual Performance and Physiology

INTRODUCTION

The Naval Submarine Medical Research Laboratory is currently conducting a series of shallow saturation dives to test the limits to which air can be used as breathing mixture for divers living for extended periods of time at hyperbaric pressure. Discounting decompression, the two major concerns for compressed air-breathing divers are nitrogen narcosis and oxygen toxicity. Nitrogen narcosis, which normally occurs at 200 to 300 ft, is the lesser of the two problems for shallow habitat divers, since the depths involved frequently do not reach these values. Oxygen toxicity is of grave concern since the partial pressures of oxygen breathed by the divers greatly exceed surface values and man's tolerance to hyperoxia is notably limited.

In order to determine the safe depths at which divers can live, a battery of medical, physiological, and performance tests was administered to subjects who lived in the NavSubMedRschLab pressure chamber. In the first study, SHAD I, two men lived for thirty days breathing air at a simulated depth of 50 ft; in the second study, SHAD II, two men lived for 28 days at a depth of 60 ft. In both studies, periodic excursions on air to depths greater and lesser than the saturated depth were made to test the men's ability to withstand this additional strain.

The tests included a number of measures of visual physiology and visual performance, since many of the symptoms of oxygen toxicity involve the visual system.[1-4] There are consistent reports in the literature of hyperoxia causing constriction of the visual fields, diminution of acuity, and constriction of blood vessels, all of which may occur before the final symptom — the convulsive seizure. In addition, several authors claim that the eye is more sensitive to oxygen poisoning than other parts of the body. Margolis and Brown,[5] for example, view the eye as the limiting factor in the use of hyperbaric oxygenation, and Noell[6] states that visual cell death was more prevalent than convulsions in rabbits exposed to high oxygen levels. This paper is a report of the results obtained with the visual tests during SHAD I and SHAD II.

THE TESTS EMPLOYED AND THEIR RATIONALE

1. The Ortho-Rater. This is a device used for mass screening of visual acuity; it provides a rapid measure of both monocular and binocular acuity under controlled lighting at both near (13 inches) and far (simulated 26 ft) viewing distances. The acuity test is a checkerboard, which the subject must differentiate from three gray squares of equal size. The Ortho-Rater was included, since visual acuity has been

shown to decrease under hyperoxic conditions.

Also included in the Ortho-Rater are measures of the phorias, both vertical and horizontal, for near and far distances, and of depth perception, based upon binocular disparity. While there is no reason, to our knowledge, to think that phoria or depth perception would be affected by hyperoxia, there are a number of reports suggesting they suffer under confinement.[7-9] Therefore, they were included simply to have a means of assessing the effects of confinement on our visual measures.

2. Field of View. This measure of the extent of the field of view is an addition to the Ortho-Rater. Two spherical targets are provided, one as a fixation target and the other, which is movable, as a test target. The subject simply states when the moving target appears (or disappears) in his field of view, as is commonly done in kinetic perimetry. Four measures were made for the field on both the right and left, two moving out of the field and two moving in, on each side.

Visual field constriction is one of the most commonly cited symptoms of oxygen poisoning;[1,4] Nichols and Lambertsen report fields may be as small as 10 degrees just prior to convulsions.

3. Night Vision Test. Since visual field constriction is such an important feature of the oxygen toxicity syndrome, a second test was included which is based upon the measurement of sensitivity throughout the visual field. This is the NSMRL Night Vision Test,[10] which is administered to a dark-adapted subject. The test is composed of 120 small lights, presented at various positions throughout the subject's visual field, above, below, to the right, or the left of a central fixation point. Two lights are presented on each trial and the subject is asked to report their position relative to the fixation. He is scored in terms of the total number of stimuli correctly identified.

This test should provide a much more sensitive test of changes in visual field sensitivity than does the routine assessment of field of view.

4. Fundus Photographs. A Zeiss Ikon Fundus Camera was used to photograph the left eyes of each of the divers. The pupil must be dilated for the photographs and the divers were trained to take each other's pictures. A procedure worked out previously for photographing and measuring retinal vessel size was employed.[11] The same field of view, which includes the optic disc and temporal vessels in the lower field, is photographed each time and measures made of the temporal artery and vein calibres at the same locations.

Constriction of the retinal vessels is one of the most frequently reported symptoms of breathing hyperbaric oxygen.[4] Both arteries and veins are reduced in size, with the amount of change apparently dependent upon the original sizes of the vessel and exactly where they are measured.[12-14]

5. Visual Evoked Response. Visual evoked responses were recorded from

bipolar electrodes, with the active electrode located at O_Z, over the primary visual cortex, the reference at C_3, and the left ear as the ground. The signal was fed, by a short connection through the chamber wall, to a Grass P511 amplifier and a Tektronix Inc. oscilloscope for on-line monitoring. The EEG was recorded on tape with a Hewlett-Packard tape recorder for later analysis. Simultaneously, the signal was analyzed on line for evoked responses by a Technical Measurement Corp. computer of average transients.

For the evoked responses, the analysis interval (that is, the duration of cortical activity following a stimulus that was summed by the computer) was one second. One hundred of the one-second intervals were used to obtain an evoked response; these were automatically counted by a TMC pre-set, sweep counter.

Two stimuli were used for the visual evoked response: one was a pattern of vertical stripes formed of opaque black tape and translucent thin paper; the other was a blank field of the same size. Both the striped pattern and the blank field were backlighted by a Grass PS-2 photostimulator set at an intensity of 16 and mounted on the outside of a porthole of the chamber. At the subject's viewing distance of 28 inches, the individual stripes subtended an angle of 1 degree and the overall pattern, 10 degrees. Two different flash rates were employed for viewing the striped targets: one flash per second and 16 flashes per second.

The visual evoked response was included because extensive previous research has shown that decrements in visual evoked responses occur for divers breathing air at depth, but not for divers breathing helium-oxygen; the decrement is thus presumably a correlate of nitrogen narcosis and was measured, not only at the saturated depth, but also during the deeper excursions.[15-19]

6. Electroencephalograms. As part of the procedure for obtaining visual evoked responses, the diver wears normal EEG electrodes. It was thus possible to obtain routine EEGs from one channel, O_Z to C_3, as part of the regular testing. After a VER was obtained, the subject was told simply to remain quiet, with his eyes open or closed, for one and a half minutes each, while the EEG was recorded on tape, and on a portable polygraph. The tape was later analyzed for the amplitude of response at each frequency with a Federal Scientific Spectrum Analyzer and Averager.

Convulsions are of course the final stage in oxygen toxicity and as such are just as obvious behaviorally as in the EEG.[20-24] However, there are reports of changes in EEG patterns prior to actual convulsions and for this reason it was considered essential to monitor the EEG routinely.

7. The Farnsworth-Munsell 100-Hue Test of Color Vision. This test is a simple but very sensitive measure of the ability to discriminate colors. It consists of almost 100 plastic caps on which a wide array of different colors are mounted. The colors, which encompass the entire color circle from red through yellow, green, blue, purple

and back to red, are divided into four panels with two endpoints each. The subject's task is to arrange the colors in order so that they progress in a regular color series from one endpoint to the other. The test has been used extensively to separate persons with normal color vision according to their ability to discriminate hues, to measure the color confusions of color defective individuals, and to study acquired deficiencies of color vision.[25,26]

The test was included in the SHAD II experiment because it was realized that there were few if any investigations in the literature of the effect of hyperbaric oxygen on color vision.

EXPERIMENTAL SCHEDULE

Complete details on the diving profiles can be found in NavSubMedRschLab Report No. 775.[27] Briefly, the men remained at 50 ft or at 60 ft for the one-month interval. Periodic excursions to deeper and shallower depths were begun after the first week at saturation depth and gradually increased in frequency until, during the last week, there were one or two excursions every day.

During SHAD I, vision tests were scheduled every three to four days throughout the saturation period. The visual evoked responses and EEGs were recorded almost every day and in addition prior to and during each excursion to deeper depth. Preliminary data were collected a number of times during the pre-dive period of two weeks; these served the purposes both of obtaining control data and of training the subjects to give each other the tests. In addition, control data were again collected following the saturation period.

During SHAD II, all tests and procedures were identical to those used in SHAD I, with the exception that testing was done less frequently to keep the men from becoming too familiar with or bored with the tests. In addition, the test of color vision, the F-M 100-Hue Test, was added.

RESULTS

Ortho-Rater

Acuities are tabulated in Table I, for both monocular and binocular testing at both near and far distances. There is very little change in the data for any of the subjects throughout the course of the dive. An acuity of 1.0 is the equivalent of 20/20 vision; 1.2 is the same as 20/17. All men have relatively good acuity and with few exceptions could read all the targets correctly. There is no evidence of a decrement during the dive; acuities during the dive are the same as the pre-dive tests or slightly better.

The phoria and depth measures throughout the dives are listed in Table II. All subjects have very small amounts of vertical phoria; this is typical of the general population. For lateral phoria, at far, the population is slightly esophoric, with 1.0 to 2.0 Δ diopters the average value. For near vertical phoria, the trend is however definitely exophoric, with two-thirds of the population requiring from zero to -7.5Δdiopters. All of these men display more exophoria at near than at far, as is true of the general population.

Table I. Acuities $\left(\frac{1}{\text{vis. angle (min)}}\right)$ during the saturation dives (cont)

S	Dive Day	50 ft						S	Dive Day	60 ft					
		Far Acuity			Near Acuity					Far Acuity			Near Acuity		
		Binoc	Right	Left	Binoc	Right	Left			Binoc	Right	Left	Binoc	Right	Left
JW	Pre-	1.0	.8	1.0	1.2	1.2	1.2	GS	Pre-	1.2	1.0	1.2	1.2	1.2	1.2
	dive	1.0	.8	1.0	1.1	1.2	.9		dive	1.2	1.2	1.2	1.2	1.2	1.2
		1.2	.9	1.0	1.1	1.0	1.2			1.2	1.2	1.2	1.2	1.2	1.2
	2	1.2	1.0	1.2	1.2	.9	1.2		5	1.2	1.2	1.2	1.2	1.2	1.2
	3	1.1	1.0	1.2	1.1	.9	1.2		11	1.2	1.2	1.2	1.2	1.2	1.2
	6	1.2	.9	1.2	1.1	1.0	1.2		18	1.2	1.2	1.2	1.2	1.1	1.2
	10	1.2	1.0	1.2	1.1	1.1	1.0		26	1.2	1.2	1.2	1.2	1.2	1.1
	14	1.1	1.0	1.2	1.2	1.2	1.2								
	16	1.1	1.0	1.1	1.2	1.1	1.2								
	21	1.1	1.0	1.1	1.2	1.2	1.2								
	23	1.1	1.0	1.1	1.2	1.1	1.2								
	26	1.1	1.0	1.2	1.2	1.1	1.2								
	28	1.1	1.0	1.1	1.2	1.1	1.2								
	Post-	1.2	.8	1.2	1.2	.9	1.2		Post-	1.2	1.2	1.1	1.2	1.2	1.1
	dive	1.1	.7	1.2	1.2	1.1	1.1		dive						
LB	Pre-	.7	.6	.8	1.1	1.0	1.0	RF	Pre-	1.2	1.0	1.0	1.2	1.2	1.1
	dive	.8	.7	.8	1.1	1.0	.9		dive	1.0	1.0	.9	1.2	1.2	1.1
		.6	.7	.8	1.1	1.0	1.0			1.1	1.2	1.0	1.2	1.2	1.2
	2	1.1	.8	.9	1.2	1.2	1.1		5	1.1	1.0	.9	1.2	1.1	1.2
	3	1.0	.9	.9	1.2	1.2	1.2		11	1.2	1.1	1.1	1.2	1.2	1.2
	6	1.1	1.0	1.0	1.2	1.2	1.2		18	1.2	1.1	1.1	1.2	1.2	1.1
	10	.8	1.0	1.0	1.1	1.2	1.2		26	1.1	1.0	1.0	1.1	1.0	1.2
	14	1.0	.9	1.1	1.2	1.2	1.2								
	16	1.0	.9	1.0	1.2	1.2	1.1								
	21	1.1	1.0	1.0	1.2	1.2	1.2								
	23	1.1	.9	1.0	1.2	1.2	1.2								
	26	1.0	1.1	1.1	1.1	1.2	1.1								
	28	1.0	1.0	1.1	1.1	1.2	1.1								
	Post-	1.0	.9	.9	1.0	1.0	1.1		Post-	1.2	1.2	.9	1.2	1.2	1.2
	dive	1.1	.9	1.0	1.1	1.1	1.0		dive						

Table II. Phoria and depth measures during the saturation dives

S	Dive Day	Vertical Phorias[a] Far	Vertical Phorias[a] Near	Lateral Phorias[b] Far	Lateral Phorias[b] Near	Depth in seconds of angle	S	Dive Day	Vertical Phorias[a] Far	Vertical Phorias[a] Near	Lateral Phorias[b] Far	Lateral Phorias[b] Near	Depth in seconds of angle
50 ft							60 ft						
LB	Pre-	.5 R	.5 R	-1.7	-6.0	83	RF	Pre-	1.0 L	1.0 L	-0.7	-7.5	83
	dive	.5 R	.5 R	-2.7	-4.5	32		dive	.5 L	.5 L	-0.7	-10.5	83
		.5 R	.5 R	-1.7	-7.5	83			.5 L	.17 L	-0.7	-4.5	83
	2	.5 R	1.0 R	-2.7	-7.5	12		5	1.0 L	.5 L	-0.7	-10.5	19
	3	.5 R	.5 R	-0.7	-4.5	10		11	.5 L	.17 L	-0.7	-9.0	43
	6	.5 R	.5 R	-1.7	-7.5	10		18	.5 L	.17 L	+0.3	-10.5	43
	10	.5 R	.5 R	-1.7	-6.0	10		26	.5 L	.17 L	+0.3	-6.0	83
	14	.5 R	.5 R	-2.7	-6.0	10							
	16	.5 R	.5 R	-1.7	-6.0	10							
	21	.17 R	.5 R	-1.7	-6.0	10							
	23	.5 R	.5 R	-1.7	-4.5	10							
	26	.5 R	.5 R	-1.7	-7.5	10							
	28	.5 R	.5 R	-1.7	-1.5	10							
	Post-	.5 R	.5 R	-1.7	-6.0	10		Post-	.5 L	.17 L	+0.3	-4.5	362
	dive	.5 R	.5 R	-1.7	-3.0	10		dive					
JW	Pre-	.17 R	.17 L	+1.3	-1.5	12	GS	Pre-	.17 R	.17 R	-1.7	-3.0	19
	dive	.5 L	.17 L	-4.3	+1.5	19		dive	.17 R	.17 R	+2.3	-1.5	9.7
		.17 L	.17 L	+2.3	0	19			.17 L	.17 R	+1.3	0	9.7
	2	.17 L	.17 L	+2.3	-1.5	13		5	.17 R	.17 L	-0.7	0	12
	3	.5 L	.17 R	+2.3	-1.5	10		11	.17 R	.17 L	+0.3	-3.0	12
	6	.17 L	.17 L	+2.3	-3.0	13		18	.17 R	.17 R	+0.3	-1.5	12
	10	.17 L	.17 R	+1.3	-3.0	10		26	.17 L	.17 L	+0.3	0	9.7
	14	.17 L	.17 L	+0.3	0	10							
	16	.17 L	.17 L	+1.3	-1.5	13							
	21	.17 L	.17 R	+2.3	-1.5	27							
	23	.17 L	.17 L	+2.3	-1.5	19							
	26	.17 L	.17 L	-0.7	-3.0	10							
	28	.17 L	.17 L	+0.3	-3.0	19							
	Post-	.17 L	.17 L	+2.3	-3.0	19		Post-	.17 R	.17 L	+2.3	-4.5	9.7
	dive	.17 L	.17 L	+0.3	-3.0	10		dive					

[a] Vertical phorias are measured in prism diopters with either the right or left eye higher (R or L).
[b] Lateral phorias are measured in prism diopters with plus values indicating esophoria and minus values exophoria.

None of their phoria measures shows any consistent changes over time during the dive. A tendency toward greater esophoria (less negative or greater positive dioptric correction) might be expected if confinement were having an effect; the data during confinement for all the men were generally within the ranges of their pre-dive values.

The data for the depth perception test are also listed in Table II. While the men differ greatly in native ability on this test, there is once again no evidence of deterioration for any of them.

Field of View

Figure 1 presents measurements of the field of view for the subjects of both depths during the testing period. Fields are approximately 90 degrees on each side, a normal result; there is no indication of change during the saturation period for any of the subjects.

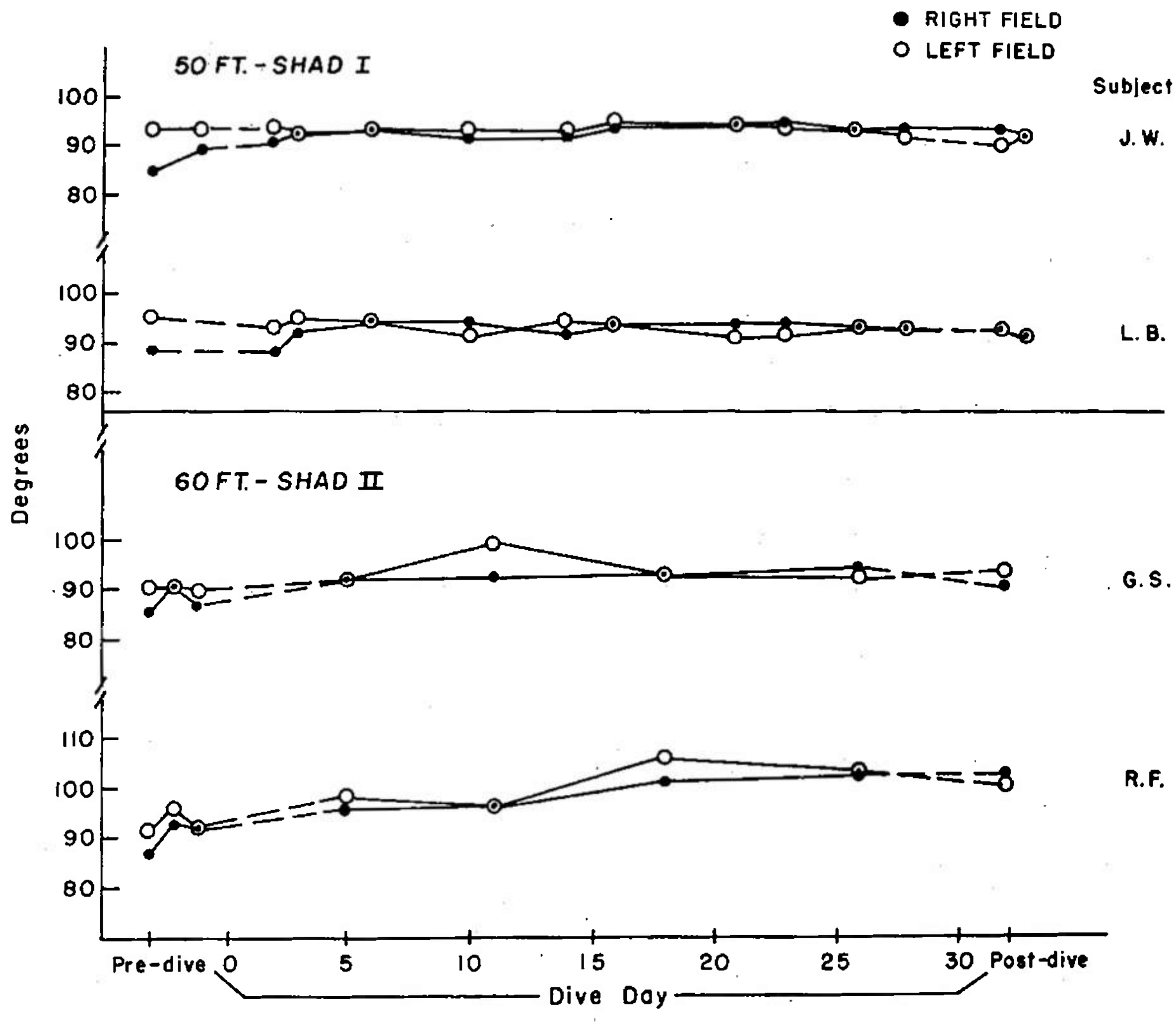

Fig. 1. The size of the field of view during the saturation period at 50 ft, at the top, and at 60 ft, at the bottom.

Night Vision Test

Figure 2 shows the profile of Night Vision Test scores over the entire testing period. At both 50 ft and at 60 ft, the values are essentially flat during the entire dive period. These scores are the total number adjusted for guessing. During SHAD I, the uncorrected total scores rose steadily during the dive; this was, however, a reflection of increased errors which rose from less than five errors on the pre-dive measures, to more than twenty, for both men, at the end of the saturation period. While the increase in error rate could be a consequence of increased entopic phenomena during the dive, it did not occur at all during the 60 ft dive. The more likely explanation thus is increased guessing by these two men.

Sensitivity measured at different areas in the visual field did not show systematic changes over time. There was, for example, no greater loss of

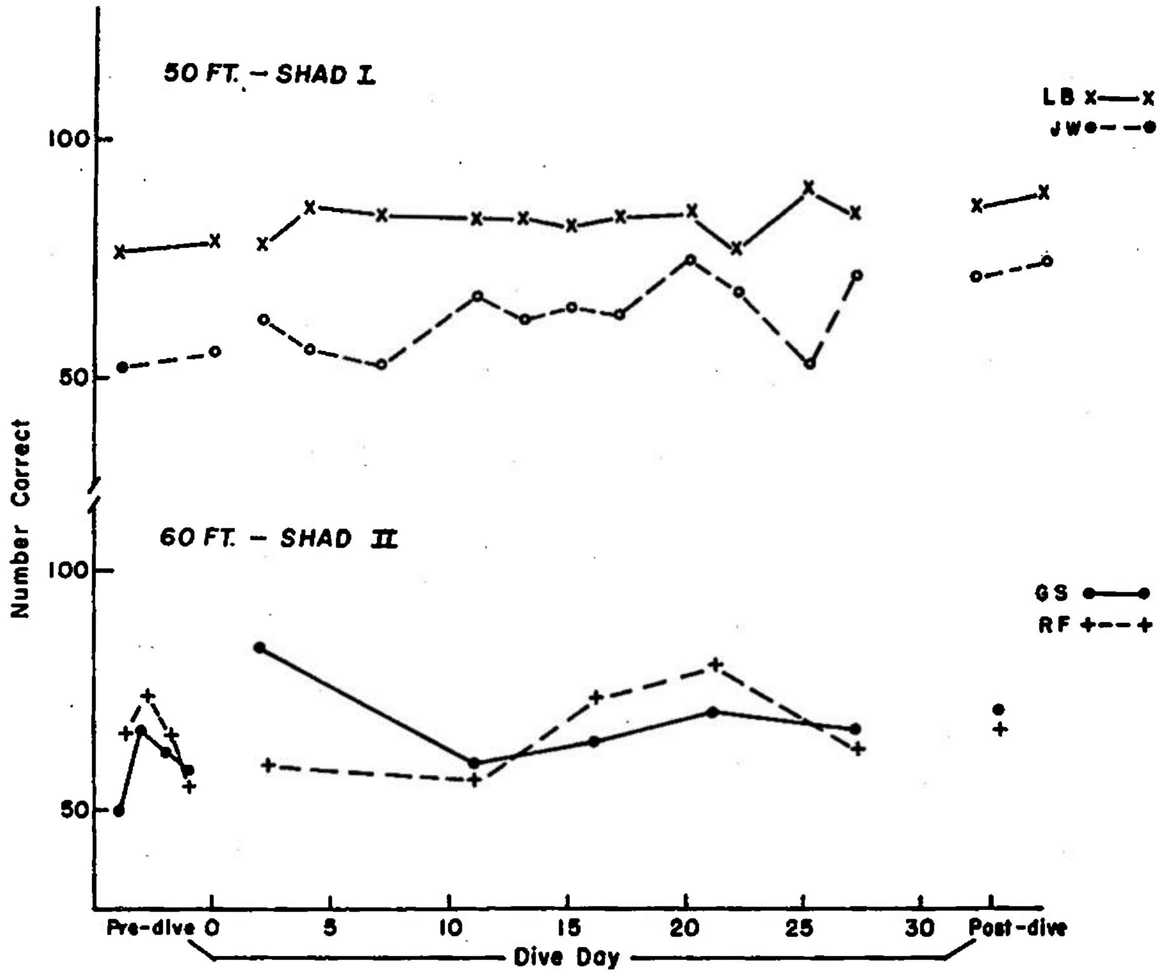

Fig. 2. Night Vision Test scores for the 50 and 60 ft saturation periods. Scores are the total number correct, out of a possible 120, corrected for errors.

sensitivity at 20 degrees from fixation than at 6 degrees from fixation. Similarly, after the original learning period was over, sensitivity, as measured by targets of different size, did not change during the dive.

Blood Vessel Size in Fundus Photographs

The measures of the temporal artery and vein in the fundus photographs of each of the men are shown in Table III. Both the arteries and the veins of all the men decreased in size during the saturation period. For some individuals, the vein constricted more while for others it was the artery, but all average values were smaller at depth than at the surface.

There were frequent irregularities in the data — unusually large or small values. These undoubtedly reflect the

Table III. Calibres (micra) of retinal blood vessels during the saturation periods

Dive Day	50 ft				Dive Day	60 ft			
	LB		JW			RF		GS	
	Artery	Vein	Artery	Vein		Artery	Vein	Artery	Vein
Pre-dive	108.0	133.3	95.0	137.0	Pre-dive	90.0	136.8	116.0	134.8
	104.0	132.7	94.4	133.6		88.0	134.0	105.2	126.8
1	92.8	117.6	99.2	132.0	7	82.4	120.8	93.2	117.2
4	89.0	130.0	90.4	135.2	11	92.0	120.0	106.0	118.8
10	88.0	126.0	96.8	124.8	18	72.0	108.8	102.3	112.0
13	85.2	140.0	95.2	141.6	23	76.8	112.0	110.4	138.4
16	88.8	137.6	86.0	139.0	26	86.0	108.8	102.0	136.0
19	101.2	132.0	80.0	153.2					
23	76.8	114.0	86.4	130.8					
29	97.2	129.2	105.2	149.2					
Post-dive	113.2	145.2	114.0	156.0	Post-dive	98.0	134.0	118.0	142.0
Mean surface	108.4	137.2	101.2	142.0		92.0	134.9	113.1	134.5
Mean depth	90.0	128.0	92.4	138.3		81.8	114.1	102.8	124.5

uneven quality of the photographs, which were occasionally too fuzzy for accurate measurement. Nonetheless, clear-cut trends are obvious: constriction occurred immediately, during the first week of the dive, and there was no tendency for greater amounts to occur with time. This is clearly shown in the average values, for all four divers, plotted as a function of time in the dive in Fig. 3. In general, the blood vessels constricted and remained constricted, until the post-dive period.

Visual Evoked Response

At saturated depth of 50 ft. The visual evoked responses (VER) to flashes once a second were very consistent from day to day for both of the men. This allowed measurement of both the amplitude and the latency of the major components for each recording session, and the calculation of an average VER. A comparison of the average VER, for 20 sessions at 50 ft, with the average control data, for 3 sessions at the surface, is shown in Fig. 4 for the striped target. There are no significant differences between the two VERs for either man.

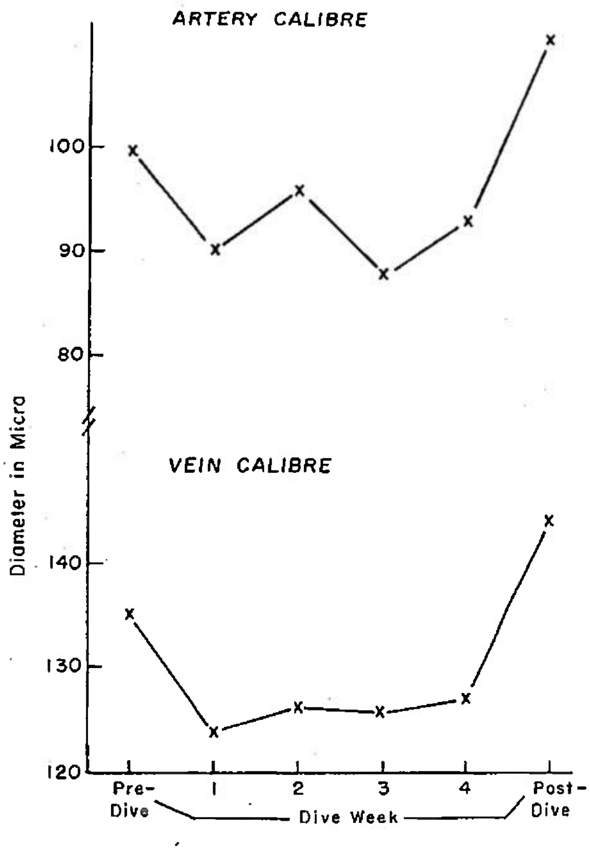

Fig. 3. The average diameter of arteries and veins for all four men plotted as a function of week of saturation period.

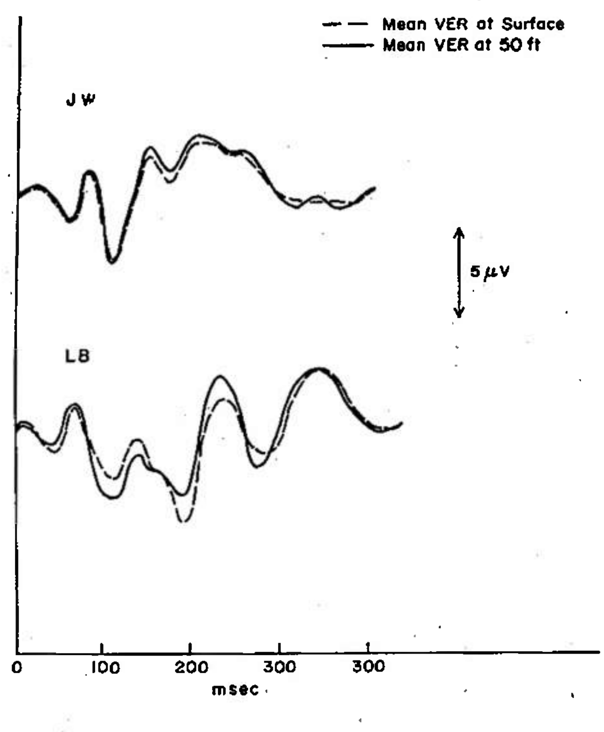

Fig. 4. Visual evoked responses to a striped pattern illuminated once a second. The VER for the surface is the average of three measures and for 50 ft, the average of 20 measures. Since the recording is bipolar, up on the figure refers to greater negative activity at the inion than at C_z; down to greater positive.

In order to determine whether there were changes in the pattern of the VER over time, weekly averages were made of the data. None of these weekly VERs differed significantly from the data shown in Fig. 4.

There were, however, differences in the waveform elicited by the different visual targets. Figure 5 shows the comparison of VERs for the blank and the striped field for both of the men, averaged over the 20 sessions at 50 ft. The amplitude of the two VERs are significantly different for JW at component E and for LB, at components C, D, and E; in addition the latency for LB is different at D.

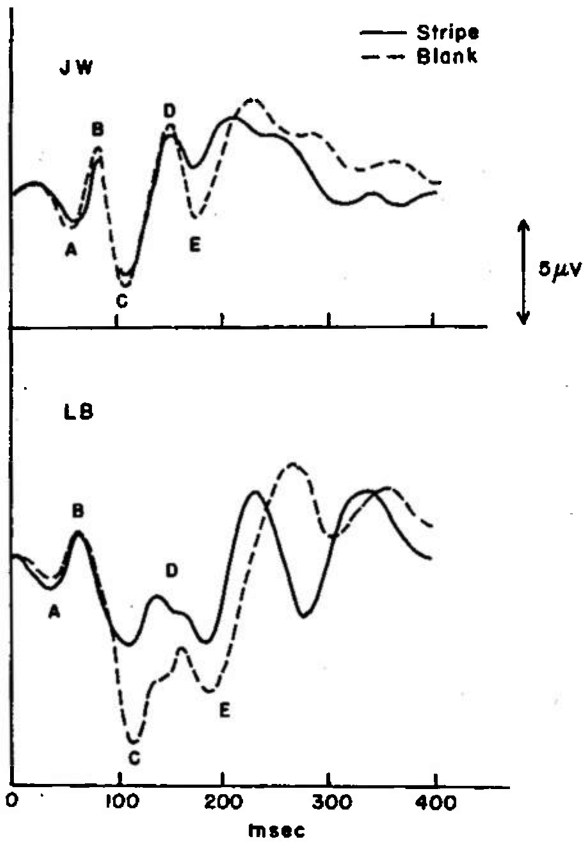

Fig. 5. Comparison of the VER to a blank and a striped field illuminated once a second. Curves are the average of twenty VERs each at a saturated depth of 50 ft.

Typical waveforms for the VER to 16 flashes per second are shown in Fig. 6. Again the responses of the men were consistent from day to day; LB's response was always very regular and of large amplitude while that of JW was smaller, irregular and somewhat erratic. These differences are common in the population; some individuals follow the 16 flashes with extreme consistency while others cannot. The mean amplitudes of the 16 individual responses are given in Fig. 7, at the top, for the daily measures. The changes over time appear to be simply random fluctuations in response amplitude with no systematic trends.

The greater amplitude and regularity of LB's VERs are apparent in the data. The overall average for 20 sessions at 50 ft was 3.47 $\mu V \pm 1.21$ for JW and 7.19 $\mu V \pm 0.98$ for LB. In addition, Z scores (mean/σ) were calculated for each of the daily sessions. This measure of regularity is independent of the amplitude; the overall average for JW was 4.14 and 6.30 for LB, again indicating the greater variability of JW's data.

<u>At a saturated depth of 60 ft.</u> The response evoked by the slow rate of stimulation for RF and GS at 60 ft were very similar to those at the surface. No extensive statistical analysis was performed, since their data were somewhat variable from day to day and there was considerably less data available than for the men at 50 ft. Nonetheless, it was clear that evoked responses at 60 ft fell within the range of responses at the surface and that there were consistent differences between the response to the striped and the blank field.

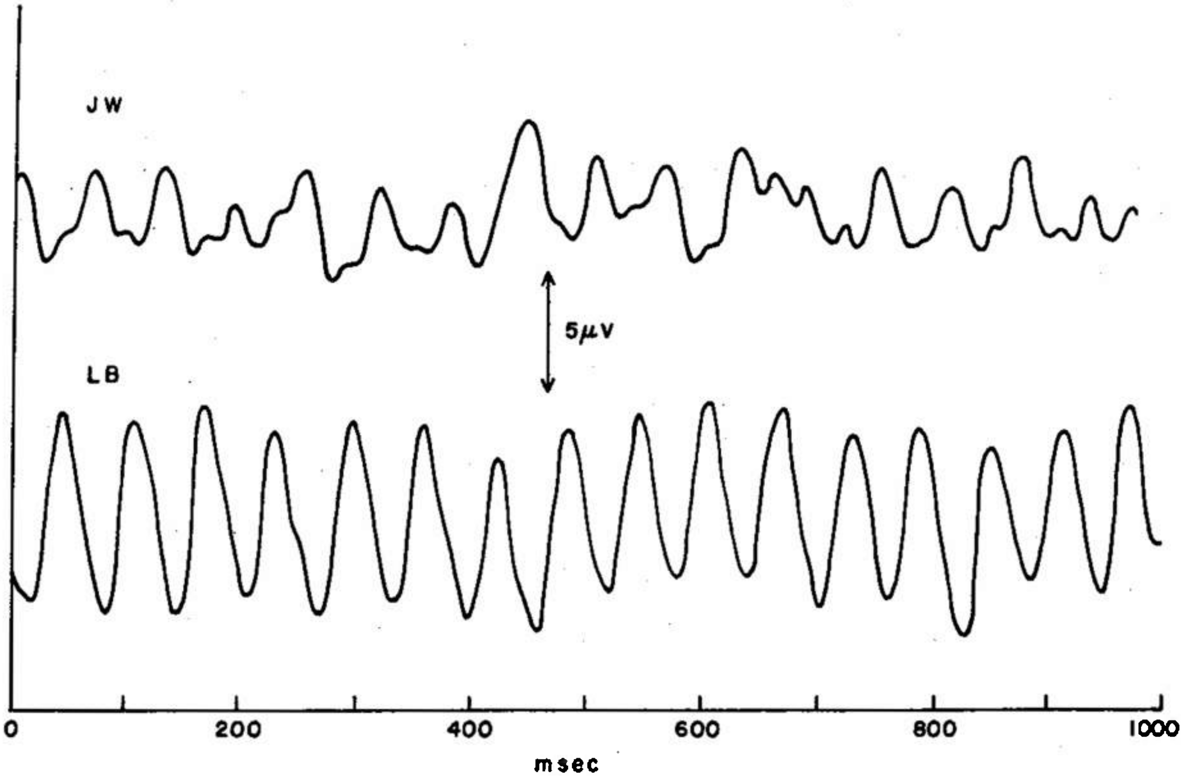

Fig. 6. Sample VERs to 16 flashes per second for JW and LB at a saturated depth of 50 ft.

Responses to the rapid rate of stimulation are shown in the bottom of Fig. 7 for the complete saturation period. Both men have a sizeable amplitude of response to the 16 flashes, generally around 4 to 5 μV, but there is no indication of a systematic change over the course of the saturation period and no evidence of a decrement in response.

<u>During excursions to deeper depths</u>. Figure 8 is a comparison of the average waveform of the response to the striped target illuminated once a second at the saturated depth and at 200 ft. The differences in waveform for RF and GS were small, similar in size to their daily variability, and of little significance. On the other hand, consistent changes were found in the data of both JW and LB, but the response differed for the two men. The typical performance was evidenced by JW with a large increase in positive activity (or a decrease in negative) around 160 to 170 msec at depth compared to the saturated or surface curves. Reduced negative activity has been found repeatedly in dives to 200 ft or more on air. Compilation of data over many dives has shown 18 out of 26 subjects, or about 70%, to give this specific effect.[18,28]

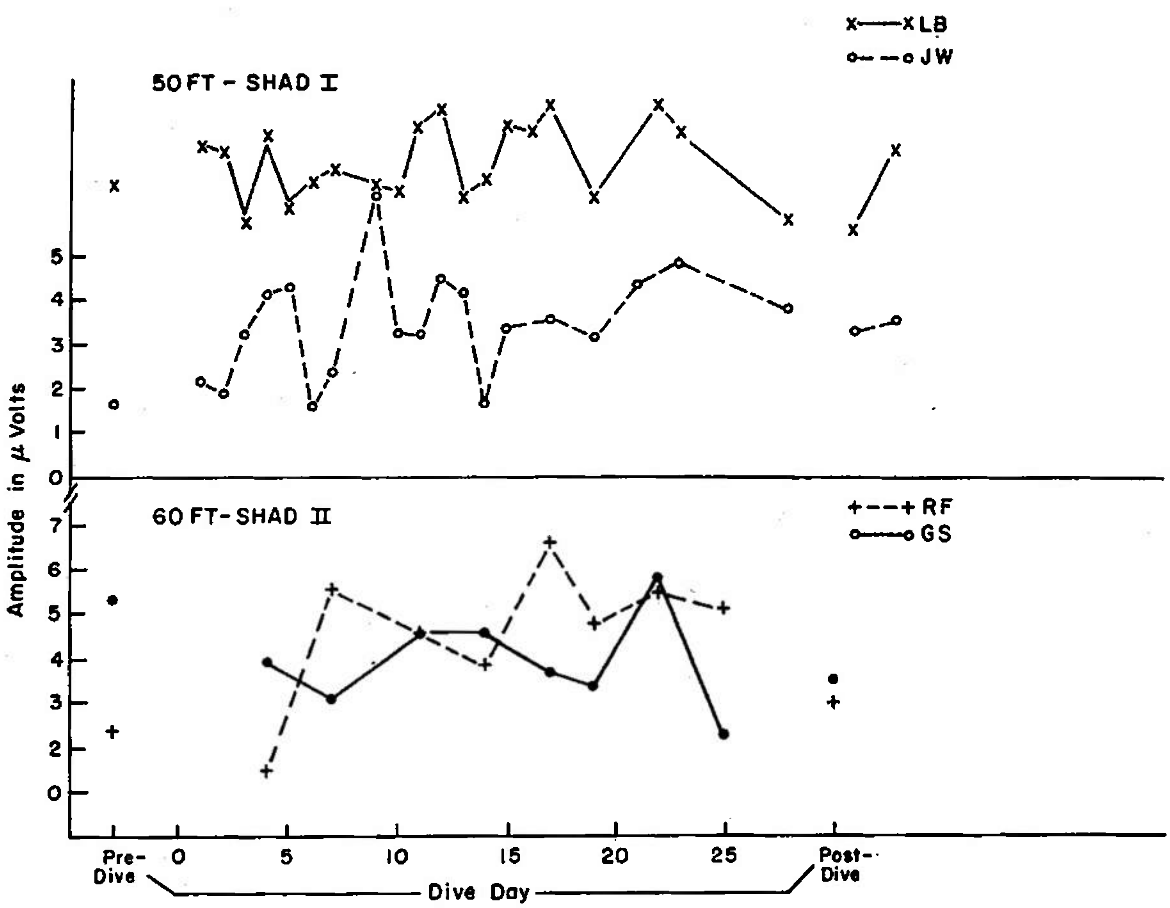

Fig. 7. The amplitude of the response to 16 flashes per second during the course of the 50 ft saturation period, at the top, and the 60 ft saturation period, at the bottom.

A comparison of LB's VERs at 50 ft and at 200 ft shows the opposite effect, heightened negative activity in the range from 100 to 200 msec. This difference, too, was consistent in each of his three VERs at 200 ft, but, in our experience, it is quite unusual with air diving. Generally, individuals who do not show the typical result of less negative activity at 170 msec simply show no difference at all. Interestingly, the pattern of activity displayed by LB at 200 ft is similar to that elicited by the blank field at 50 ft.

Comparison of the responses to 16 flashes per second at depth to those recorded immediately prior to the excursions are given in Table IV. Once again there are large individual differences among the men. Both LB and GS show large decrements at 200 ft in both the amplitude and regularity of the VER to 16 flashes. A typical record for GS

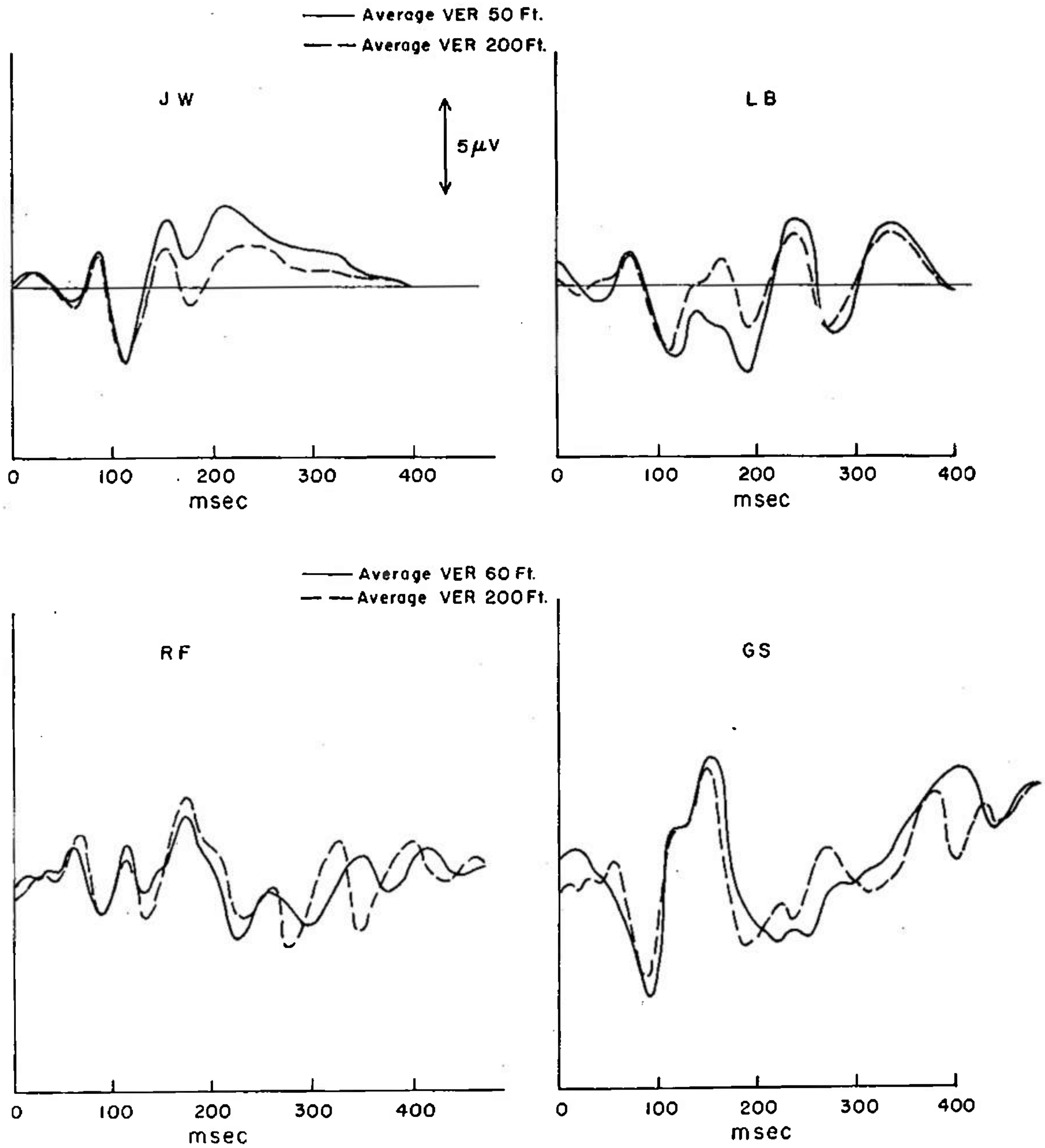

Fig. 8. Comparison of the average VER to a striped target obtained at the saturated depth with that obtained at 200 ft.

is shown in Fig. 9 on the right; his responses at 200 ft were without exception much poorer than at the saturated depth. Such decrements are typical of the VERs to rapid flash rates and have been found repeatedly in other dives.[15,18,19,28]

JW and RF show no decrements, but rather consistent increases in both response amplitude and regularity. An example for RF is shown on the left in Fig. 9. Such increases in response amplitude are unusual in our experience with bounce dives to 200 to 300 ft,

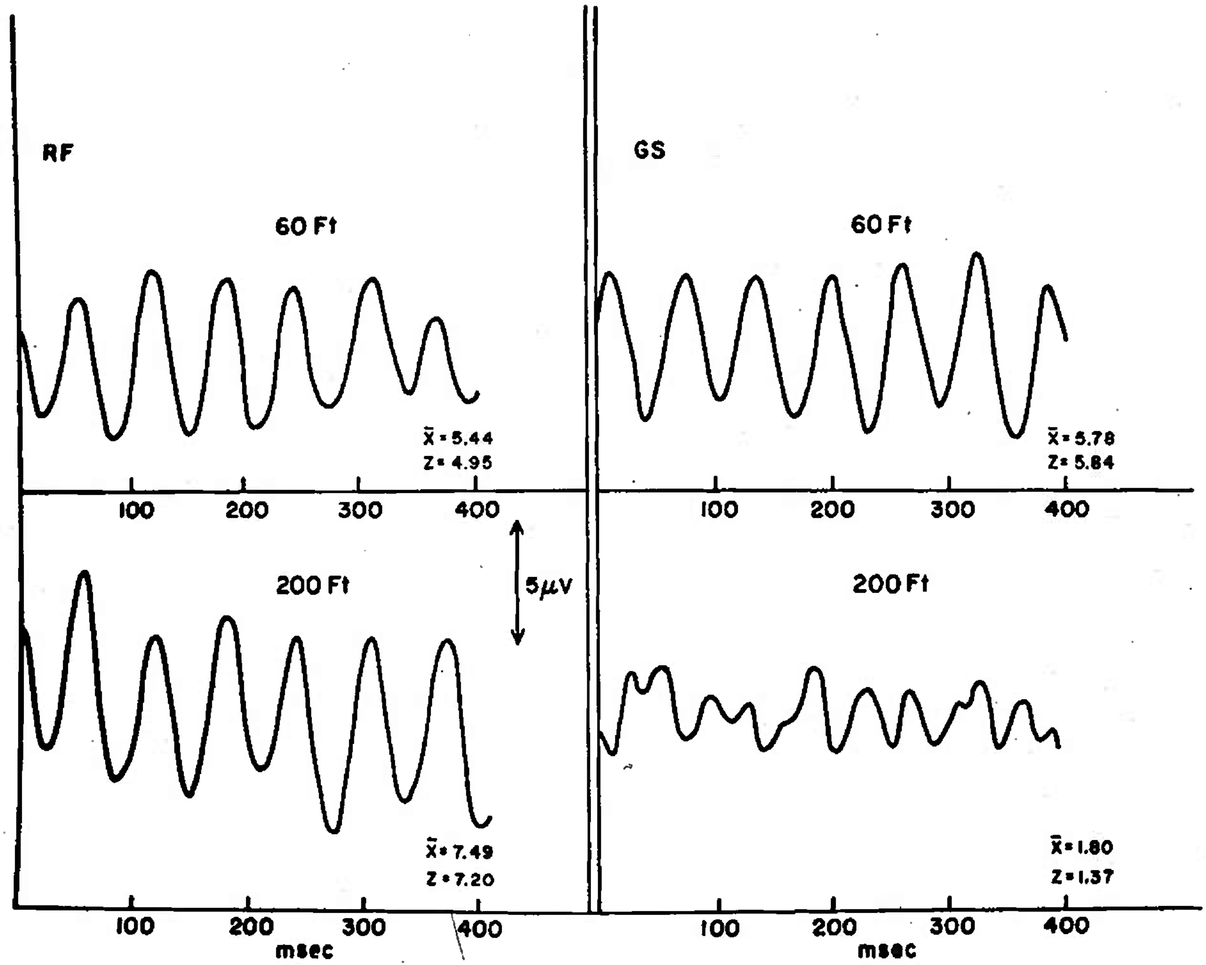

Fig. 9. Sample data of the changes in the VER to 16 flashes per second for RF and GS during excursions to 200 ft on dive day 22.

Table IV. Ratio of excursion to pre-excursion measures for amplitudes and regularities of the VERs to 16 flashes/sec. All excursions are to 200 or more feet from the saturated depth

Subject	Amplitude	Regularity	N of dives
JW	1.39	1.32	3
LB	0.65	0.76	4
RF	1.10	1.31	4
GS	0.41	0.42	4
Mean	0.89	0.95	

and the reason for the heightened response is not known. It is possible that it relates to oxygen consumption, since we have had a subject in the past who was unable to follow 16 flashes regularly at the surface, but responded very well after breathing oxygen.

EEGs

The raw EEGs were analyzed by a Federal Scientific Frequency Analyzer into the amount of activity, in μvolts, at each frequency throughout the range from zero to 50 Hertz.

The records were then measured for the largest peaks in the theta range (4 - 7 Hz), in the alpha range (8 - 12 Hz) and in the higher frequencies (20 - 30 Hz). Representative data are given in Fig. 10 showing the amplitude of alpha with eyes closed throughout the dive period for both saturation depths. The EEGs of the four men are quite different: LB's are of low amplitude throughout and generally show little change during the entire saturation period. The EEGs of JW and GS, on the other hand, are of very large amplitude and are marked by wide variations in amplitude from day to day. These do not, however, seem to be systematically related to time in the dive. RF has moderate amplitude alpha which increases during the

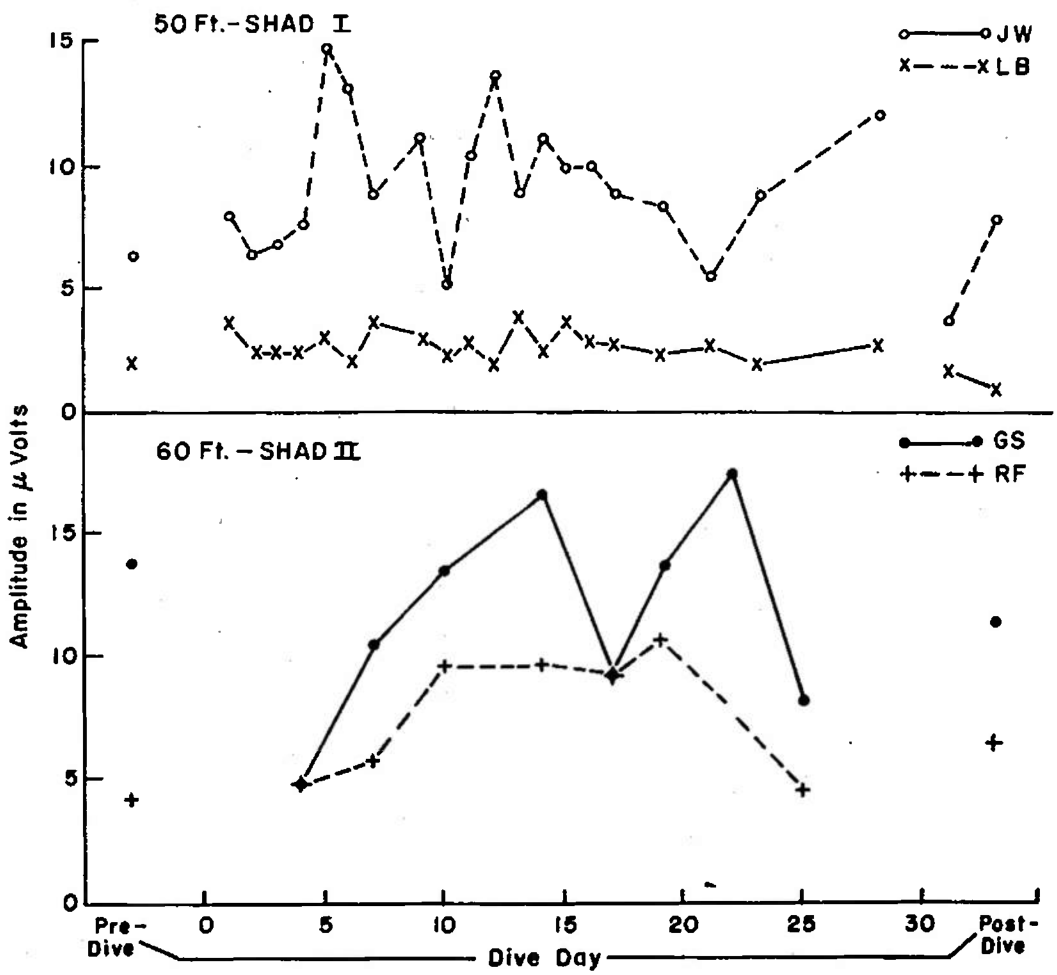

Fig. 10. The amplitude of alpha in the EEG during the course of the 50 ft saturation period, at the top, and the 60 ft saturation period, at the bottom.

saturation period. JW and LB also have larger amplitude at depth than on the surface: fifteen of the twenty measures at 50 ft are higher than the largest control value for JW and 18 of 20 for LB. Neither theta amplitudes or those at higher frequencies show this increase during the dive for any of the men.

Correlations among the various measures of EEG activity are listed in Table V. The amount of alpha and the amount of theta are positively correlated to a small degree for all four men, but only two of the correlations are significant. This relationship probably reflects little more than an overall change in amplitude at all frequencies from day to day, due perhaps to good or bad electrical resistance. It further attests to random nature of the alpha amplitude variations since manifestations of abnormal EEGs should result in a negative correlation: that is, less alpha coupled with increased theta. Similarly the lack of correlation between alpha amplitude and alpha frequency is an indication of random variation; depressed cerebral activity often is evidenced by a lowering of both alpha amplitude and frequency.[29,30]

Another measure of EEG activity made was the amount of activity at 16 Hertz during the visual evoked response to 16 flashes (VER 16). This measure is highly correlated with the amplitude of the VER 16, as is to be expected since they are different measures of essentially the same data.

Table V. Correlations (r) between various measures of EEG activity based on N measures

	50 ft				60 ft			
	LB		JW		RF		GS	
	r	N	r	N	r	N	r	N
Amplitude of alpha and of theta	.53**	23	.36	23	.56*	14	.29	14
Amplitude and frequency of alpha	-.37	16	.02	23	-.33	14	.23	14
Amplitude of 16 Hz and VER 16	.76**	22	.59**	21	.78**	14	.87**	14
Amplitude of alpha and of VER 16	.43*	22	.31	21	-.40	14	-.31	14

* significant at .05 level
** significant at .01 level

Finally, amplitude of alpha is not systematically related to the size of the VER 16 for the men, a finding consistent with previous data.[28]

The Farnsworth-Munsel 100-Hue Test

The error scores on the color discrimination test during the 60 ft saturation period are shown in Fig. 11. Both men would be categorized as having average color discrimination, since their surface control data were in the range of 40 to 50 errors; the mean error score for 250 submariners tested recently was 34 ± 21 errors. Superior discrimination is generally categorized as zero to 16 errors.

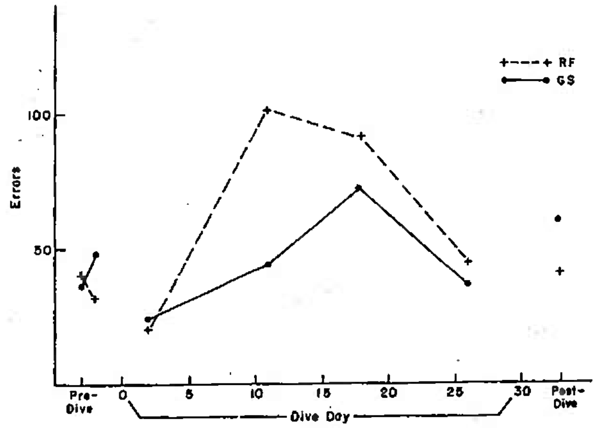

Fig. 11. Number of errors made by the men during SHAD II on the F-M 100-Hue test of color vision.

Both men show occasional scores during the saturation period which are considerably poorer than their surface control data. GS has one such score, on dive day 18, and RF has two, on dive days 11 and 18. The causes of these poor performances are unknown, but there are several reasons for thinking that they should be attributed to random variability, lack of motivation, or emotional attitudes rather than to hyperbaric oxygen. First, the poorest performances are found during the middle of the dive period, when moods were most extreme, rather than at the end of the exposure period. Second, there was no systematic pattern of errors, which is commonly found in results on the 100-Hue test in a number of acquired color vision deficiencies.[26] Finally, there is evidence from a group of four subjects tested on the surface a total of seven times.

The average scores of these four, for the seven testing sessions, are given in Table VI along with the data for GS and RF. Two of the controls had good color discrimination and their variability from day to day was small. The other two performed comparably to GS, both in terms of overall score and variability. Since the range of these two, without any stress, duplicated or exceeded that of GS, including his worst day during the dive, a hyperbaric effect on color discrimination can be discounted. While no one duplicated RF's extreme range, it is likely that here too random variability and motivation are involved.

Table VI. Comparison of error scores on the F-M 100-Hue test of the two divers with four controls on the surface

S	N of tests	Mean error score	σ	Range
Divers:				
GS	7	45.7	16.1	24-72
RF	7	52.9	31.2	20-102
Controls:				
TP	7	4.0	4.6	0-12
LM	7	27.4	6.3	20-36
PP	7	55.3	16.9	24-72
BC	7	49.0	15.8	32-76

DISCUSSION

The major outcome of this investigation is that there was no evidence of deterioration in the tests of visual performance or physiology. Since the tests included covered all of the major visual symptoms of oxygen toxicity commonly documented in the literature, the conclusion is that there is no evidence here that compressed air cannot be used in shallow water habitats at 50 or 60 ft for as long as thirty days. Many of tests gave completely straightforward, negative data. Thus, there was no loss of visual acuity and no constriction of the visual field; decrements in these tests would have been indicative of oxygen poisoning.

The decrease in the diameter of the retinal vessels must be interpreted with regard to what is known about the effects of high pressure oxygen. Vasoconstriction in the retinal vessels is an extremely common finding,[12-14,31] but does not necessarily mean that the oxygen supply to the tissues is reduced. In fact, a number of investigators have measured PO_2 during constriction and found it to be higher than normal, at least originally, while breathing 100% oxygen;[4,14,32] the vasoconstriction then may simply serve as an attempt to reduce the supply of oxygen to the tissues to a normal level. Despite this, vasoconstriction cannot be dismissed as unimportant; several deleterious effects are possible. Ledingham[3] and Margolis and Brown[5] both suggest that hypoxia can be a problem despite breathing 100% O_2, while Nichols and Lambertsen[4] speculate that other essential nutrients normally supplied by the blood may be in short supply to the retina due to the constriction.

While the underlying mechanisms are not known, it is clear that high partial pressures of oxygen can cause severe and irreversible damage to the retina. Retinal lesions are easily produced in dogs breathing 100% O_2 at three ATA for only four hours.[5] Margolis and Brown, in fact, speculate that their gross counterpart, the cotton wool spot may be visible in views of the fundus. No such problems were seen in the fundus photos of these men.

Similarly Noell[6] has shown that visual cell death occurs in rabbits exposed to 3 ATA of 100% O_2 for five to six hours. Both authors suggest that inactivation of essential enzymes by oxygen must be added to the list of possibilities of the cause of the injury.

It should be noted that the partial pressures used in these animal studies are not excessive compared to those endured in shallow habitats and in air excursions from them. The partial pressure of oxygen at 50 ft is 7.4 psi, the equivalent of about 50% O_2 on the surface. Noell produced visual cell death in rabbits (admittedly an animal sensitive to oxygen) with 100% oxygen on the surface or 14.7 psi for several days. The lesions in dogs were produced with 44 psi, a much higher value, but an excursion to 300 ft on air incurs a psi of about 30. It is obvious that the limits of tolerance are being approached and careful monitoring of the divers is essential.

The EEG, too, must be interpreted in terms of the known effects of high pressure oxygen; here the gross results are unequivocal. All authors agree that the final symptom of O_2 poisoning is a convulsive seizure as is seen in idiopathic epilepsy - a "grand mal" variety, with all-or-none features, that is evident at all recording sites.[20-24] The details of the precursors of the "grand mal" are not quite so well defined. Working with cats, the seizure is preceded by an increase in the number of slow waves, according to Cohn and Gersch[21] and to Sonnenschein and Stein,[22] and by an increased frequency and decreased amplitude of EEG, according to Voronov.[23] Working with human subjects, Donald[24] lists both an increase in slow waves (3 to 5 Hz) and in fast waves (25 to 30 Hz), coupled with a decrease in the amplitude and frequency of alpha. Unfortunately none of the studies mentioned measured the amplitude or the frequency of the changes but simply estimated them by eye. However, it is obvious there is no evidence in our data of any of the EEG changes generally thought to precede seizure: the one change found in SHAD I and II - an increase in alpha - is one of the few possibilities never described as a precursor.

The only changes in the visual evoked response from surface control data occurred during the excursions to 200 ft or more. The changes were similar to those that have been well-documented previously [15,19,28] for some subjects. However, two of the men showed enhanced amplitude and regularity of response to rapid stimulation at depth and the reason for this is unknown. In fact the evoked response must be considered an exploratory measure in research on oxygen toxicity since there is little in the literature to indicate whether its effects might be enhancement or deficit. Nonetheless, the marked sensitivity of the electrical response of the eye to hyperbaric oxygen [6,33] makes its inclusion advisable; the effects of oxygen on the VER are the object of continuing research.

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13. ABSTRACT

In order to determine the safe depths at which divers can live while breathing air, a battery of medical, physiological, and performance tests were administered to subjects who lived for a month in the NavSubMedRschLab pressure chamber at 50 ft and at 60 ft.

The tests included a number of measures of visual physiology and visual performance, since many of the symptoms of oxygen toxicity involve the visual system. The results showed no decrements in visual acuity or in the size of the field of view at either 50 ft or 60 ft. There were no abnormal changes in the EEG during saturation, and the only changes in the visual evoked response occurred during excursions from the saturated depth. Both retinal arteries and veins were constricted as is commonly found with high partial pressures of oxygen.

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