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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 761

MEASURES OF EVOKED RESPONSES AND EEGs DURING SHALLOW SATURATION DIVING

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF51.524.004-9015DA5G.09

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SUMMARY PAGE

THE PROBLEM

To monitor brain functioning and determine whether adaptation to nitrogen narcosis occurs during a long-term shallow saturation dive utilizing nitrogen/oxygen mixtures.

FINDINGS

Visual evoked responses and EEG measures made during both the saturation period and during excursion dives from saturated levels indicated that some adaptation occurred. It was not, however, complete.

APPLICATION

The results are of use in determining the depth and time limitations of nitrogen/oxygen breathing for Navy divers.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit MF51.524.004-9015DA5G. The present report is Number 9 on this work unit. It was submitted for review on 5 September 1973, approved for publication on 14 September 1973, and designated as NavSubMedRschLab Report No. 761.

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ABSTRACT

Visual evoked responses (VERs) and electroencephalograms (EEGs) were recorded during the course of a long-term, shallow, nitrogen/oxygen saturation dive. Measures were made during excursion dives and at the saturation level prior to and following each excursion. Comparison with a control series, in which bounce dives were made from the surface, revealed that some adaptive changes took place in the VER; complete adaptation however did not occur. Reduction in frequency and amplitude of alpha, in the EEG, also was found during the course of the saturation period.

MEASURES OF EVOKED RESPONSES AND EEGs DURING SHALLOW SATURATION DIVING

INTRODUCTION

Nitrogen narcosis is a primary deterrant to divers breathing air at depth. Its symptoms, while sometimes pleasurable, can be incapacitating or even lethal at depths from 250 to 500 feet, requiring that some other inert gas be used in the breathing mixture for deep diving. However nitrogen/oxygen is still the most convenient and inexpensive gas for medium depths and its limits are being explored for saturation diving.[1]

Our previous studies have indicated that the visual evoked response (VER) is a sensitive measure of nitrogen narcosis in man; we have shown progressive decrements in both the amplitude and the regularity of the VER with depth when the divers were breathing air.[2] Similar decrements have been found by other investigators[3-6] and these have been generally attributed to narcosis, since comparable losses are not found with helium. The narcosis is generally believed to result from an interference in normal neural transmission in the central nervous system by the heavy nitrogen molecules.[7,8]

Two recent investigations of narcosis are somewhat puzzling in light of these results. Ackles and Fowler[9] compared the effects of air and argon/oxygen at depth; they found large decrements with both gases, but the losses with argon were not greater as might be expected from its narcotic potency. Kinney, McKay and Luria[5] found large decrements for divers breathing air by mask in a helium saturation dive, but the amount of loss was not related to the depth or the partial pressure of the nitrogen. In fact the two smallest decrements, in a total of five tests, were at the two highest nitrogen partial pressures.

There are several possible explanations of these findings. First is the possibility that the decrements in evoked response amplitude are a curvilinear function of depth which reach an asymptotic value between 40 to 60% of their surface value for a given individual. This assumption fits well with the published data; there are indications in all three studies of a leveling-off of the loss at 250 to 350 feet. Furthermore the asymptote theory is more logical than the one concerning a linear relation with depth, since the latter makes the unlikely prediction of cessation of all evoked response around 450 feet or 170 psi of nitrogen. Thus, Ackles and Fowler's failure to find a difference between argon and air is explained by the fact that the VERs for both gases were at the asymptotic value. Similarly, our data would, under this hypothesis, be viewed simply as experimental error around the 50% asymptotic value.

The second possible explanation--particularly for our data--is that the lesser decrements evidenced at higher partial pressures of nitrogen represent an adaptive phenomenon. Adaptation, through repeated exposures to air at depth, has been reported frequently for experienced divers;[10,11] Adolfson[12] reports adaptation among his divers exposed repeatedly to 400 ft while breathing air; Walsh and Bachrach[13] report a similar appearing phenomenon for rats.

An opportunity arose to answer some of these questions in a saturation dive conducted at Ocean Systems Inc. at Tarrytown, New York. Although the primary concern in the investigation was to test decompression tables and excursion limits from shallow saturated conditions, ample opportunity was available for physiological research on the diver-subjects. Consequently, a program was set up to record EEGs and VERs from diver-subjects periodically, while saturated at various depths, and during excursion dives from saturated levels. Control data were obtained at the surface and during bounce dives from the surface, prior to and following the saturation period.

PROCEDURE

Electrophysiological Recording

EEG and evoked responses were recorded from bipolar electrodes located at O_z and C_2P with a ground electrode on the subject's ear. Electrode positions were chosen to maximize the evoked response in the visual and somatosensory modalities. O_z is located over the primary visual projection area while C_2P (approximately 1/2 way between C_3 and P_3) is over the projection area from the hand. While recording from the visual modality, the somatosensory served as the reference and vice versa. 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 Corporation Computer of Average Transients (CAT).

For the evoked responses, the analysis interval (that is, the duration of cortical activity following a stimulus that was summed by the CAT) 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.

The stimulus for the visual evoked response was a pattern of vertical stripes formed of opaque black tape and translucent thin paper. The striped pattern was backlighted by a Grass PS-2 photo stimulator; both were mounted on the outside of a porthole of the chamber. At the subject's viewing distance of about one foot, the individual stripes subtended an angle of 2.5 degrees and the overall pattern, 23 degrees.

Two different flash rates were employed for viewing the striped targets: two flashes per second and 16 flashes per second. Previous research has shown the two flash rates yields a sensitive measure of physiological stress, since they yield different evoked responses which probably have somewhat different origins.[14,15] The intensity setting of the Grass photo stimulator was 4. This setting yielded a luminance of about 80 foot-Lamberts for the bright stripes.

Data Analysis

Evoked responses were read out from the CAT to a Plotamatic X, Y recorder. From these records, measures of amplitude and latency of all components were made. EEGs were transferred from tape to a Beckman polygraph, for spot checks for artifacts. Analysis was performed by Federal Scientific Spectrum Analyzer and Averager; these equipments yield curves of the average amplitude at each frequency from 0 to 50 Hz in 1/4 Hz steps for one minute intervals of EEG.

Dive Schedule

Details of the experimental design, chamber facilities, compression and decompression schedules are available in a summary report from Ocean Systems.[16] To summarize, the study was carried out in two phases, each consisting of a two-week saturation period. In the first, in the fall of 1972, three subjects remained at 30 feet (sea water equivalent) for one week, from October 21 to 27; they were then compressed to 90 ft for the second week, October 28 to Nov 3. In the second phase, the first week of saturation was at 120 ft from January 13 to 19, 1973, and the second at 60 ft from January 20 to 25. Again there were three subjects, but one contracted the 'flu' and did not complete the dive. All breathing mixtures during saturation periods were normoxic.

Daily excursions from the saturated level were made to various depths up to 300 ft; the breathing mixture for the excursions was always air.

Prior to each two-week saturation period, bounce dives from the surface were conducted as a control. In addition, two weeks following phase 1, another set of bounce dives to 200 and 250 feet from the surface gave additional control data.

Testing Schedule

The intent of the electrophysiological test program was to monitor EEG and VERs periodically during the saturation period and to obtain as much data as possible during the excursion dives to the deeper depths, from 200 to 300 ft. Measures were thus made on all subjects at saturation prior to and following the deep excursions. Data were then recorded from as many subjects as possible during the excursion; this depended upon the total bottom time and the availability of the subjects, since some were assigned primarily to other experiments. In all, extensive data were collected on five men. Table I summarizes the schedule, indicating the dates and the measures made on each.

The order of testing was always the same during each of these conditions. First was the visual evoked response to the rapid flash rate; this was followed in turn by 75 seconds of recording EEG with eyes closed, the visual evoked response to slow flash rate, 75 seconds of EEG with eyes open, and the somatosensory evoked response. There were a few occasions with exceptionally short bottom times that necessitated elimination of the EEG records.

Table I. Testing schedule for electrophysiological measures. Conditions during which data were collected are indicated by X.

Condition	Date	Depth (ft)	Subject GB	Subject DN	Subject LJ
		PHASE I			
Control bounce dives	10/17	0	X	X	X
		200	X	X	
		10	X	X	
	10/18	0	X	X	X
		250	X	X	
		10	X	X	X
	10/19	0	X	X	X
		150	X	X	X
Saturation Week 1	10/25	30	X	X	
		200	X	X	
		30	X	X	
	10/31 AM	90	X	X	X
		200	X	X	X
		90	X	X	X
	PM	90	X	X	X
		200	X	X	X
		90	X	X	X
	11/2 AM	90	X	X	X
		250	X	X	
		90	X	X	X
	PM	90	X	X	X
		250		X	X
		90	X	X	X
Decompression	11/3	5	X	X	X
		3	X	X	X
Control bounce dives	11/14	0	X	X	
		250	X	X	
		0	X	X	
	11/15	0	X	X	X
		200	X	X	X
		0	X	X	X

Condition	Date	Depth (ft)	Subject PU	Subject GJ
		PHASE II		
Control bounce dives	1/8	0	X	X
		0	X	X
	1/9	0	X	X
		200	X	X
		10	X	X
	1/10	0	X	X
		0	X	X
		250	X	squeeze
		10	X	
Saturation Week 1	1/15 AM	120	X	X
		250	X	X
	PM	120	X	X
		250	X	X
		120	X	X
	1/16 AM	120	X	X
		75	X	X
		120	X	X
	PM	120		X
		55		X
		120		X
	1/18 AM	120	X	X
		200	X	X
		200	X	X
		120	X	X
	1/19 AM	120	X	
		300	X	
		120	X	
	PM	120		X
		300		X
		120		X
Week 2	1/24 AM	60	X	X
		200		X
		60		X
	PM	60	X	X
		200		X
		60	X	X
Decompression	1/25	4	X	X

RESULTS

Electroencephalograms

Figure 1 shows sample data of the analysis of the EEGs, in which the amplitude of response is plotted as a function of the frequency. The left portion gives the data for the five divers, for a control run at the surface, with their eyes closed; the right portion is the same, except the men have their eyes open. Individual differences are large in both the amplitude and the pattern of the EEG response. Four of the divers have large alpha peaks when their eyes are closed, but one does not. Alpha tracings disappear for most of the divers when their eyes are open, but one man maintains a large peak and another has a smaller one. These differences are representative of the ranges found in the normal population.[17 p. 287]

Alpha

Amplitude of alpha with eyes closed, measured from data analyses such as these, is plotted in Fig. 2 for each of the divers over the course of the entire experiment. Large, consistent and highly significant ($p < .01$) reductions in alpha amplitude occur as the experimental progresses for four of the five divers. The fifth man, GB, is the man

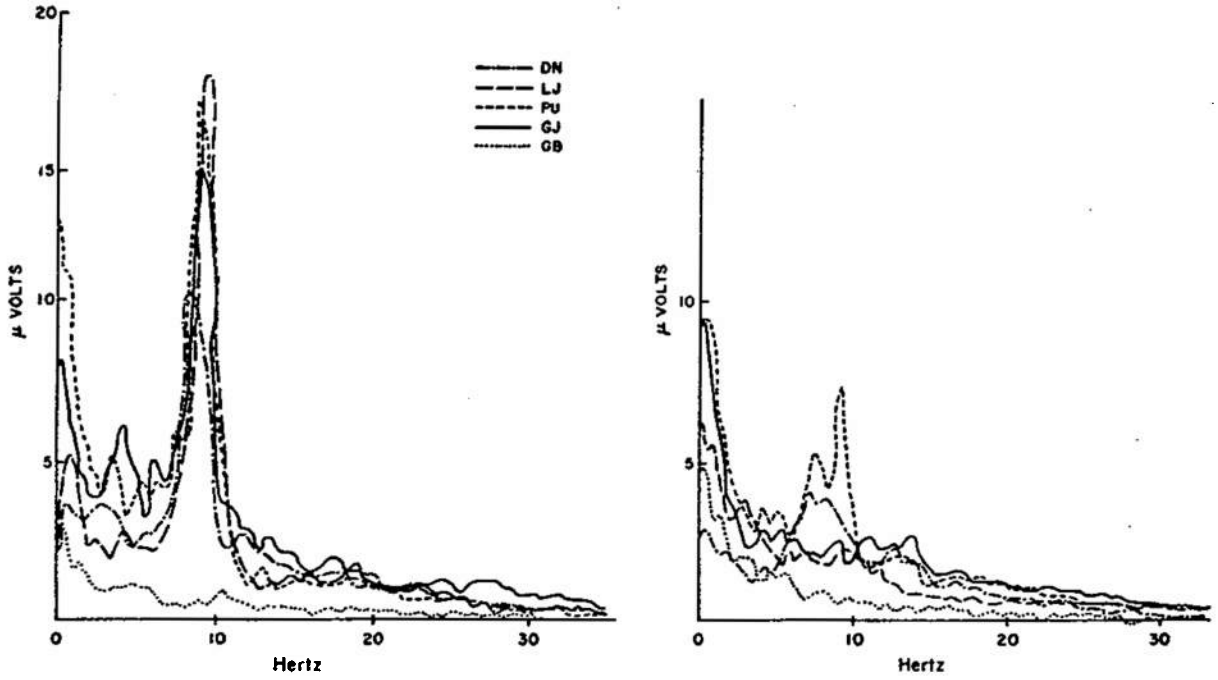

Fig. 1. Frequency analysis of the EEGs of five subjects during surface control runs. On the left is the eyes closed condition; on the right, eyes open.

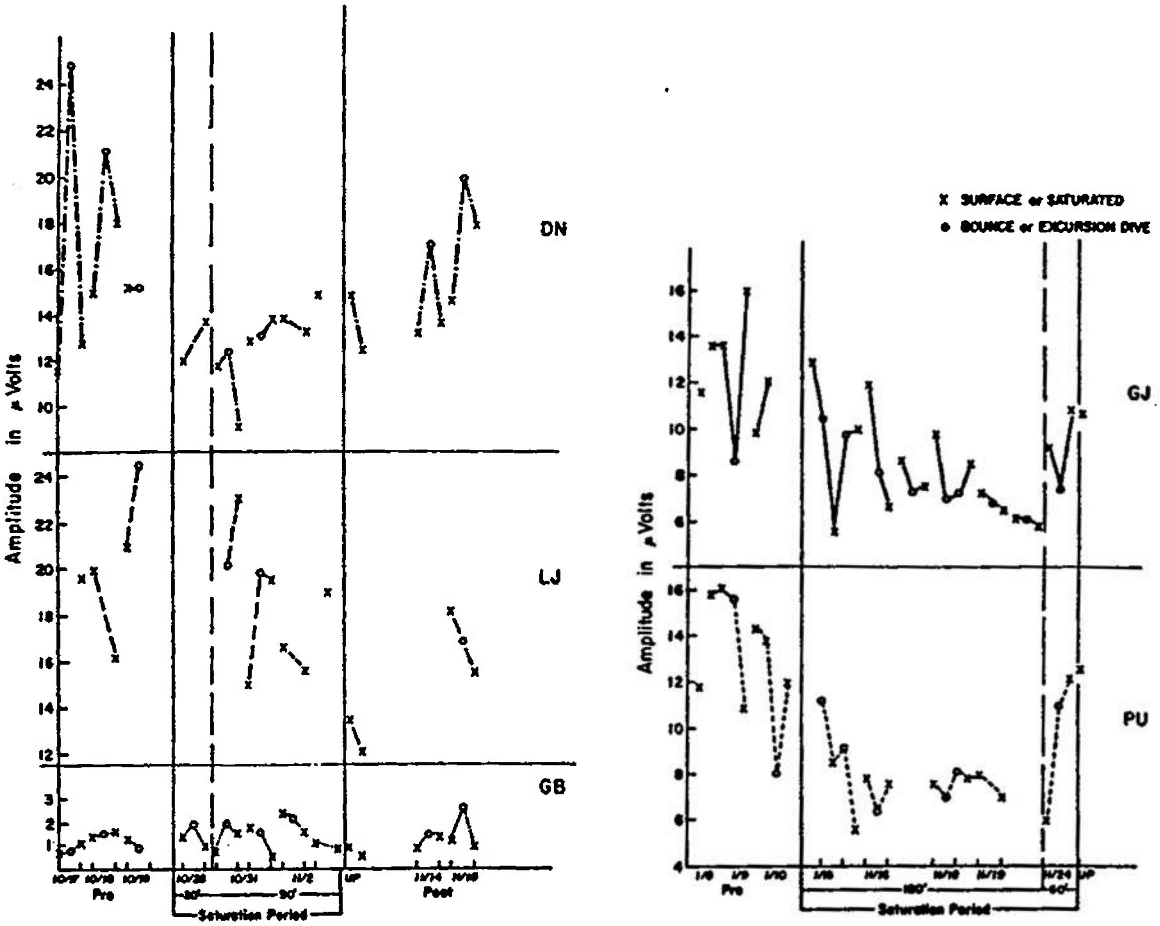

Fig. 2. Amplitude of the alpha with eyes closed for five subjects during the course of the experiment.

who has virtually no alpha amplitude when his eyes closed, so his lack of decrement is not inconsistent.* Most of the men show some recovery of amplitude on return to the surface after the dive.

Alpha amplitude during the eyes closed condition was reduced not only in amplitude but also in frequency for all divers. The data are summarized in Table II in which the mean amplitude and frequency are given in chronological order for each man. For frequency as well as amplitude, the values on decompression, or two weeks later, tend to revert to their pre-dive levels.

This reduction in frequency and amplitude of the alpha wave is not due to increased depth. This is shown in Table III which gives the amplitude and

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**At times, GB's frequency analysis had a minor bump between 8 and 12 Hz; these were measured for amplitude and frequency. At other times the frequency analysis was completely flat; in these cases, the average amplitude between 8 and 12Hz was taken as the measurement.*

Table II. Mean amplitude and frequency of alpha with eyes closed over course of saturation dive.

Divers	Pre-saturation runs	Week 1 Saturated at:		Week 2 Saturated at:		Decompression to surface	Post-saturation runs
		30'	120'	90'	60'		
Amplitude in μvolts							
DN	16.72	12.80		12.76		13.60	15.84
GB	1.40	1.50		1.52		0.80	1.45
LJ	20.24	-		18.60		12.75	16.83
PU	13.14		7.84		9.74	12.60	-
GJ	12.23		8.46		7.65	10.80	-
Frequency in Hertz							
DN	8.79	9.20		8.38		8.80	8.77
GB	10.50	10.00		9.73		9.50	9.85
LJ	9.66	-		9.19		9.45	9.83
PU	9.30		7.98		8.90	8.70	-
GJ	9.54		9.12		9.18	9.50	-

frequencies averaged for all bounce dives and for pre and post control runs made just before and after each bounce dive. The amplitude of the alpha wave for three subjects increased at depth, while for the other two, it decreased; no changes in frequency are apparent.

Analysis of alpha amplitudes and frequencies during the other conditions (eyes open and during the visual and somato sensory evoked responses) yielded no changes that were consistent among subjects.

Theta

The chronological profile of theta amplitude in the eyes closed condition in the five subjects is shown in Fig. 3. Theta activity, defined here as the largest peak in the 4 to 7 Hz range, is constant throughout the dive for three subjects. The other two subjects, PU and DN, have large increases, up to amplitudes double that of the surface level, during the dive. For both men, the largest increases appear to be at the deeper saturated condition. These

Table III. Mean amplitude and frequency of alpha for eyes closed. Comparison of measures made prior to, during, and following each bounce dive.

Divers		Pre	Dive	Post
		Amplitude in μvolts		
DN	$\bar{X}$	13.48	17.48	14.00
	σ	1.40	4.48	2.82
GB	$\bar{X}$	1.49	1.71	1.19
	σ	0.72	0.57	0.39
LJ	$\bar{X}$	17.99	19.48	17.46
	σ	2.31	3.30	6.76
PU	$\bar{X}$	10.98	9.58	9.00
	σ	3.80	2.98	2.62
GJ	$\bar{X}$	10.21	7.90	9.01
	σ	2.72	1.34	3.32
	$\bar{X}$	10.83	11.23	10.13
		Frequency in hertz		
DN	$\bar{X}$	8.45	8.79	8.78
	σ	0.54	0.12	0.45
GB	$\bar{X}$	9.99	10.09	10.04
	σ	0.38	0.64	0.67
LJ	$\bar{X}$	9.46	9.64	9.23
	σ	0.26	0.33	0.33
PU	$\bar{X}$	8.71	8.55	8.39
	σ	0.72	0.81	0.82
GJ	$\bar{X}$	9.26	9.27	9.15
	σ	0.28	0.36	0.26
	$\bar{X}$	9.17	9.27	9.13

differences are significantly larger for the deeper saturated condition than the pre-saturation data for both men (PU: $\underline{t} = 2.61$, $\underline{p} < .05$; DN: $\underline{t} = 8.01$, $\underline{p} < .01$).

Sample EEG data for the two men are shown in Fig. 4 in which surface control data are compared with records made during excursion dives from saturated levels. The reduction in alpha and increase in theta shown by the frequency analysis are evident in the raw EEG.

The same increases in theta amplitude during the saturation period are found in the EEGs of these two men under all conditions; that is, with their eyes open and during the evoked responses. Figure 5 gives theta amplitudes for the five divers analyzed from EEGs recorded during the VER to rapid stimulation. Theta activity is again constant for the other three divers.

It is apparent in both Figures 3 and 5 that there is no consistent change in theta amplitude during the excursion dives. This was supported by statistical analysis which yielded no significant differences between theta amplitudes or frequencies in data determined prior to, during, and following each excursion.

Visual Evoked Responses

Slow Flash Rate. Examples of the response evoked by the striped pattern illuminated two times per second are shown in Fig. 6. Three control runs at the surface are shown for each diver. The waveform of the evoked response is complex, consisting of various components which differ in latency and amplitude. While there are certain consistencies in waveform among the different subjects (for example, all show a prominent

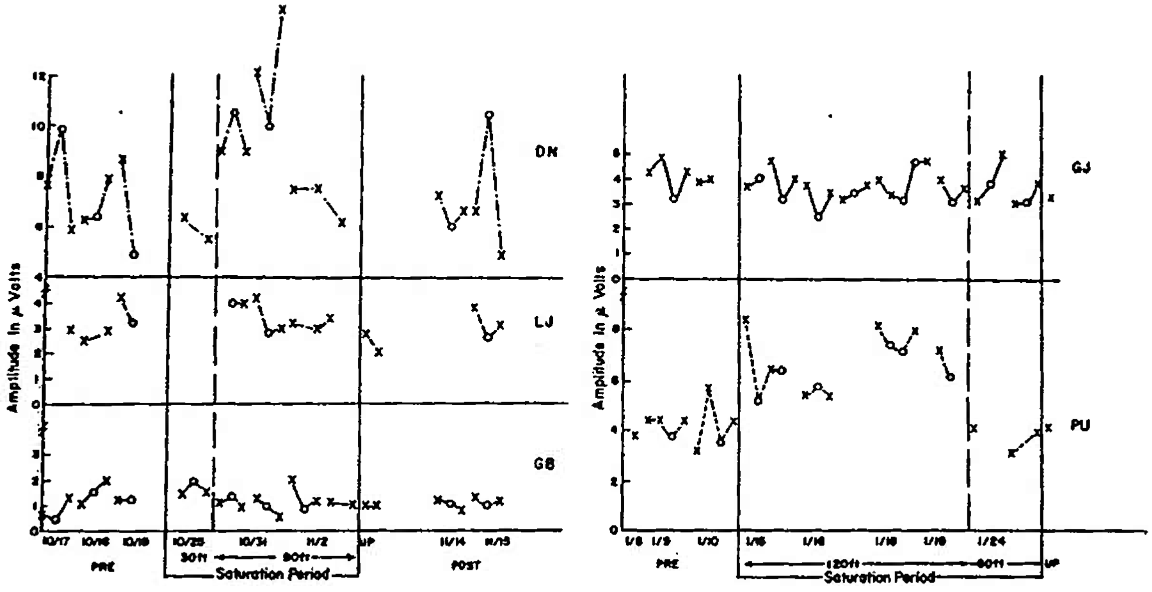

Fig. 3. Amplitude of theta with eyes closed for five subjects during the course of the experiment.

dip around 100-120 msec), there are also large individual differences in waveform. This is the normal result in evoked responses to slow stimulus rates.[14]

In addition to this waveform difference, the five divers showed large individual differences in repeatability of the waveform. At one extreme, GB gave the same waveform, with extreme consistency throughout the entire course of the experiment, including pre- and post-saturation control dives. When he re-entered the experiment as a substitute three months later, his waveform was identical to his earlier pattern. At the other extreme, the waveforms of one subject changed markedly during the saturation period, so much so that they were not recognizable as being from the same subject that ran in the pre-dive controls. The other three men had generally reproducible waveforms with an occasional unusual record.

In the following section the effects of depth and time at depth on the evoked responses are analyzed. GB's data are used throughout because the analysis is straightforward, due to his extreme consistency. Waveforms of the other men are not analyzed so extensively, but examples of pertinent effects will be shown.

Figure 7, GB's first dive in this experiment, shows the typical waveform differences found at depth.[2,5,17] Some components change only slightly or not

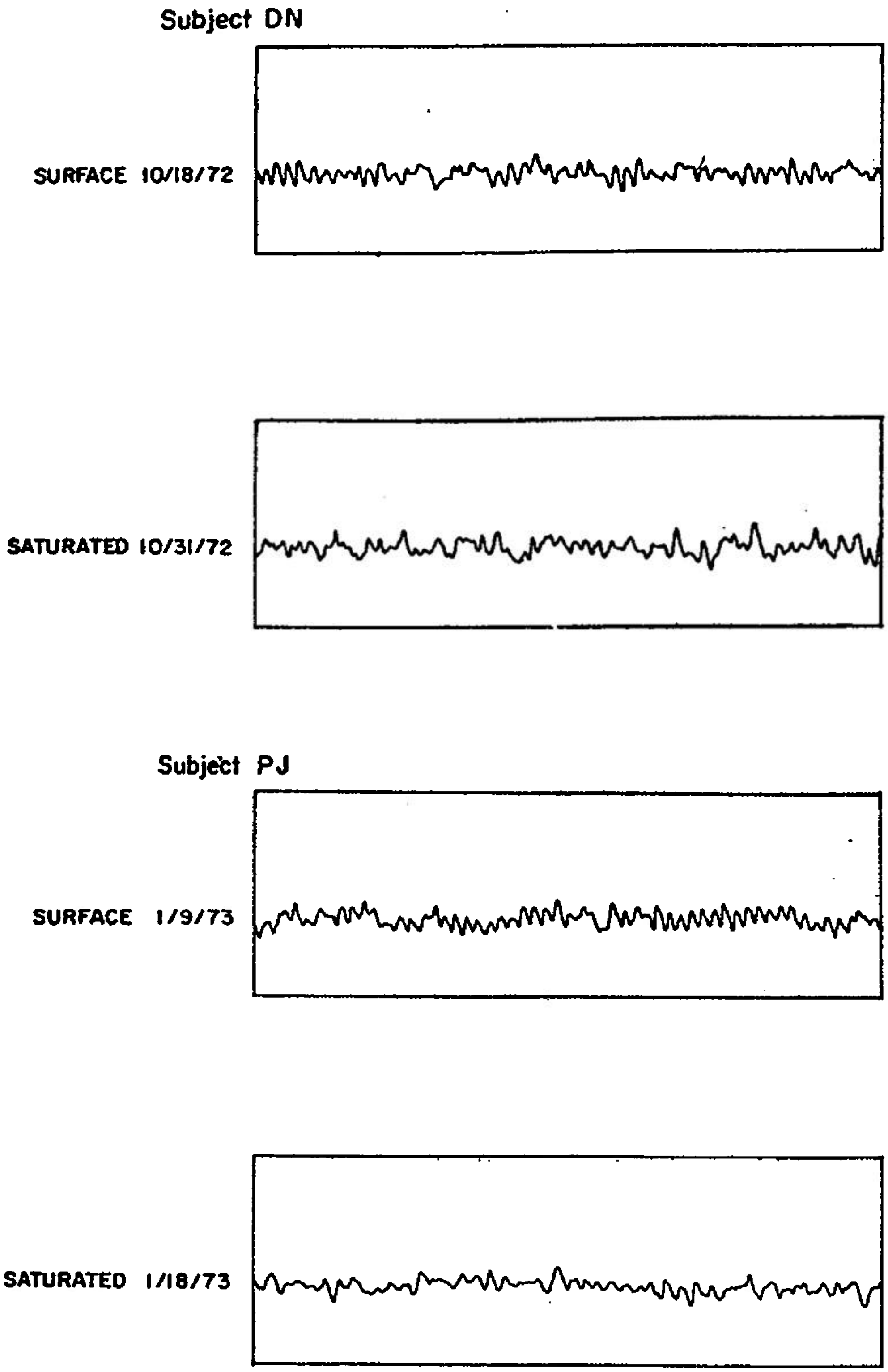

Fig. 4. Sample EEG for two men during surface control runs and during excursion dives from saturated levels.

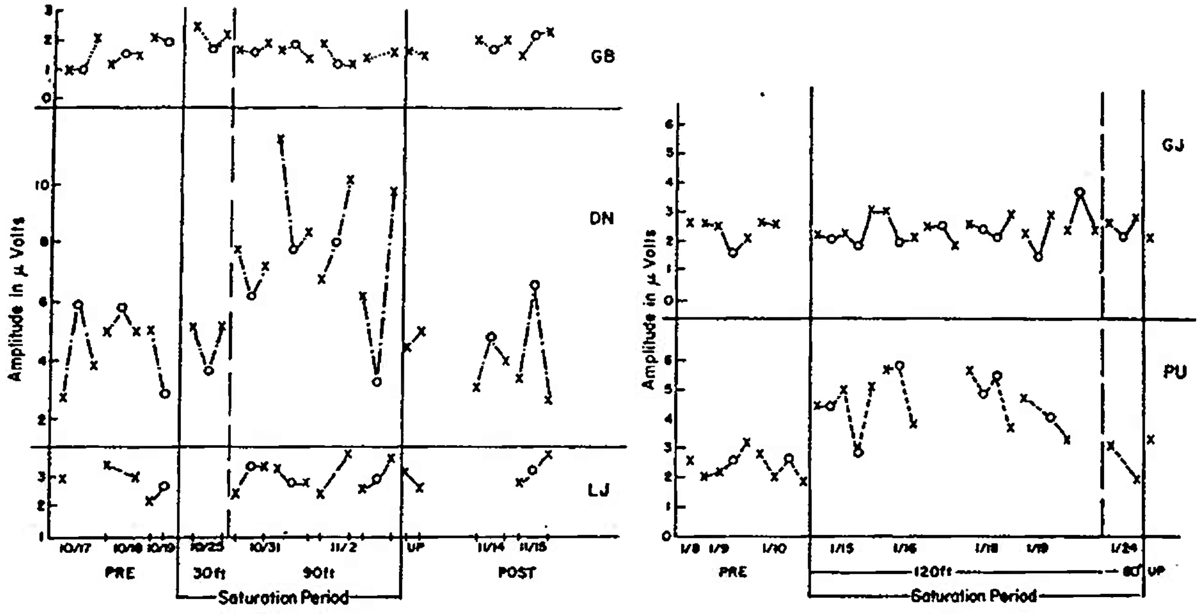

Fig. 5. Amplitude of theta during evoked response to rapid flash rate for five subjects during the course of the experiment.

at all, but others, particularly component N 170, either are greatly reduced or disappear completely.* Sample evoked responses over time for GB are given in Fig. 8; in each case the waveform obtained during a bounce or an excursion dive is compared with responses obtained just prior to and following it. The same decrement in amplitude of component N 170 msec (illustrated in Fig. 7) is found in the bounce dives from the surface to 250 and 150 ft on 10/18 and 10/19, respectively. During the saturation period a gradual change is apparent; the differences between the pre-post waveforms and those taken during the bounce dive disappear. Following the saturation period, there is some evidence of the decrement at depth on the first bounce dive but not on the second. Statistical analysis reveals these effects to be significant: the amplitude of component N-170 is significantly less during bounce dives than at the surface ($\underline{t} = 7.65$, $\underline{p} < .01$) and does not differ significantly on 10/31 and 11/2 ($\underline{t} = 2.18$) in excursions from saturated levels.

Two factors apparently contribute to the disappearance of the difference during the saturation period. First, component N-170 is significantly smaller at 90 ft, throughout the saturation period, than it is at the surface ($\underline{t} = 3.56$, $\underline{p} < .01$). Second, component N-170 during excursion dives from 90

Since the recording is bipolar, 'up' refers to greater negative activity at the inion than at the reference electrode; 'down' refers to greater positive activity. The components are labeled according to the approximate time at which they occur.

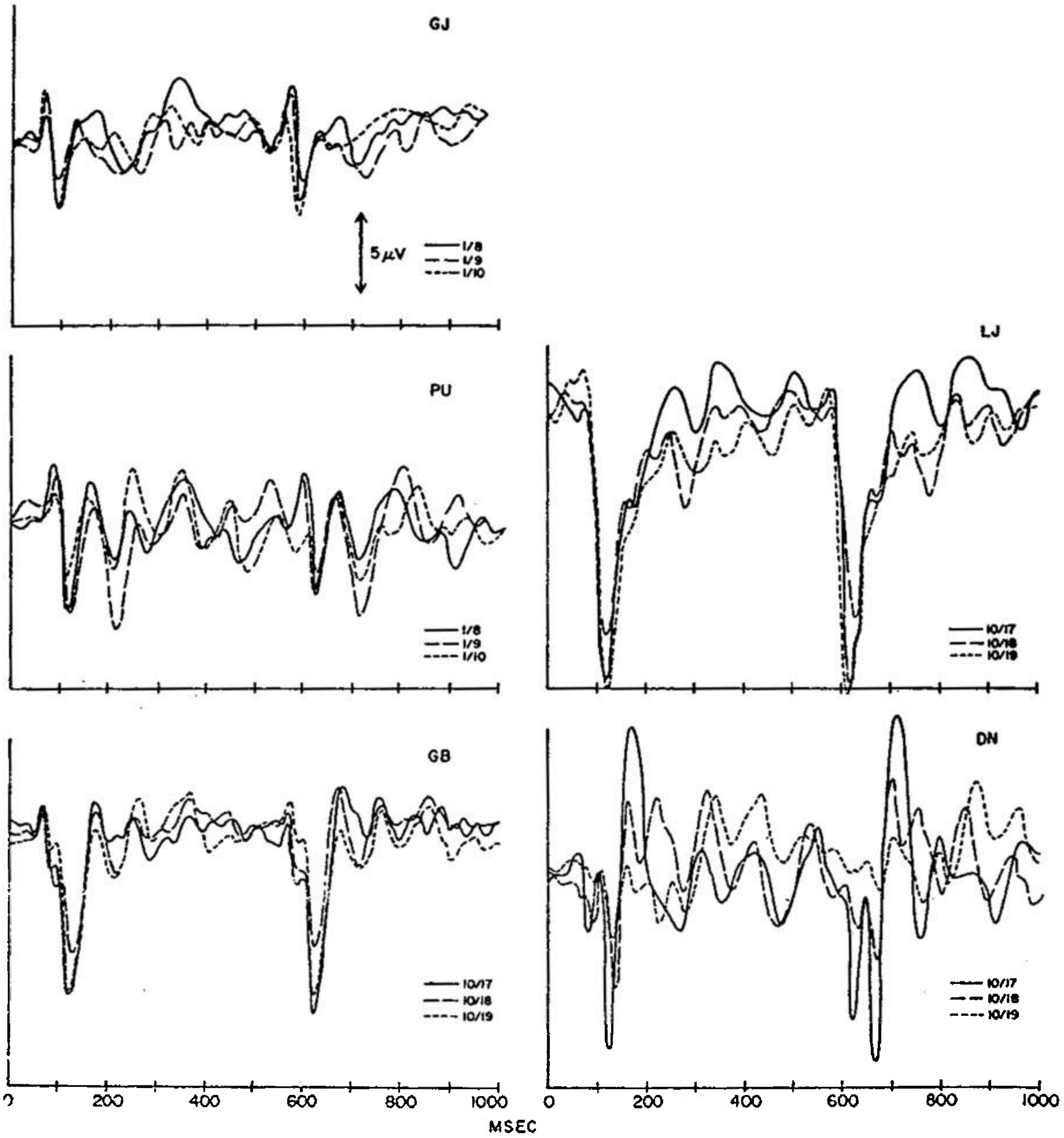

Fig. 6. VERs to the slow flash rate for each of the five subjects at the surface.

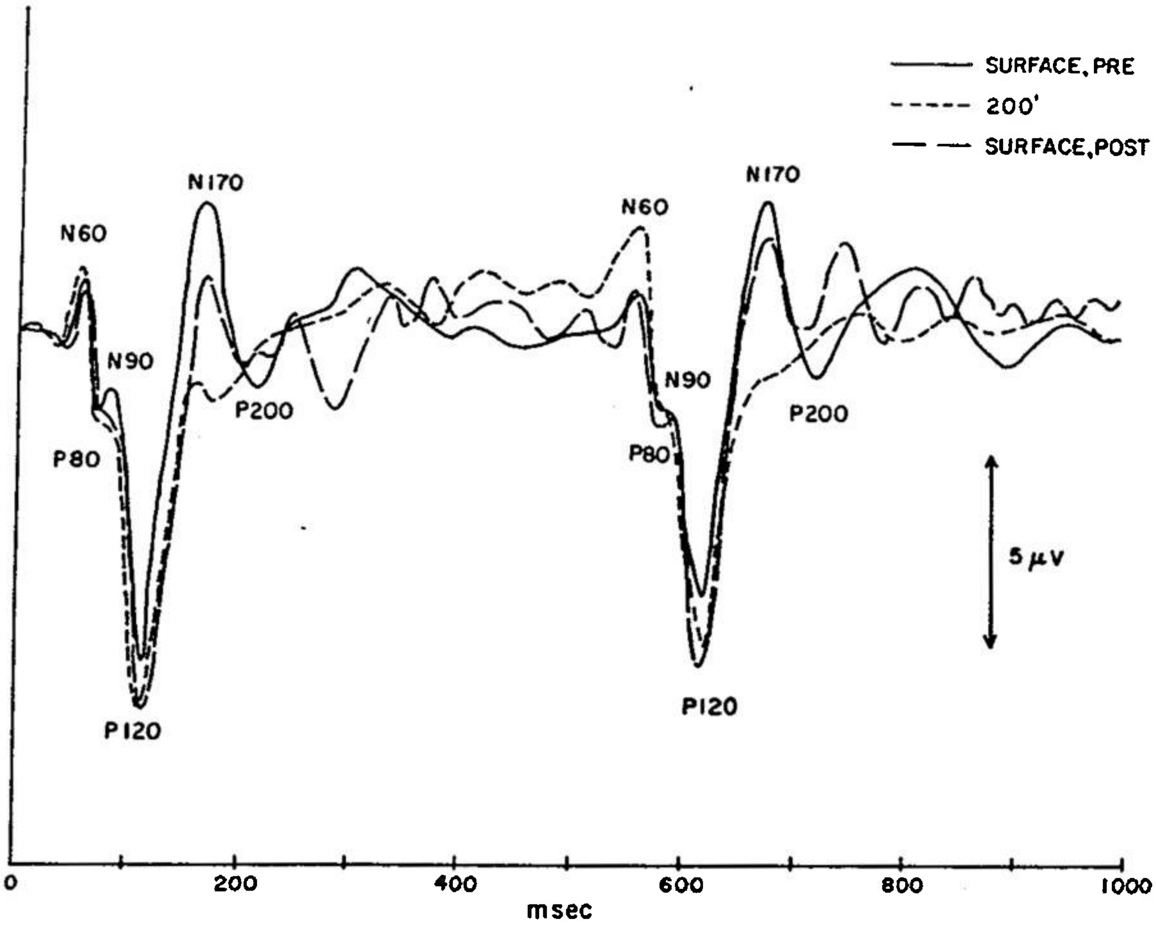

Fig. 7. A comparison of GB's VER at 200 ft with VERs recorded at the surface prior to and following the dive.

ft is significantly more prominent than during bounce dives from the surface ($t = 3.86$, $p < .01$). Thus, there is evidence in the analysis of GB's waveforms of some adaptive process since the differences in waveform originally found are no longer apparent during the second week of saturation.

The same adaptive changes in waveform are evident in the data of most of the other men. LJ's data are particularly clear-cut, even though there are much less data available since he was not a regular subject for the electrophysiological measures. Figure 9, top, shows his evoked responses in his two bounce dives from the surface, one prior to the saturation period and one two weeks following it. The same differences in waveform between the surface and depth are evident in both; at depth, his data show both a decrement in the primary positive response at 120 msec and a large increase in positive activity at 170 msec. The

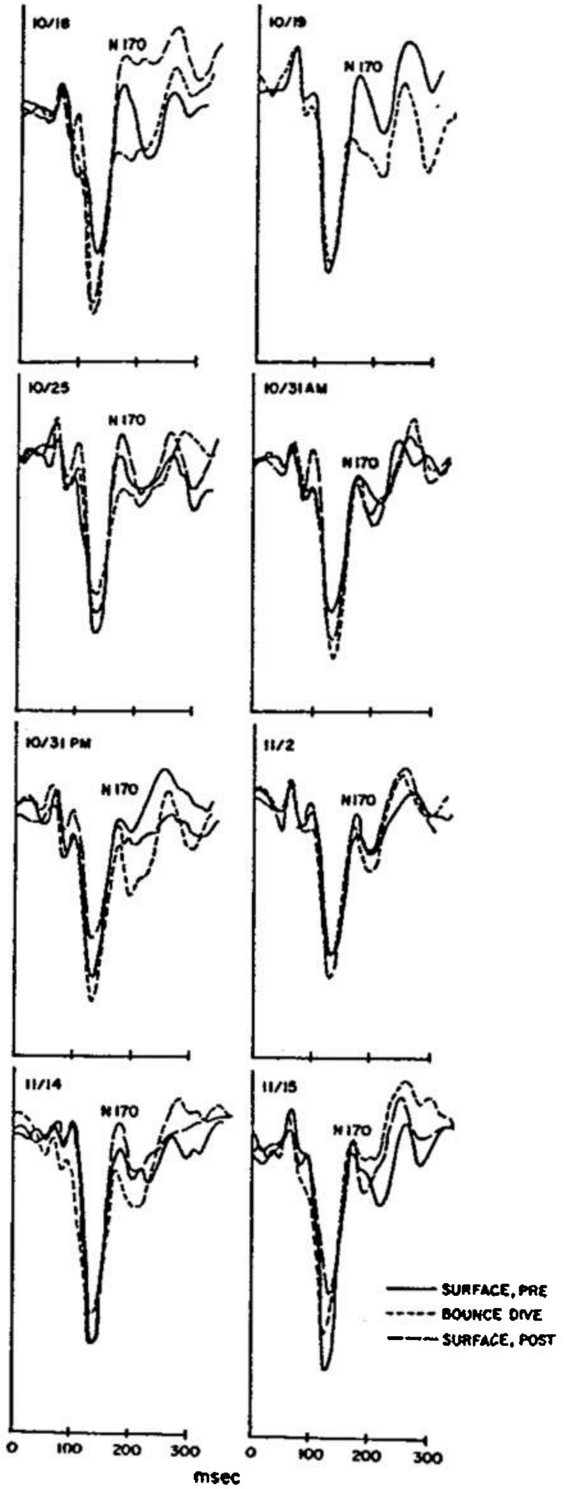

Fig. 8. A chronological comparison of GB's VERs recorded at depth with those prior to and following the dives. Data on 10/25 through 11/2 was collected during the saturation period.

latter is, of course, the same as was seen in GB's data, as a loss of the negative component at 170 msec. Waveforms taken during the second week of the saturation period, Fig. 9 bottom, do not show this difference between the saturated level, 90 ft, and the excursion depth. Furthermore, all the waveforms during saturation are clearly much more like the surface data than the data at depth, once again giving evidence of an adaptive process.

Similar examples are to be found in the waveforms of DN and PU; thus differences in waveform, generally in the amount of negativity around 150 to 200 msec, are found in comparisons of the data at the surface and at depth during the first few bounce dives. These differences disappear gradually and are gone completely after a few days in the saturation period.

In addition to these adaptive changes in the waveform of the visual evoked response, another somewhat unusual change occurred during the saturation period in the waveforms of some of the men. This is illustrated in Fig. 10 which compares the normal waveform, for PJ and GJ, at the surface with sample data obtained at depth. The unusual records consist of synchronized activity in the range of 10 to 11 Hertz. It is quite comparable in appearance to what is usually called the after-discharge*

**The visual evoked response of some individuals contains rhythmic activity which starts after the response to light is fairly well completed, around 300 msec, and continues until the next flash occurs. The VER of other individuals is completely flat during this time interval.*

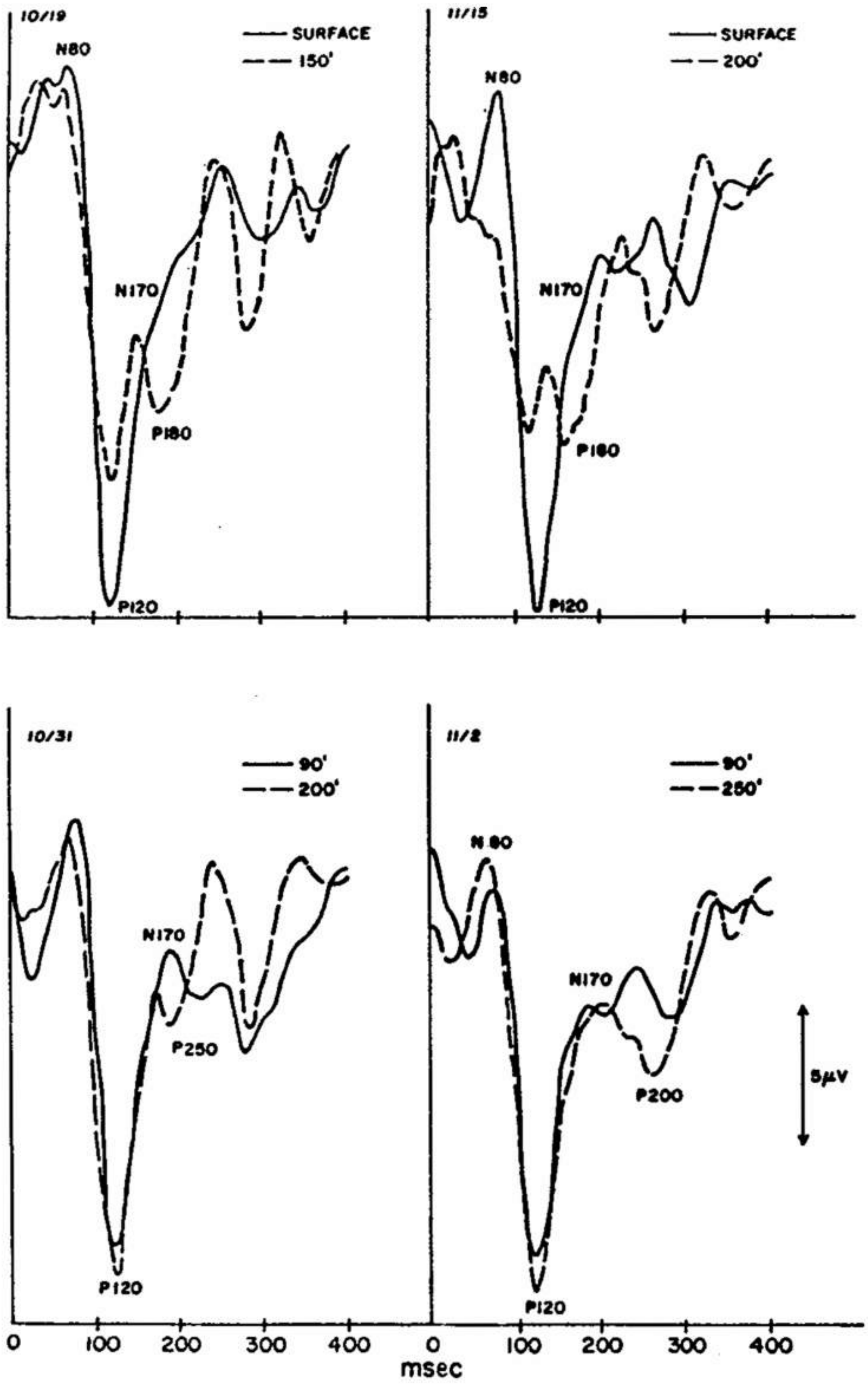

Fig. 9. Comparison of LJ's VERs recorded in dives from surface controls (top) and in excursions from saturated levels (bottom).

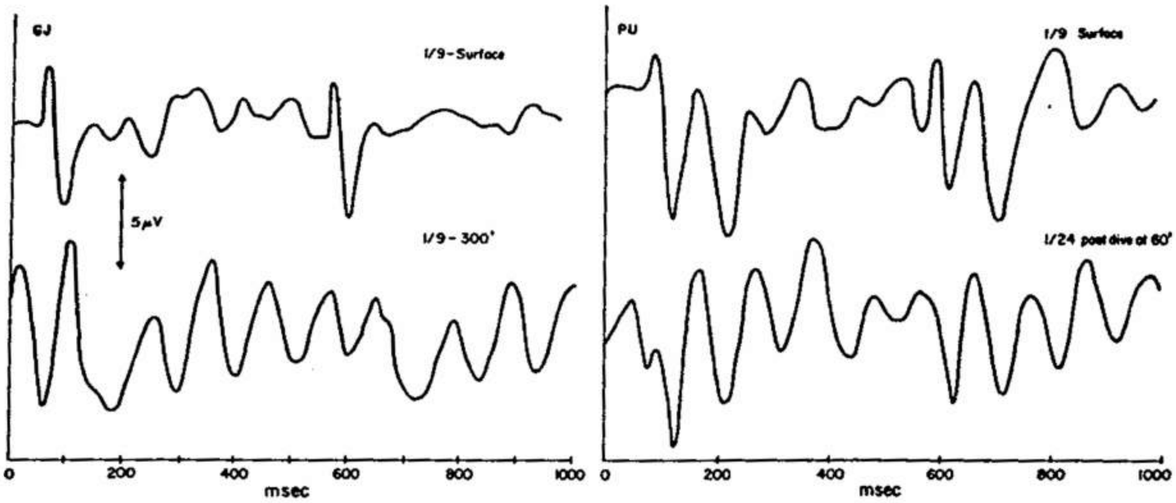

Fig. 10. Sample unusual VER obtained at depth compared to a surface control VER for GJ (left) and PU (right).

but is much more prominent in that the synchronized activity is go great it almost obliterates the response to the light.

These synchronous waveforms were never seen in the responses of GB or LJ. DN had one such record, at 200 ft on 10/25 (an excursion dive from 30 ft). GJ's data included five such records, all during the saturation period; four of the five were on excursion dives to 200, 250, or 300 ft. PU had the largest number; 12 records were almost completely composed of synchronous activity. This type of record was first seen on the third day of bounce dives from the surface, in all the records on that day. After that the synchronized activity was evident in all excursions to deeper depths from saturated levels and in some of the records at saturation as well.

Rapid Flash Rate. Figure 11 gives a sample of the visual evoked response to 16 flashes/sec. Each one second interval contains 16 individual responses. The amplitude of each is measured and a mean and standard deviation of the 16 individual measures is calculated. In addition a Z score, or $\frac{mean}{\sigma}$, is obtained as a measure of the regularity of the 16 responses that is independent of their amplitude. The figure illustrates differences in regularity; although the mean amplitude is quite similar for the two records, the bottom one is much more variable and consequently has a much smaller Z score.

Previous studies have shown two measures of the evoked response to rapid flashes that change significantly with depth. First the amplitude of the response was decreased at depth compared to its magnitude at the surface, and second, the variability of the 16 individual responses was greater at depth than at the surface, prior to the dive.[2,5]

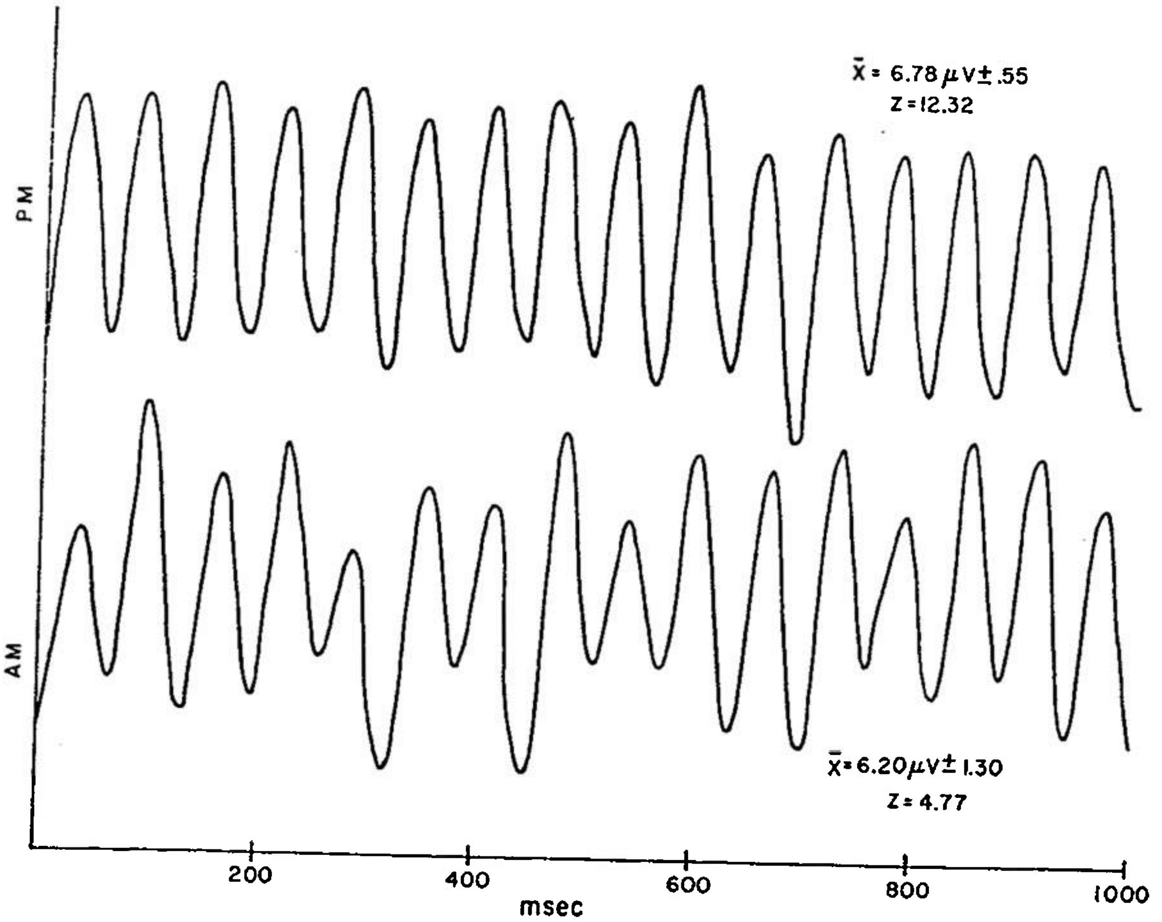

Fig. 11. Sample VERs to rapid flash rate recorded on two occasions for LJ.

Table IV summarizes in the same manner the data obtained during the course of this experiment; the values given are the ratios of measures made during a bounce or an excursion dive to those recorded just prior to it. There is no decrement in mean amplitude of the VER at depth compared to the prior surface run for any of the subjects; the overall ratios of each subject are very close to 1.0. In order to determine whether there was any trend over time, mean data for four different time periods were calculated: (1) bounce dives from the surface prior to the saturation period, (2) and (3) excursion dives from saturated levels during the 1st and 2nd weeks, and (4) post saturation period dives from the surface. These data are also shown in Table IV. Again there were no consistent changes in relative amplitude of response.

Table V gives a similar analysis of the relative Z scores, measured overall and for the same four time periods. Here there is evidence of a change. In their first dives, four of the five subjects show the decrease in regularity of response found previously. This

Table IV. Relative amplitude of evoked responses to rapid flash rate. Data are ratios of dive measures to pre-dive measures.

	GB		DN		LJ		PU		GJ		Mean all Ss
Overall $\bar{X}$	1.00		1.12		0.99		0.98		1.06		1.03
N	9		10		6		7		8		
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	
Pre-saturation period	0.98	3	1.27	3	1.05	1	0.98	2	0.81	1	1.02
Saturation Week 1	0.76	1	1.17	1	-		0.98	5	1.11	5	1.00
Saturation Week 2	1.10	3	1.01	4	1.04	4	-		0.96	2	1.03
Post-saturation period	0.98	2	1.10	2	0.72	1	-		-		-

decrease gradually disappears until week 2, the ratios of all five subjects are 1.0 or over. This indicates of course, that the regularity of the evoked response at depth is as good as it was prior to the excursion and suggests an adaptive process.

In addition to analyzing the amplitude and variability of VERs to rapid flash rates relative to the pre-dive data, assessment of the absolute amplitudes and their variability was also carried out. These measures are given in Table VI, for data collected at the surface, during bounce dives from the surface, during the deeper saturation period (whether 90' or 120') and during excursions from the saturated level. Comparison of amplitudes during bounce dives to those of the surface runs or comparing those during excursions to saturated levels reveals again the same lack of change found in the relative amplitude measures. However, there

Table V. Relative regularity of evoked responses to rapid flash rate. Values are ratios of the Z scores obtained during a dive to those immediately prior to it.

	GB		DN		LJ		PU		GJ		Mean all Ss
Overall $\bar{X}$	0.74		1.02		1.02		1.08		1.31		1.03
N	9		10		6		7		8		
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	
Pre-saturation period	0.57	3	0.92	3	0.73	1	0.85	2	1.34	1	0.88
Saturation Week 1	0.35	1	0.89	1	-		1.15	5	1.30	5	0.92
Saturation Week 2	1.02	3	1.12	4	1.20	4	-		1.35	2	1.17
Post-saturation period	0.78	2	1.02	2	1.02	1	-		-		-

is a distinct difference between absolute amplitudes while saturated from those on the surface. Analysis of variance reveals a significant interaction; the data for GB and DN are significantly poorer while saturated than while on the surface.

Table VII gives a similar analysis for the Z scores during the various dive conditions. Z scores during bounce dives are lower than they are on the surface for four of the five divers; this is the same phenomenon as was found in the relative measures. However the excursion values are not poorer than those during saturation runs; the basis of the adaptive trend in Table V appears to be reduced regularity of the saturated runs (compared to the surface) with no further decrement encountered at greater depths.

The Z scores during the saturation period were further analyzed for trends over time. These results are shown in Fig. 12. There is a consistent decrease in regularity during the course of the saturation period; values

Table VI. Absolute amplitude, in μvolts, of VERs to rapid flash rate during different dive conditions

S	Surface		Bounce		Saturation			Excursion		Week
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	depth	$\bar{X}$	N	
GB	4.54	11	4.50	5	3.05	8	90'	3.71	3	2
DN	6.05	11	7.05	5	3.51	8	90'	2.96	4	2
LJ	6.49	8	6.01	2	5.81	7	90'	6.32	4	2
PU	3.49	8	3.93	2	3.92	7	120'	3.44	5	1
GJ	3.93	7	2.94	1	4.90	7	120'	5.43	5	1
Mean all <u>S</u>s	4.90		4.89		4.24			4.37		

Table VII. Regularity of VERs to rapid flash rate during different portions of the dive. Values given are the mean Z score based on N measures.

S	Surface		Bounce		Saturation			Excursion		Week
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	depth	$\bar{X}$	N	
GB	9.37	11	6.32	5	6.66	8	90'	7.60	3	2
DN	5.03	11	4.51	5	2.68	8	90'	2.42	4	2
LJ	8.38	8	6.63	2	5.92	7	90'	8.22	4	2
PU	4.52	8	4.46	2	2.52	7	120'	2.90	5	1
GJ	4.18	7	6.02	1	4.70	7	120'	5.35	5	1
Mean all <u>S</u>s	6.30		5.59		4.50			5.30		

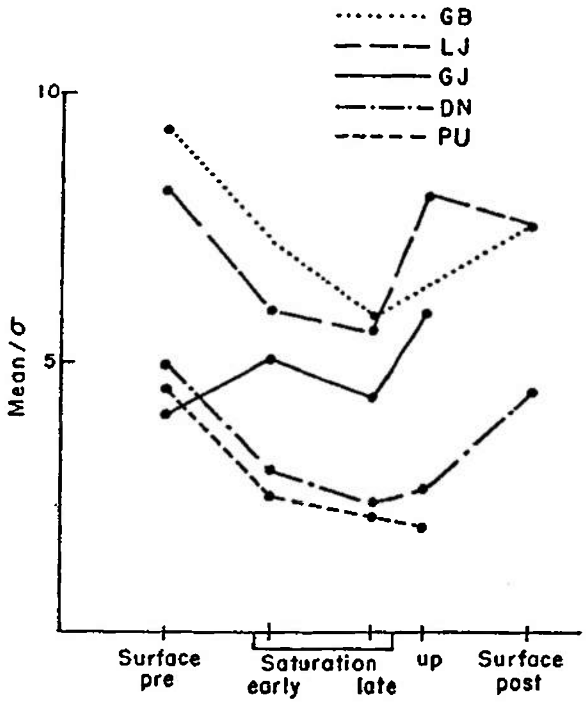

Fig. 12. Variability of the VER to rapid flash rate as a function of time in saturation.

revert toward their surface level following saturation.

Relation Between EEG and VERs

Evoked response to rapid flash rate. Since EEGs were recorded while the visual evoked responses were being measured, data on a variety of interrelations between the two are possible. Table VIII summarizes these comparisons for the response evoked by the rapid flash rate. There is generally good agreement between the amplitude of the evoked response and the amplitude at 16 Hertz in the EEG, as determined by the frequency analysis. Several measures attest to this: (1) the amplitude measures in microvolts are in good agreement; (2) the correlations* are generally high, and (3) the amplitude at 16 Hz in the EEG show the same lack of significant changes with depth or time that were found in the VER 16 measures discussed in the preceeding section.

Table VIII also gives the results of other measures of the EEG, determined by the frequency analysis, for the time period while the evoked response was being recorded. Amplitudes of peaks in both the alpha and theta frequencies were measured for each of the runs. Alpha amplitudes are, of course, considerably reduced from what they are in the eyes closed condition (Tables II and III), except for GB, and theta levels are of the same general order of magnitude as they are in the eyes closed condition. Correlations between the evoked response and amplitude of alpha and of theta are small and rarely significant. Correlations with alpha are generally negative; that is, as the evoked response increased in size the amount of alpha decreased; there were no general trends for the amplitude of theta.

Evoked response to slow flash rate. It is more difficult to determine the relation between EEG measures and the response evoked by the slow rate of stimulation since the VER is a complex waveform with many components for

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**All correlations discussed in this section were determined for data points from each of the individual runs, including the measures made prior to, during, and following each bounce or excursion dive; this results in 20 to 30 pairs per man.*

Table VIII. Relation between visual evoked response (rapid flash rate) and frequency analysis of EEG.

Diver	Amplitude of VER (µv)	Amplitude of EEG at 16 hz (µv)	r
GB	3.93	3.20	.74**
DN	4.92	4.68	.70**
LJ	6.18	5.52	.64**
PU	3.77	2.22	.33
GJ	4.78	2.34	.27

	Alpha amplitude (µv)	r with VER	Theta amplitude (µv)	r with VER
GB	1.62	-.36	1.70	-.06
DN	6.58	-.30	5.72	-.31
LJ	3.70	-.12	2.58	+.05
PU	4.40	+.25	3.62	+.40*
GJ	4.27	-.17	2.38	-.22

* $p<.05$
** $p<.01$

comparison. However, the largest component in the VER waveform was chosen to compare with the amplitude at two Hertz in the EEG on the reasoning that, being largest, it should contribute most to the response at two Hertz in the EEG. This component, P 120 msec, is very prominent in the evoked response of three of the subjects (GB, LJ and DN). Correlations between the amplitude of this major component and the amplitude at two Hertz in the frequency analysis of the EEG were very small. They were +.37 for GB, +.15 for LJ, and -.01 for DN.* Nor were there any significant correlations between the amplitude of alpha or theta and the amplitude at 2 Hz in the EEG. Part of the explanation for this lack of correspondence is the fact that movement artifacts occur in the one to three Hertz range of the frequency analysis and obscure the purely visual response to the stimulus.

DISCUSSION

The major question asked in this investigation was whether or not there is evidence of adaptation to narcosis in the visual evoked response during long-term saturation diving. An affirmative answer emerges from the consistent waveform changes in specific components of the evoked response to slow flash rates. A comparison of evoked responses recorded at the surface with those at depth (150, 200, or 250 ft) showed a specific component to be either greatly reduced or missing completely during the first two or three bounce dives from the surface. This same change has been found in other bounce dives to 200 ft or more for divers breathing air. During the saturation period, however, the missing component gradually re-emerged until, during later records, there was no difference between evoked responses measured prior to, during, and following each excursion dive. This change is apparently one of true adaptation, rather than a simple reduction of the difference in depth; it is manifest originally at the 150 ft bounce dives from the surface, but not during the saturation period during a 160 ft increase in depth (the excursion dives from 90 ft to 250 ft.

Some additional evidence of adaptation is found in another measure of narcosis, the regularity of the VER to rapid flash rates. The original bounce dives from the surface produced the normal increase in variability that has been found previously. During the saturation period, there was no increase in variability during excursion dives from the saturated level; increases would be expected if no adaptation occurred.

Our previous research has shown three different measures of the evoked response to be correlated with depth for divers breathing air or nitrogen-oxygen mixtures. These were the changes in components of the VER to slow flash rates, a reduction in amplitude of the VER to rapid flash rates, and an increase in variability of the latter.[2,5,18] In this study changes

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**The data for PU and GJ were not analyzed because the unusual synchronized waveforms discussed previously made it impossible to find the major component in many VERs.*

were found in the original bounce dives from the surface in only two of these measures; furthermore, the size of the decrement in variability was not nearly as large as found previously for similar partial pressures of nitrogen. The reasons for the lesser effects in the study are unknown but may be due simply to the fact that the subjects were highly experienced divers before beginning the study and had already achieved considerable adaptation.

However, there is evidence in all three measures of the VER that despite considerable experience, adaptation is not complete. Comparison of data collected during the saturation period, even at the end, with surface controls reveals decrements: component N-170 was significantly reduced from its surface level; the amplitude of the response to the rapid flash rate was significantly smaller for two men, while saturated; and the variability was significantly greater for four of the men, even at the end of the saturation period. The evidence thus indicates that adaptation of gross deficits occurs, but that minor decrements persist, even at the relatively shallow saturation depths.

Perhaps the most consistent finding in the entire investigation was the reduction in alpha amplitude and frequency, under the eyes closed condition, during the course of the saturation period. Such changes are unusual for normal conditions,[17,19] but have been reported previously in saturation dives.[20-22] The cause of the reduction is difficult to ascribe; possible factors are the confinement, the pressure, or the breathing mixture. Similar reductions in amplitude and frequency of alpha are commonly reported in sensory deprivation experiments[23-25] in which confinement is obviously a factor. However, one study in which the conditions of confinement were varied showed that reduction of sensory stimulation was essential to the decrement; simply having the subjects recline for a 7 day period did not result in a change of alpha frequency.[24] There is some indication in the data that the phenomenon is related to depth in that the largest changes tended to appear at the deeper saturation level regardless of whether it occurred during the first or second week.

In addition to the changes in alpha, another sizeable difference in the EEGs was found in the amount of theta activity in two of the men. Increases in theta are commonly found together with reductions in alpha amplitude and frequency and are generally considered manifestations of a depression of cerebral activity. While they may indicate only drowsiness, alpha reductions and theta increases are also common symptoms of a number of abnormal occurrences, such as reduction of CO_2 tension in the blood, a low blood glucose level, anoxia, and hyperventilation.[18] The etiology of the EEG changes in this saturation dive are unknown and will be the object of further study; even if they represent only an increased level of drowsiness, the question of why this should occur during the dive needs an answer.

Another question deserving further investigation is the origin of the unusual visual evoked responses which appeared in the data of three of the five subjects at irregular intervals. These VERs to the slow flash rate consisted almost entirely of rhythmic activity in the 9-11 Hz range. The activity is similar in appearance to the after-discharge found in some subjects but is much more prominent, almost completely obliterating the response to the flash. Unfortunately the origin of the after-discharge is itself unknown.[26-28] While prominent after-discharges are found in subjects with high amplitudes of alpha and are of the same general frequency,[29] a number of investigations indicate that the after-discharge cannot be viewed simply as synchronized alpha activity.[29-32] Similarly, in this study, attempts to link the unusual VERs to alpha, or to theta, were unsuccessful; that is, analysis of the EEG recorded during the time period that the VER was being recorded did not indicate exceptionally high alpha or theta.

The possibility exists that the unusual waveforms might be related to high partial pressures of oxygen, since the vast majority occurred during excursion dives or immediately following them. Similar synchronous activity has been found in a saturated dive employing implanted rats who breathed oxygen at higher partial pressures than air.[33]

SUMMARY

Analysis of the EEGs of the diver subjects during the course of the two week saturation period at depth revealed two changes. First the frequency and the amplitude of alpha activity was reduced when compared to surface measures made prior to and following the saturation period. Second the amplitude of theta activity rose considerably for two of the men; there was no change in theta for the other three during the same time period.

Several measures of VER were made both during excursion dives, and prior to, and following them, at saturated levels. Progressive changes in some components of the VER to the slow flash rate during the repeated excursions gave evidence of adaptation. Similar results were found in a progressive increase over time in the regularity of the VER to rapid flash rates. The adaptation was not complete, however, since the data at the end of the saturation period did not return completely to the levels measured at the surface.

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13. ABSTRACT

Visual evoked responses (VERs) and electroencephalograms (EEGs) were recorded during the course of a long-term, shallow, nitrogen/oxygen saturation dive. Measures were made during excursion dives and at the saturation level prior to and following each excursion. Comparison with a control series, in which bounce dives were made from the surface, revealed that some adaptive changes took place in the VER; complete adaptation however did not occur. Reduction in frequency and amplitude of alpha, in the EEG, also was found during the course of the saturation period.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
adaptation to nitrogen narcosis						
visual evoked response and EEG						
hyperbaric effects						