

ELECTROENCEPHALOGRAPHIC CHANGES DURING SATURATION EXCURSION
DIVES TO A SIMULATED SEAWATER DEPTH TO 1000 FEET

by

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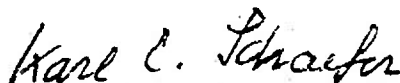
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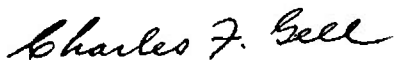
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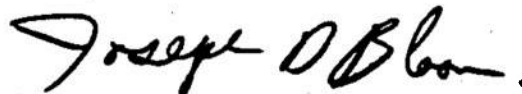
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SUMMARY PAGE

THE PROBLEM

To determine electroencephalographic changes during saturation excursion diving to a simulated water depth of 1000 feet.

FINDINGS

EEG records were obtained in two subjects during saturation excursion dives to 1000 ft depth. Subsequent computer analysis produced the following findings: During the compression to saturation depth of 800 feet at a rate of 3.5 feet per minute, similar EEG changes were observed in both subjects, consisting of: (1) lowering of the mean frequency, (2) decreasing the percentage of fast waves (theta activity), (3) increasing the percentage of 6 - 8 Hz waves (theta activity).

During the subsequent saturation period at 800 ft, the EEG changes observed during the compression to 800 ft were reversed within 14 hours in subject C. D., and 18 hours in subject D. F. It was concluded that the EEG changes found during the compression phase represent a compression syndrome and were produced by the rate change in pressure, rather than by the pressure of helium per se.

Toward the end of the 36 - hour saturation period at 800 ft and the subsequent decompression period subject C. D. exhibited a consistent decrease in mean frequency and an increase in percent of 6 - 8 Hz Frequency (theta activity) which appeared to be correlated with an increase in CO₂ activity excretion in the urine and a decrease in alveolar CO₂ tension. These findings were interpreted as being caused by hyperventilation rather than by the effects of pressure per se.

Inhalation of nitrogen - oxygen mixtures (3.5 atm N₂, 1.4 atm O₂) at different depth levels during decompression produced in both subjects symptoms of narcosis, performance deterioration and EEG changes (shifts to lower frequency ranges or predominance of low frequency bands) at the lower depth level.

APPLICATION

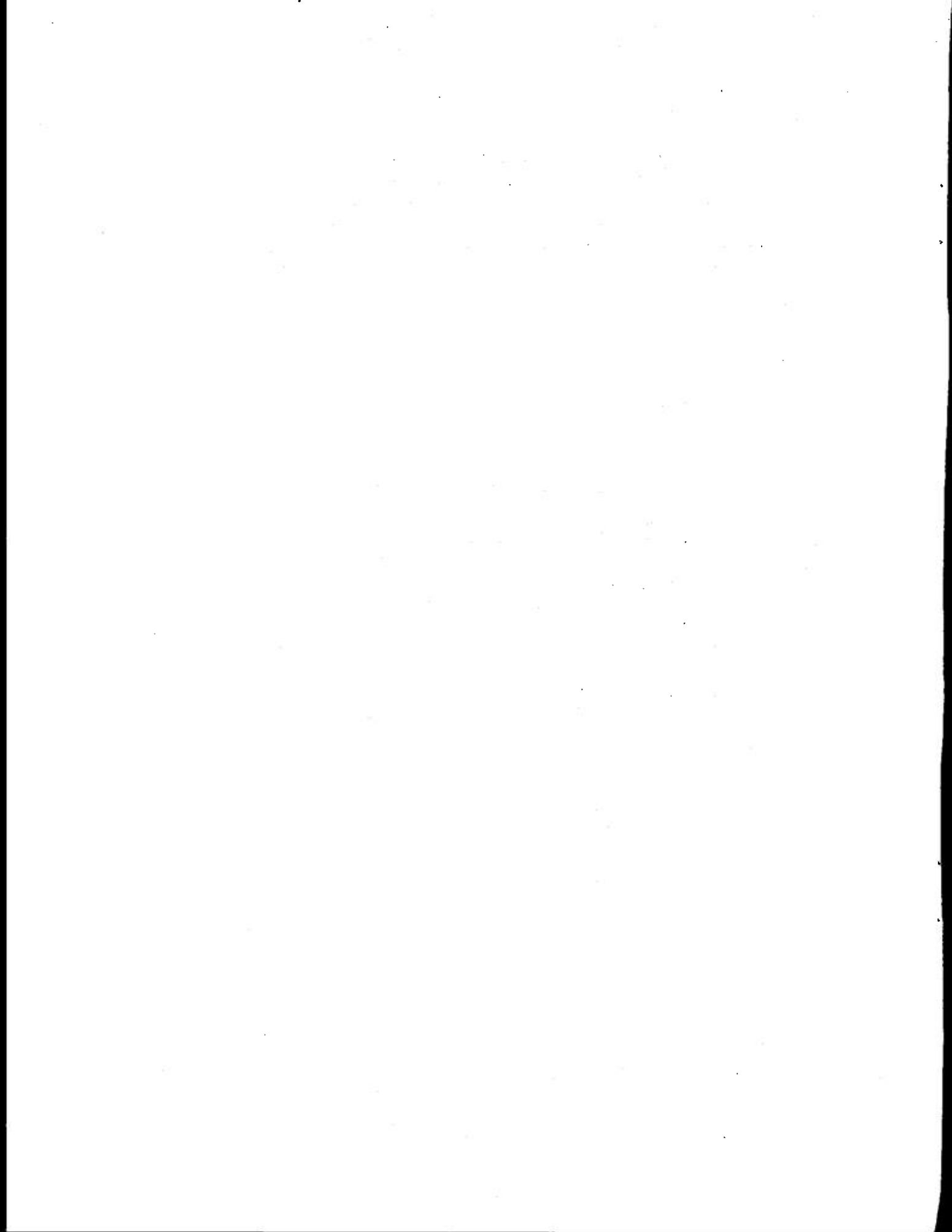
These findings are important for submarine and diving medical officers, scientists and others who are concerned with the safety and well being of personnel in diving operations. Results indicate that the compression rate during deep dives has to be kept below 3.5 feet per minute to avoid occurrence of symptoms or EEG changes produced by compression.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MR005.01.01-0063BOKL -- Physiological Effects of Excursions Dives from the Gas -- saturated State at Depths. The present report is No. 6 on this work unit. It was approved for publication on 11 November 1971 and is designated as Naval Submarine Medical Research Laboratory Report No. 687.

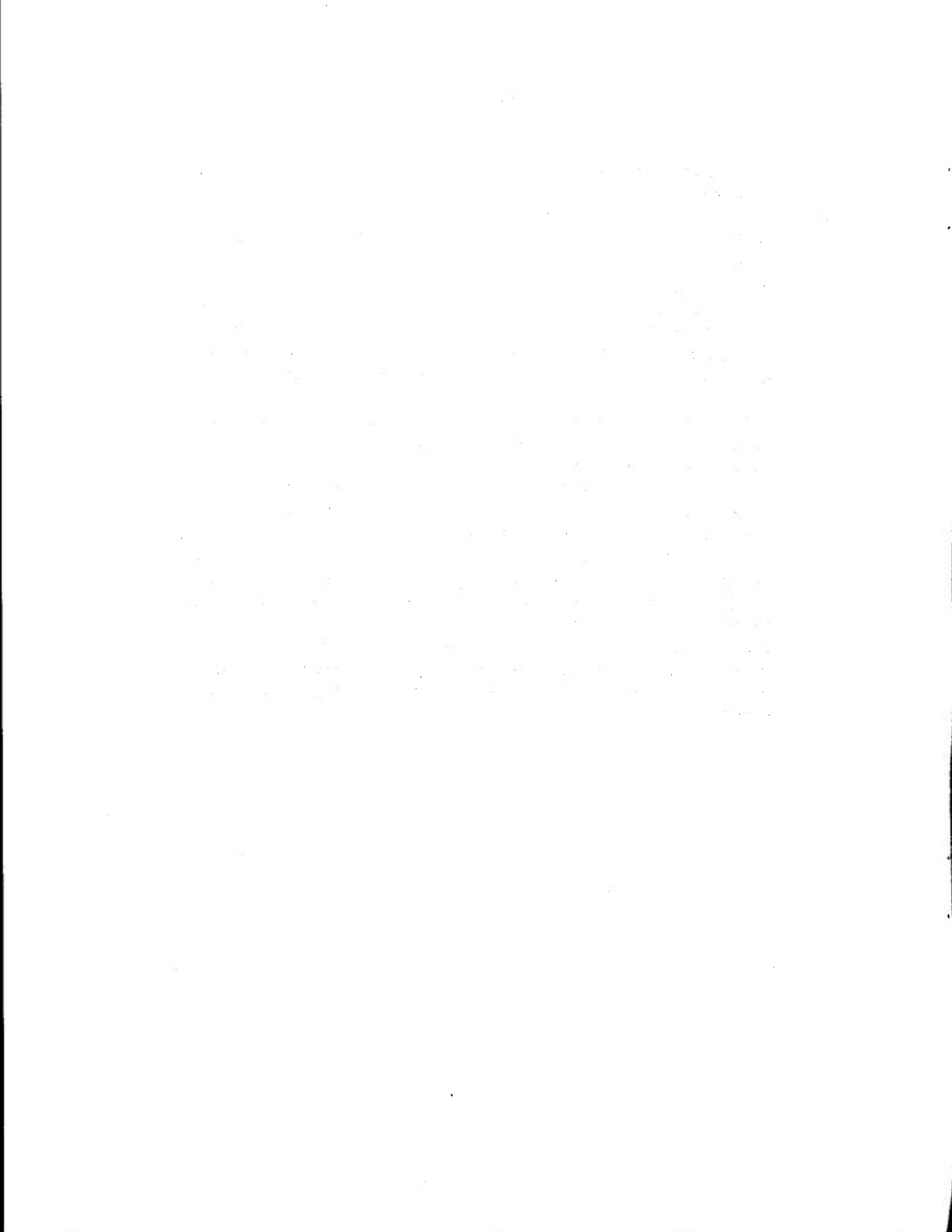
This study was carried out jointly with Drs. Proctor and Lee and Mr. van den Ende of the Edsel B. Ford Institute, Detroit.

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ABSTRACT

EEG records were obtained in two subjects during saturation excursion dives to 1000 feet in depth. Computer analysis produced the following findings. During the compression to saturation depth of 800 ft. at a rate of 3.5 ft per min., similar EEG changes were observed in both subjects; these consisted of: (1) lowering of the mean frequency, (2) decrease in the percentage of fast waves (18-50 Hz), (3) increase in the percentage of 6-8 Hz waves (theta activity). During the subsequent saturation period at 800 ft, the EEG changes observed during the compression to 800 ft were reversed within 14 hours in subject C. D., and 18 hours in subject D. F., which indicated that the EEG changes found during the compression phase represent a compression syndrome. During the latter part of the 36-hour saturation period at 800 ft, and the subsequent decompression period, subject C. D. exhibited a consistent decrease in mean frequency and an increase in percent of 6-8 Hz frequency (theta activity) which appeared to be correlated with an increase in CO₂ excretion in the urine and a decrease in alveolar CO₂ tension, suggesting a hyperventilation effect. Inhalation of nitrogen-oxygen mixtures (3.5 Atm N₂, 1.4 Atm O₂) at different depth levels during compression produced in both subjects symptoms of narcosis, performance deterioration and EEG changes (shifts to lower frequency ranges or predominance of low frequency bands) at the lower depth level. At greater depth levels, no symptoms of narcosis or performance changes were observed, but slight changes in the EEG occurred.



ELECTROENCEPHALOGRAPHIC CHANGES DURING SATURATION EXCURSION DIVES TO A SIMULATED SEAWATER DEPTH OF 1000 FEET

INTRODUCTION

Very few systematic investigations of the electroencephalogram (EEG) during saturation-excursion dives have been carried out. There are obviously great difficulties in obtaining good EEG records during extended simulated dives in chambers. This report deals with electroencephalographic studies performed during saturation excursion dives to pressures equivalent to 1000 feet of seawater (FSW) in conjunction with studies of lung functions, pulmonary gas exchange, and urinary electrolyte excretion, details of which were previously published (Dougherty and Schaefer, 1969,⁶ and Schaefer, Carey and Dougherty, 1970).¹⁴

MATERIAL AND METHODS

Two divers carried out a saturation dive to 800 FSW. The compression rate was 3.5 ft/min. Subject D. F. made a 30-minute excursion dive to 1,050 FSW, and Subject C. D., a 5-minute excursion dive to 1,112 FSW. Both divers later spent 2.75 hours at 1,000 feet. Their total time under pressure was 13 days.

The decompression schedules were developed by Mr. Andre Galerne, President of International Underwater Contractor's Inc. (IUC). The oxygen tensions varied from 300 to 450 mm. Hg. During decompression following the dives, the subjects breathed a special gas mixture (3.5 Atm N₂, 1.4 Atm

O₂, balance Helium) through a respiratory mask for 10 minutes at every 100-foot level starting at 600 feet. During the last 50 feet of decompression, however, 100% O₂ was inhaled by mask, alternating with 21% O₂ in N₂ every 20 minutes (P_{O₂} = 760 to 1,912 mm. Hg).

The life support system, developed by AIRCO, (Halfon, A., 1968),⁸ during both dives provided accurate environmental control. The ambient CO₂ pressure was kept under 2 mm. Hg at all times during the dives.

Studies of pulmonary function tests, a pulmonary gas exchange and urinary electrolyte excretion performed on the two subjects during the dive have been reported elsewhere (Dougherty, J. H. Jr., 1969⁶ and Schaefer, K. E. *et al.*, 1970).¹⁴

EKG and EEG were recorded on a polygraph located outside the chamber while the divers rested and exercised. A specially designed skullcap was employed in obtaining the EEGs. The divers learned quickly to use the skullcap efficiently. Leads from the subjects through the chamber did not exceed a length of 2 meters. They were connected to Tektronix Preamplifiers (Model 122) placed outside in the chamber wall near the penetration. From the amplifiers another cable about 3 meters in length led to the Grass Polygraph and to an Ampex Tape recorder (Model SP-300). With this procedure, good EEG records were obtained throughout the dive.

Four channels of EEG were recorded for each of the two subjects. Most sessions were 6.0 minutes long and consisted of alternating 1.2 minute periods with eyes-open and eyes-closed (usually starting with eyes-open). Several sessions also included periods of exercise (and recovery from exercise) and during additional sessions the subject breathed a gas mixture of 3.5 Atm N₂, 1.4 Atm O₂, balance Helium.

Although all four channels were analyzed, channels three and four had the least amount of artifact (60-cycle noise, muscle potential, etc.), and most of the results discussed were obtained from these channels. About two-fifths of the total EEG recorded was converted to digital form and was analyzed by a pattern-recognition program termed, the symmetry-decision method. In most cases the second and third (eyes-closed and eyes-open) 1.2 minute periods for a session were chosen for analysis. Larger samples were taken for the control sessions (one-atmosphere pressure) and for the exercise, recovery, and gas mixture recordings.

The analog to digital conversion was performed at a rate of 200 samples per second and with the resolution of 6 bits. A capacitive coupling was used to eliminate slow changes (of the order of two seconds or more) in the signal voltage. Amplifiers used for each channel were adjusted so that the maximum amplitude for that channel covered the range of the A-to-D converter.

Method of EEG Analysis

A computer technique, called the symmetry-decision method, was de-

veloped by one of the authors (Lee, 1971) to analyze the EEG recorded during the experiment. It was designed to simulate the classification of the EEG which is performed by an electroencephalographer, but with far greater speed and precision. The following is a brief description of the method.

If we consider a digitized EEG (the result of an analog-to-digital conversion), the first step in the analysis is the identification of maxima and minima in the signal. Maxima are defined by a series of three points, the middle of which is greater than the other two, and for minima, the middle point is less than the other two. The fundamental unit for the analysis is the "peak wave" which consists of all the points between two successive minima.

The basic process used in the analysis is the classification of peak waves according to amplitude and duration. The amplitude of a peak wave is the vertical distance between its highest point of the average of its end points (the two successive minima), and the duration is the time between its end points. For ease in interpretation, we usually use the term "frequency" instead of duration for describing peak waves. A wave is said to belong to a certain frequency category if the reciprocal of its duration falls within the limits of that category.

There is one additional aspect of the analysis: the distinction between "simple" and "composite" waves. It is well known that in the EEG signal, waves of different frequency may be present simultaneously. Fast waves are superimposed on slow waves. A simple wave

is a peak wave which appears symmetrical, like a sine wave. A composite wave is a long duration (slow) wave with a superimposed higher frequency signal. It is a series of two or more peak waves which by their shape form an overall larger wave. The exact criteria for distinguishing between the two types of waves are based upon symmetry considerations. For example, a very asymmetrical peak wave which rises abruptly forms the beginning of a composite wave.

Summary variables for EEG analysis.

We have described a method by which an EEG signal is analyzed into simple and composite waves, and each wave is classified according to amplitude and frequency categories. With respect to amplitude, since a 6-bit conversion was made, a scale of 1 to 64 was obtained. In order to better discriminate the smaller waves (which constituted the majority of the signal) an exponential set of categories was used. These were 0-4, 5-17, 18-39, and 40-64. The frequency categories were 0-1.99, 2-3.99, 4-5.99, ... 16-17.99 and 18 Hz or more.

The following variables were used in the final summaries:

1. Percentage of time in which the signal was composed of alpha waves (8-11.99 Hz).
2. Percentage of time for simple-wave alpha waves.
3. Percentage of time for composite-wave alpha waves.

4. Percentage of time for composite-waves (for all frequencies).
5. The mean frequency (weighted by time) for all frequencies.
6. Percentages of waves (by time) in the two higher amplitude categories.
7. Percentages of waves (by time) in the highest amplitude category.
8. The mean frequency weighted by time for waves in the alpha range.
- 9-18. Percentage of waves (by time in each of the 10 frequency categories).

RESULTS

Vital statistics and diving experience of the two subjects participating in the saturation excursion dives are presented in Table I. They were healthy experienced divers, highly motivated and very cooperative.

To facilitate the interpretation of the data a short report of the subjective experiences of the dives is given below.

The divers descended to 800 FSW over a four-hour period with stops at 200, 400 and 600 FSW for tests. During the compression, diver C. D. stood motionless for about one half hour intently watching the depth gauge. He had placed one foot forward on a chair. After half an hour he suddenly experienced an intense pain in the buttocks, which diminished somewhat during the next few hours and disappeared the next morning after a night's sleep. These

Table I. Vital Statistics and Diving Experience of Subjects.

Subject	Height	Weight (lbs.)	Age (Year)	Previous Diving Experience
C.D.	5' 11"	155	29	5 years' experience as a SCUBA diver. No definite history of decompression sickness.
D.F.	5' 10"	180	25	6 years' experience as a SCUBA diver. Graduated from Navy Underwater Swimmer School. Had previously some "skin bends". No definite history of decompression sickness.

symptoms were interpreted as signs of a mechanical interference with normal circulation. Both divers also noted a "looseness of joints" and a restriction of movements. During the exercise test at 1000 FSW, C.D. had the curious sensation in his left ankle that the joint moved a little bit in the socket. He stopped pedalling for a moment, shook the foot a few times, had some pain, then the joint felt all right. After he had pedalled for another 4-5 minutes, the sensation came back. He repeated the same maneuver, shaking his foot, and the joint seemed to come back into a normal position.

The two excursion dives from 800 to 1112 FSW by C.D. and 825 to 1050 FSW by D.F. were carried out at compression rates of 27 and 28 FSW/minute, respectively. Both subjects experienced weakness and slight tremors in both knees and thighs throughout the whole excursion dive until they returned to the

saturation level of 800 FSW. One of the divers reported a strong feeling of tension in the thigh muscles and rapid tremor. He also reported a slight tremor of the hand. Another excursion dive from 800 to 1000 FSW carried out by both divers, at the same time, at a compression rate of 17 feet/minute, a day later, did not produce any symptoms of tremor.

During the beginning of the decompression period at 669 FSW, C.D. complained about increasing pain in both knees. He related later that he had slept in a cramped position with his legs crossed. Following recompression of C.D. to 770 FSW the symptoms rapidly disappeared. During the decompression period diver D.F. breathed a special three-gas mixture: 3.5 Atm. N₂, 1.0-1.5 Atm. O₂ and the balance Helium for 10 minutes, at several depths (600, 400, 340, and 200 FSW). At 600 FSW, D.F. had no

symptoms, but at each other depth the inhalation of the high nitrogen mixture produced signs of dizziness which were considered narcotic effects. The other diver, C.D., had no reactions when breathing the same nitrogen mixture at 500 FSW. Between 50 and 40 feet both divers experienced intermittent pain in both knees which appeared again at 30 feet, and was relieved by recompression to 40 feet. However, diver D.F. reported numbness in the fingers. When numbness in the soles of the feet developed in D.F., further recompression to 60 feet was carried out which produced an improvement, but more intense pain occurred in the lower leg during the subsequent decompression at 20 feet. Another recompression to 165 feet (Navy Diving Table V-A) produced only partial relief. When the symptoms got worse during the following ascent to 60 FSW, a third massive attempt was made to relieve the symptoms by recompression to 527 FSW, but without success. He stayed at this depth for about one hour, having intermittent severe pain in both legs. Application of hot compresses helped to relieve the pain, temporarily. After another hour, he received one Bufferin tablet at the depth of 521 FSW, which in his words "acted like a hit." He slept for a while and after several hours his pain was greatly relieved, and the subsequent decompression was uneventful.

The symptoms observed during the saturation-excursion dives to 800 and 1000 FSW can be classified in three categories.

1. Helium tremors occurred in the two divers during excursion dives with very high compression rates ranging

between 27 to 40 feet/minute at depths exceeding 600 FSW.

2. Symptoms due to mechanical interference with normal circulation occurred on two occasions and responded rapidly to recompression. No EEG records were taken at the time symptoms of the first 2 categories occurred.

3. Symptoms manifested in poorly localized muscle aches and stiffness were characterized by intermittent occurrence. They did not respond to recompression and oxygen treatment and appeared to be associated with fluid and electrolyte shifts and a large CO₂ excretion in the urine (Schaefer, et al, 1970).¹⁴ In one diver, C.D., changes in the EEG could be correlated with CO₂ excretion in the urine. The helium tremors did not cause significant changes in psychological performance tests, which is in line with observations of Brauer (1968). Before and after the excursion dive from 800 to 1112 FSW of diver C.D. and directly during the stay of diver D.F. at excursion depth of 1050 FSW, choice reaction time measurements were carried out which did not show any significant differences from pre-dive control level. Inhalation of the high nitrogen mixture at 200 FSW by D.F. produced narcotic effects, indicated by dizziness and lightheadedness. These effects were found to be associated with a slight decrease in the scores of the choice reaction time test and EEG changes. Throughout all the other phases of the saturation-excursion dives of the four subjects, no significant changes in scores on the psychological performance tests were observed (Parker, J. W., 1969).¹²

Results of EEG Studies

The two subjects exhibited marked differences in their EEG under normal conditions.

Subject D.F. (A): The resting EEG before the dive showed a pattern consisting predominantly of a low amplitude fast frequency pattern. The pattern was quite variable in the 15-30 Hz range and about 20 μ V in amplitude. Triangular waves of a period of one-fourth to one-fifth second appeared continuously throughout the record, but in random fashion. These waves resemble those described as lambda waves. Opening or closing of the eyes had no effect on the basic pattern except that during the eyes-open period there was an increased amount of eye movement artifacts.

With eyes closed, Subject C.D. (B) showed a continuous 10-11 Hz alpha pattern in the parietal areas during the resting pre-dive period. The amplitude was from 50-70 μ V.

Effects of compression

Compression to 800 feet at a rate of 3.5 feet/minute produced in both subjects a lower mean frequency, a lower percentage of fast waves (18 - 50 Hz), a decrease in the percentage of large amplitudes and a tendency to increase in the 6 - 8 Hz range. These effects were more pronounced with eyes open (Figure 1).

Effects of saturation-excursion diving and decompression

In Figure 2, mean frequency values of subject C.D. are shown for each session of the experiment in which EEG

records were taken, including periods of exercise (E), recovery from exercise (R), and inhalation of gas mixture (G) during the decompression on period. Each of the E, R, and G periods is divided into three equal parts. Since most periods were ten minutes long, the first part would be for EEG recorded during the first 3.33 minutes, the second part the next 3.33 minutes and the third part the last 3.33 minutes. The upper graph of the figure represents recordings taken when the eyes were open, and the lower graph when they were closed. The bar graph shows the depth in feet for each session. Periods of compression, saturation, excursion to 1000 FSW and two decompression periods are separated by lines.

Missing data occur because of rejection due to artifacts (60 Hz), noise, muscle potentials, movements, etc.

The decline of the mean frequency during compression is reversed during the saturation period at 800 feet. Exercise and recovery from exercise at 800 and 1000 feet did not cause consistent changes. During the first decompression period a continuing fall in mean frequency was noted.

In Figure 3, mean values and interquartile ranges of mean frequency of the alpha range are shown for subject C.D. Exercise and recovery values are not included. There is a clearly pronounced trend toward a decrease in mean frequency of the alpha range throughout the experiments, with the exception of the periods with inhalation of gas mixtures. In Figure 4, the same format is used as in Figure 3 to demon-

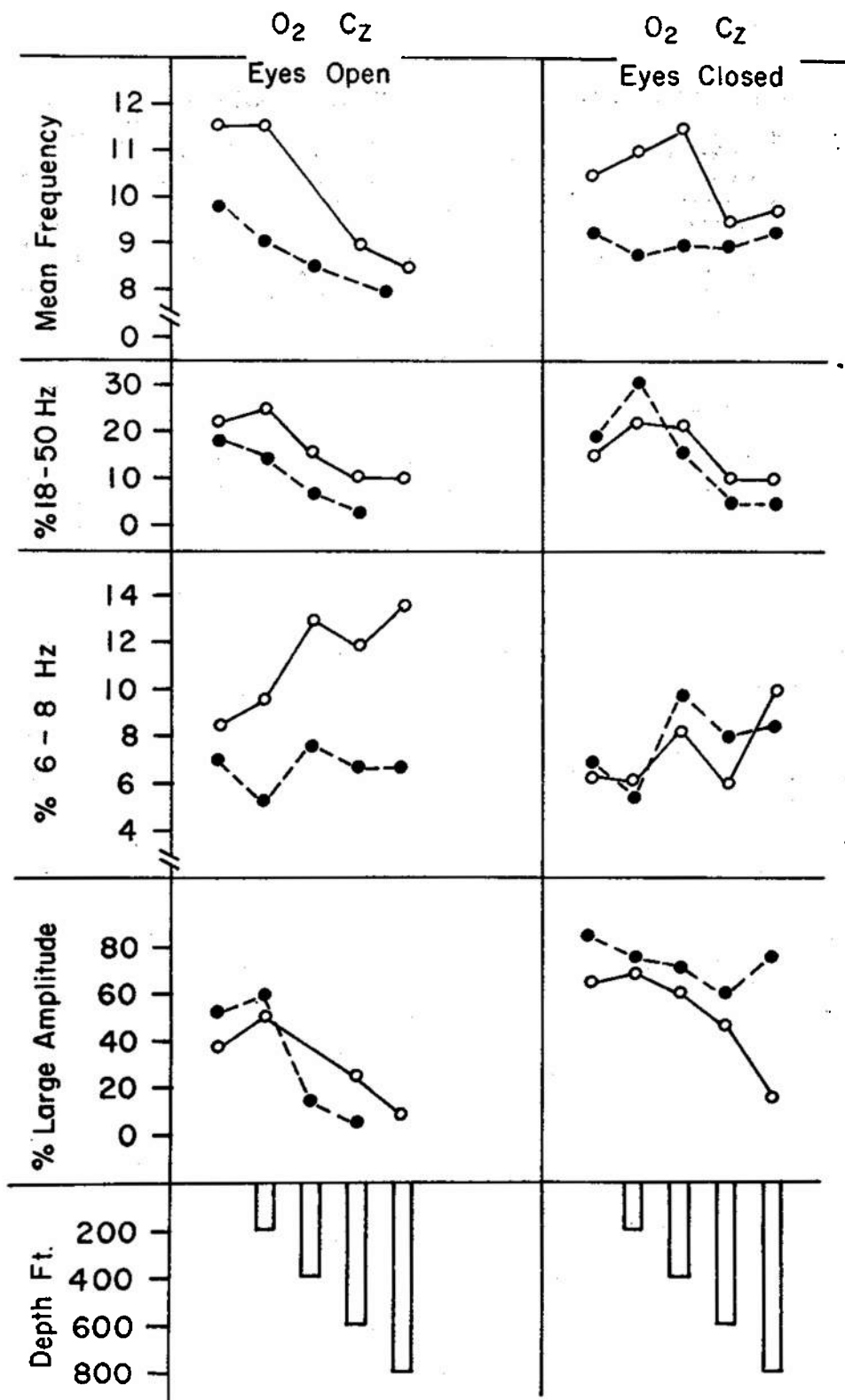


Fig. 1. Effect of compression at a rate of 3.5 feet per minute on mean frequency, percentage of 18-15 Hz frequency, percentage of 6-8 Hz frequency (theta activity) percentage of large amplitudes in two subjects with eyes open and closed. Electrode Position $O_2 - C_z$. Open circles, Subject D.F.; filled circles, Subject C.D.

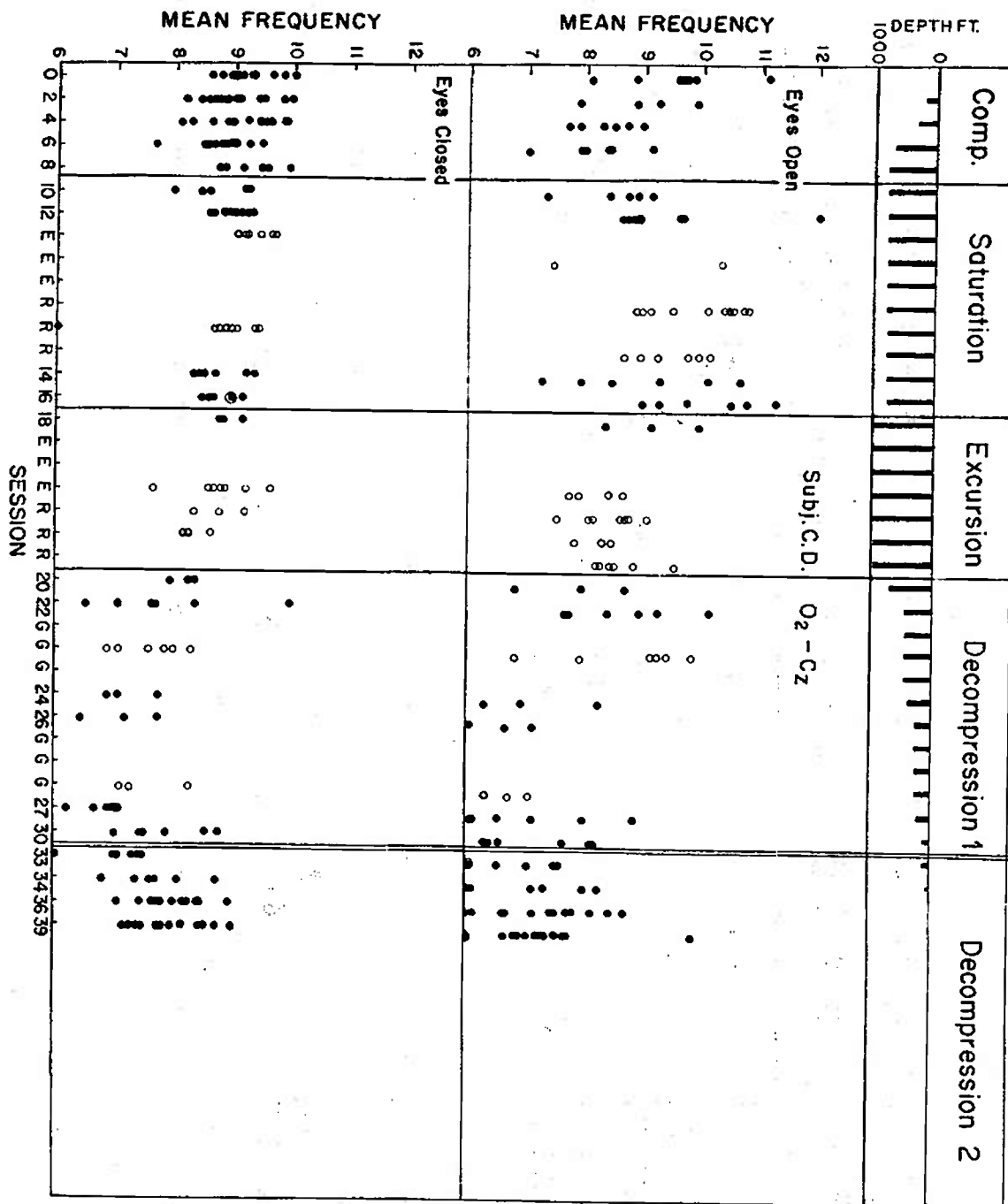


Fig. 2. Subject C. D. Time course on changes in the mean frequency during saturation diving experiment. Electrode position $O_2 - C_z$. Separation of five periods: compression to 800 feet, saturation at 800 feet, excursion to 1000 feet, the first decompression period was interrupted at 30 feet followed by recompression to 527 feet and second decompression. Numbers refer to sessions in which EEG recordings were taken. E = Exercise, R = Rest, G = Session in which a nitrogen-oxygen gas mixture was inhaled.

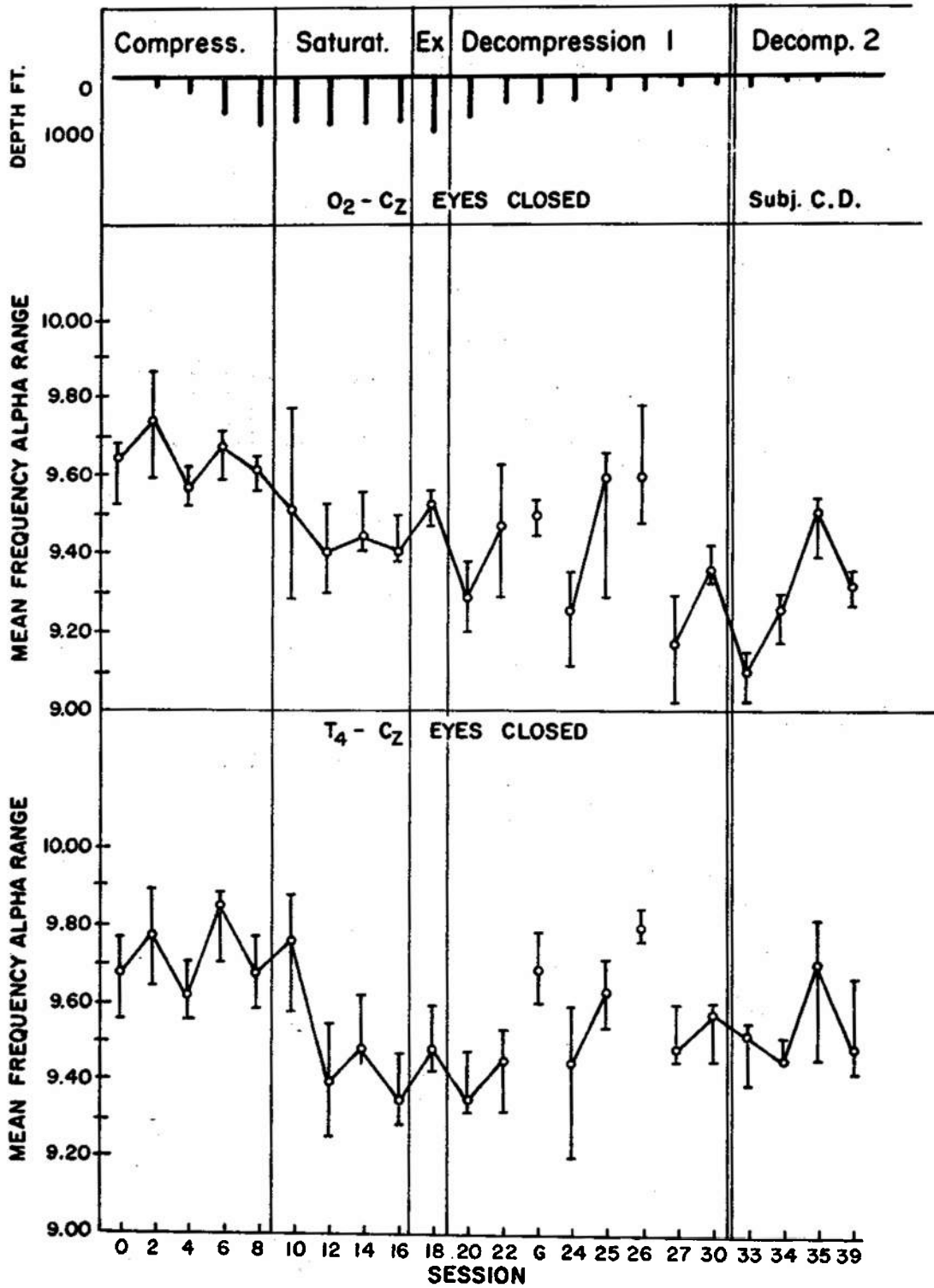


Fig. 3. Subject C. D. Mean frequency changes in the alpha range during the saturation diving experiment. Eyes closed. Two electrode positions: $O_2 - C_z$ and $T_4 - C_z$. Sessions with exercise are not included.

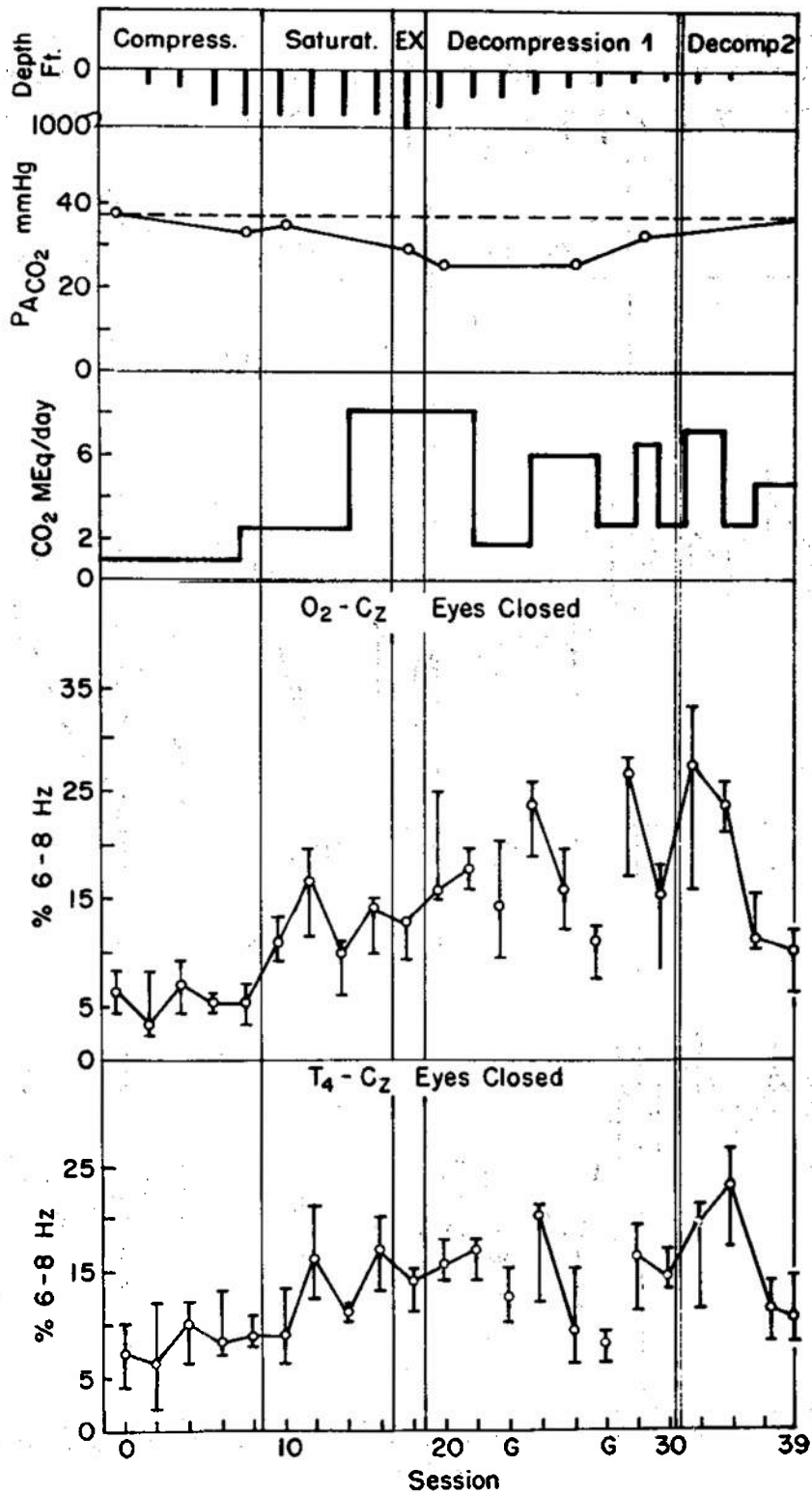


Fig. 4. Subject C. D. Time course in alveolar carbon dioxide tension, urinary CO_2 excretion and EEG changes, (percent 6-8 Hz frequency), two electrode positions $\text{O}_2 - \text{C}_z$ and $\text{T}_4 - \text{C}_z$, eyes closed.

strate the rise in percent 6 - 8 Hz waves associated with the fall in the mean frequency of the alpha range. Urinary CO₂ values and alveolar CO₂ tensions are also shown with depth. The increase in 6 - 8 Hz waves appears to be correlated with the increase in CO₂ excretion which in turn is an expression of the hyperventilation of the diver (as discussed in more detail in a separate communication (Schaefer, *et al*, 1970).

The points represent the 20-second epochs digitized for each session.

Figures 5, 6, and 7 are detailed analyses of particular 20-second periods of the EEG to demonstrate the effect of inhalation of high nitrogen-oxygen gas mixtures during decompression.

Each row (of the set of 4) of bar graph represents a different category of wave amplitude. The top row represents the lowest amplitude and the bottom row the highest amplitude. A scale with increasing intervals (to increase resolution for small amplitudes) was used to define the amplitude ranges which were 1 - 4, 5 - 17, 18 - 39 and 40 - 64 (units are arbitrarily defined). The total magnitude of each bar represents the total percentage of time (for a 20-second period), for all the waves of that particular category of frequency and amplitude. The frequency categories are 2 Hz intervals and the center values for each category is shown (the last value includes all frequencies 18 or greater). The filled in portion of each bar shows the time for simple waves and the unfilled portions shows the time for composite waves.

Figure 5 represents the pre-dive EEG of subject C.D. Most of the EEG activity in the upper half is in the higher amplitude range (4th row) and in the 9 Hz frequency band. In another channel the pattern is quite similar, the difference being that the main activity is in the middle range of amplitude (3rd row), but on the same 9 Hz frequency. In both channels, the main activity shows a predominance of simple waves (filled in portion). Inhalation of a gas mixture during decompression causes a shift in the EEG pattern (Figure 6). The main activity in the lower half of the graph is now in the second row (lower amplitude) and in the 3 - 5 Hz frequency range. A similar shift can be seen in the upper part of the graph. In both cases, a predominance of composite waves occurs (unfilled portion of bar). During the second inhalation of gas mixtures, the shift in the EEG pattern to a lower frequency range was even more pronounced. Under these circumstances, the 0 - 2 Hz band shows a pronounced activity. In this case the subject had symptoms of narcotic effects (Figure 7).

In contrast to the first subject, C.D., the other subject, D.F., did not show a decline of mean frequency during the decompression period. Following the transient decrease of mean frequency during compression, which was more pronounced in this subject, there was a return to initial values during the saturation-excursion period (Figure 8). Breathing of nitrogen-oxygen-helium gas mixtures during decompression caused in both cases a lowering of the mean frequency and resulted in an increase in the percentage of simple alpha waves (Figure 9) and a decrease in the

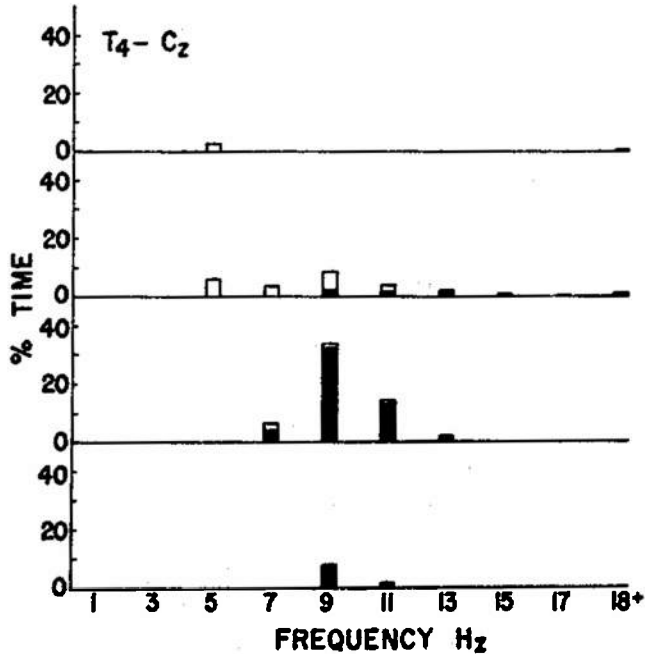
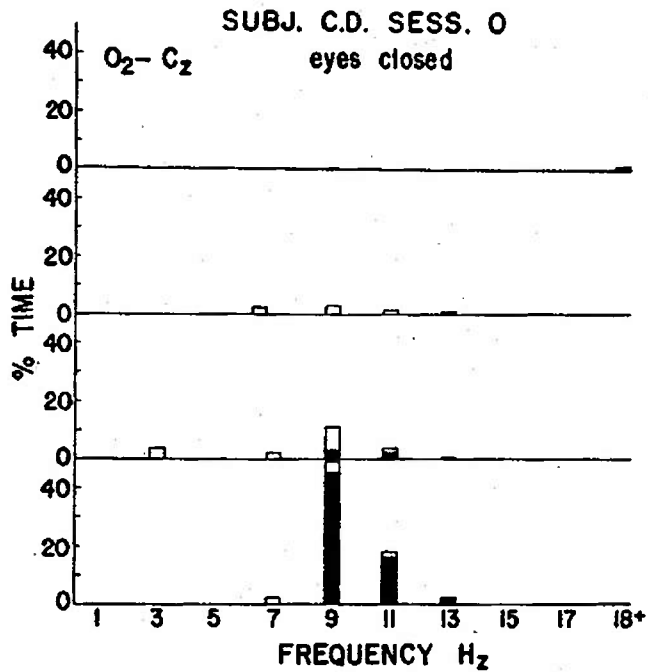


Fig. 5. Subject C.D. Detailed analysis of a 20 second period during control period prior to dive. Four rows representing different amplitudes, the lowest amplitude on the top, the highest on the bottom for different frequency ranges as described in the text. Two electrode positions $O_2 - C_z$ and $T_4 - C_z$, eyes closed.

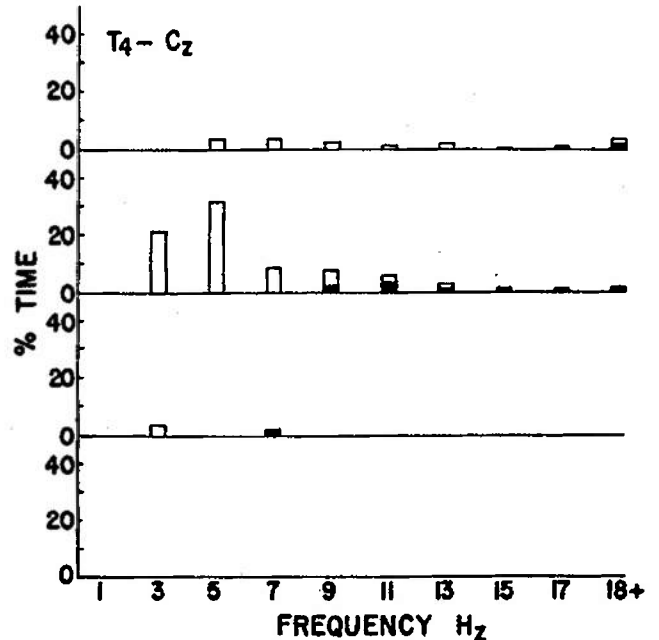
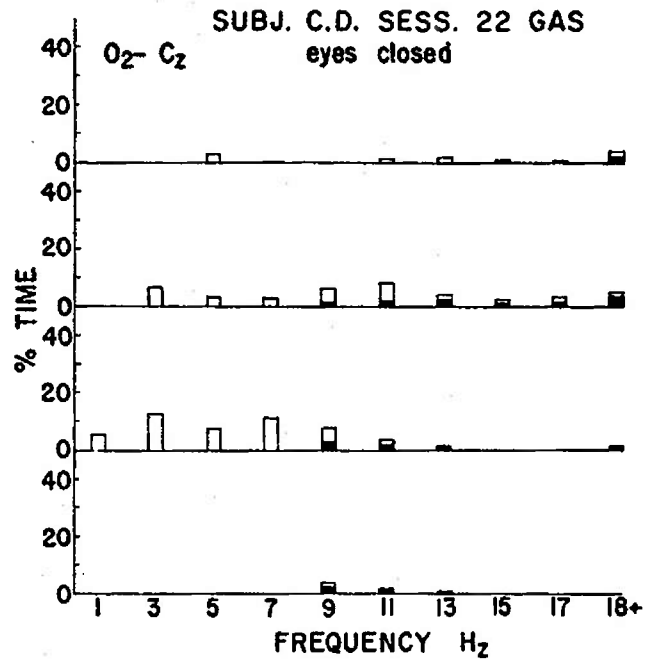


Fig. 6. Subject C.D. Same type of analysis as described in Fig. 5. during inhalation of nitrogen-oxygen gas mixture (3.5 Atm N_2 , 1.4 Atm O_2) at a depth of 500 feet. Electrode position $O_2 - C_z$, eyes closed.

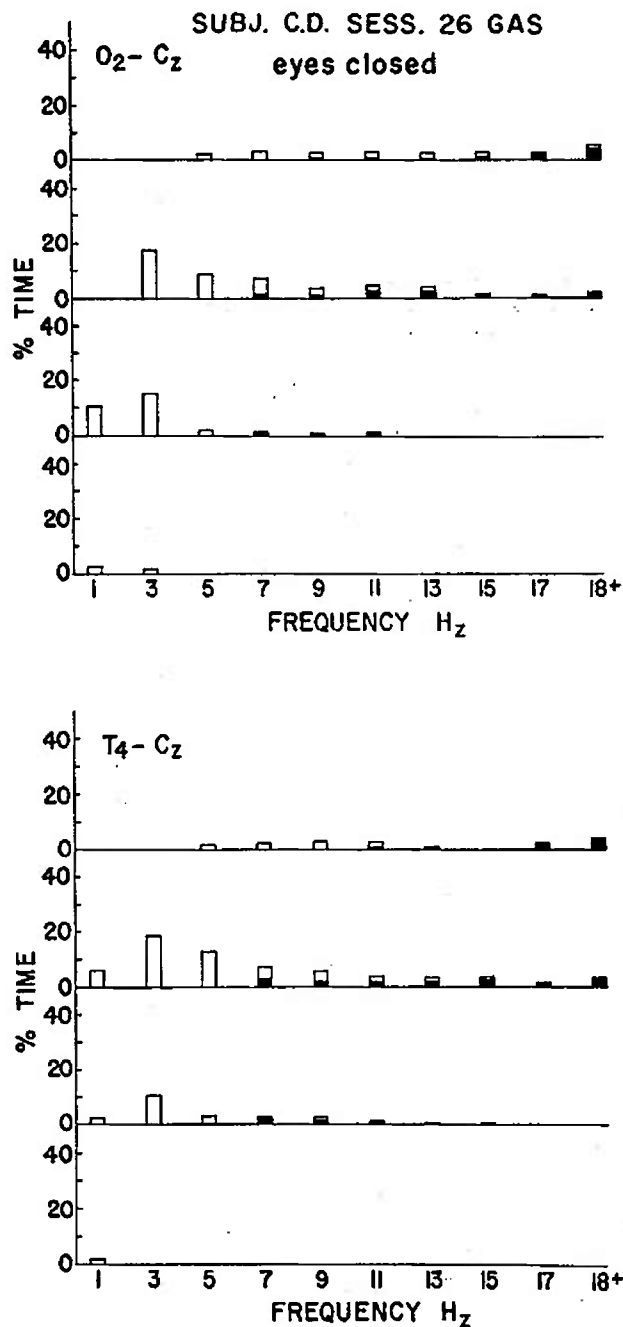


Fig. 7. Subject C.D. EEG changes during inhalation of nitrogen-oxygen mixture (3.5 Atm N₂, 1.4 Atm O₂) at a depth of 300 feet. Electrode positions: O₂ - C_z and T₄ - C_z, eyes closed.

fast frequency band (18 - 50 Hz), as shown in Figure 10. The percentage of higher amplitude was also greatly reduced (Figure 11). A general shift to a lower frequency range during gas inhalation is demonstrated in Figure 12.

A summary of the effects of inhalation of high nitrogen-oxygen gas mixtures during decompression from saturation excursion dives is given in Table II, together with the observed symptoms and results of performance tests.

The symptoms of slight narcosis and deterioration in performance tests observed in the second session in both subjects at lower depth were found to be associated with marked effects on the EEG pattern, showing a pronounced shift of activity to lower frequency bands 1 - 5 Hz range.

The two subjects carried out ten minutes of exercise at a load of 100 watts (corresponding to a medium oxygen consumption) at 800 to 1000 FSW. The EEG records during exercise and recovery did not show any significant changes.

DISCUSSION

In evaluating the reported EEG changes observed during the saturation excursion dives to 1000 FSW, one should keep in mind that the EEG changes were undetectable by the usual visual inspection and only brought to light by computer analysis.

The effects observed during the three different phases of the experiment, compression to saturation level, satu-

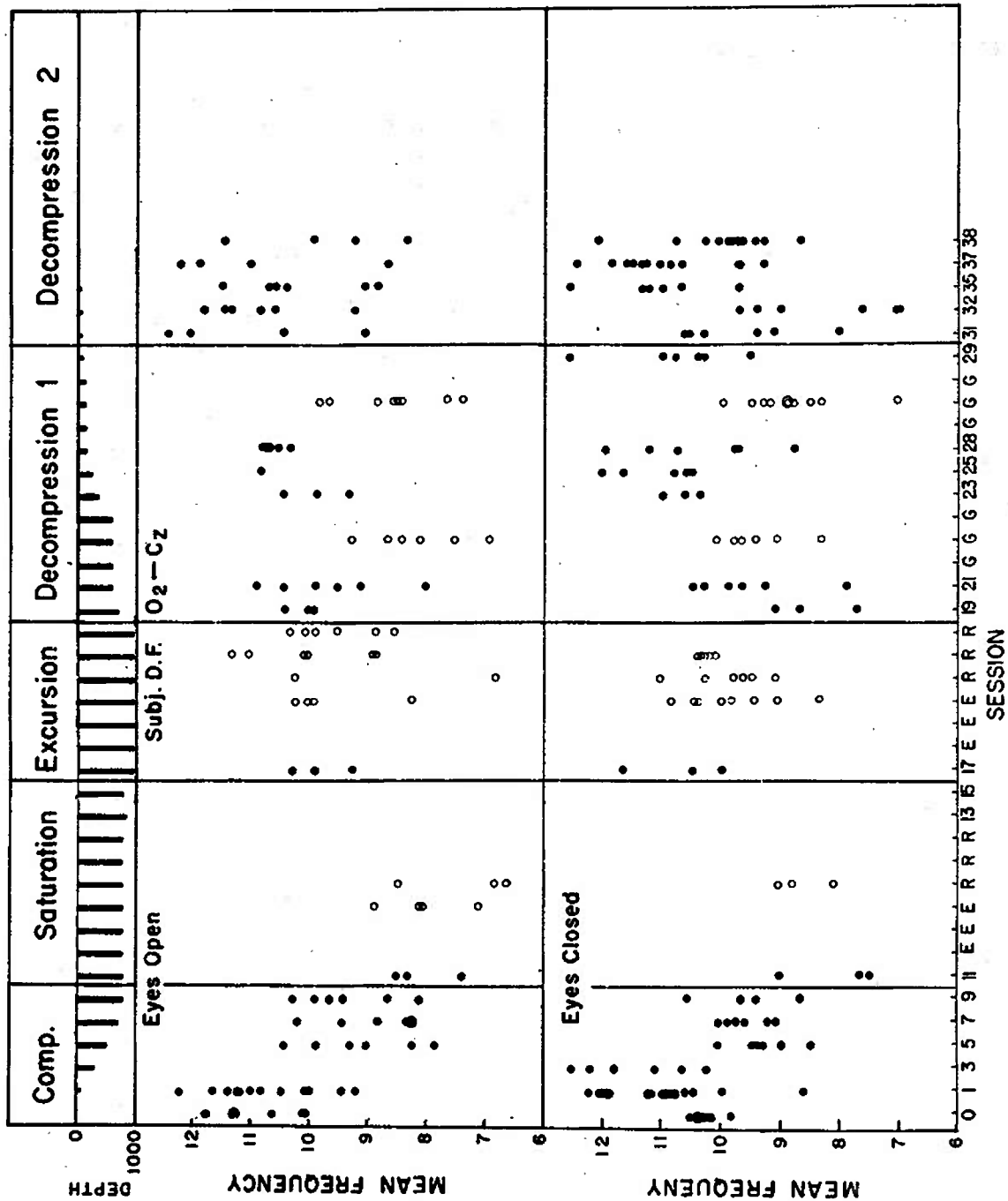


Fig. 8. Subject D. F. Time course of changes in mean frequency during saturation diving experiment. Details same as described in Fig. 2.

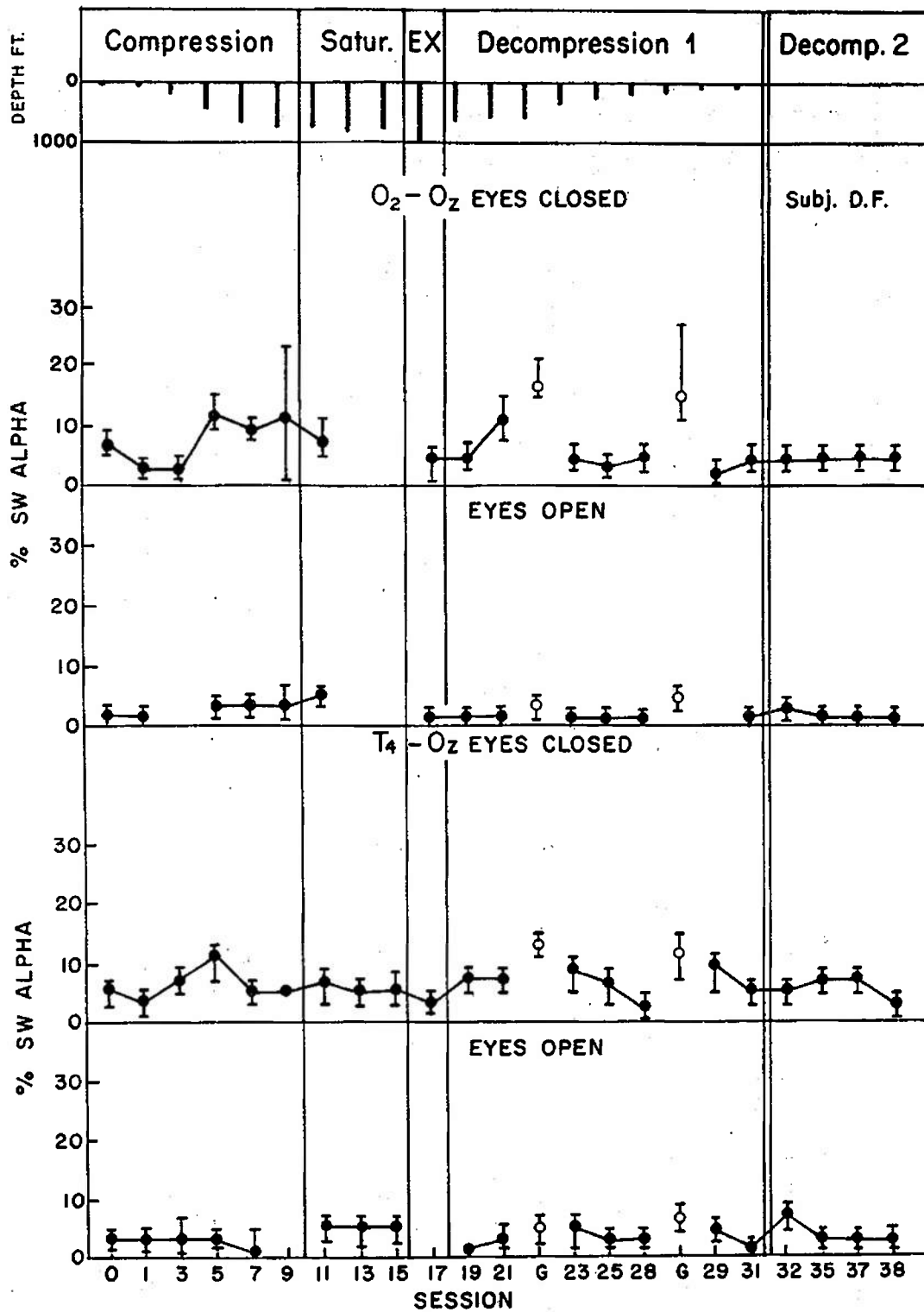


Fig. 9. Subject D. F. Percent of simple alpha waves during saturation diving experiment. Two electrode positions: $O_2 - C_z$, $T_4 - C_z$, eyes open and closed. Changes during inhalation of nitrogen-oxygen gas mixtures.

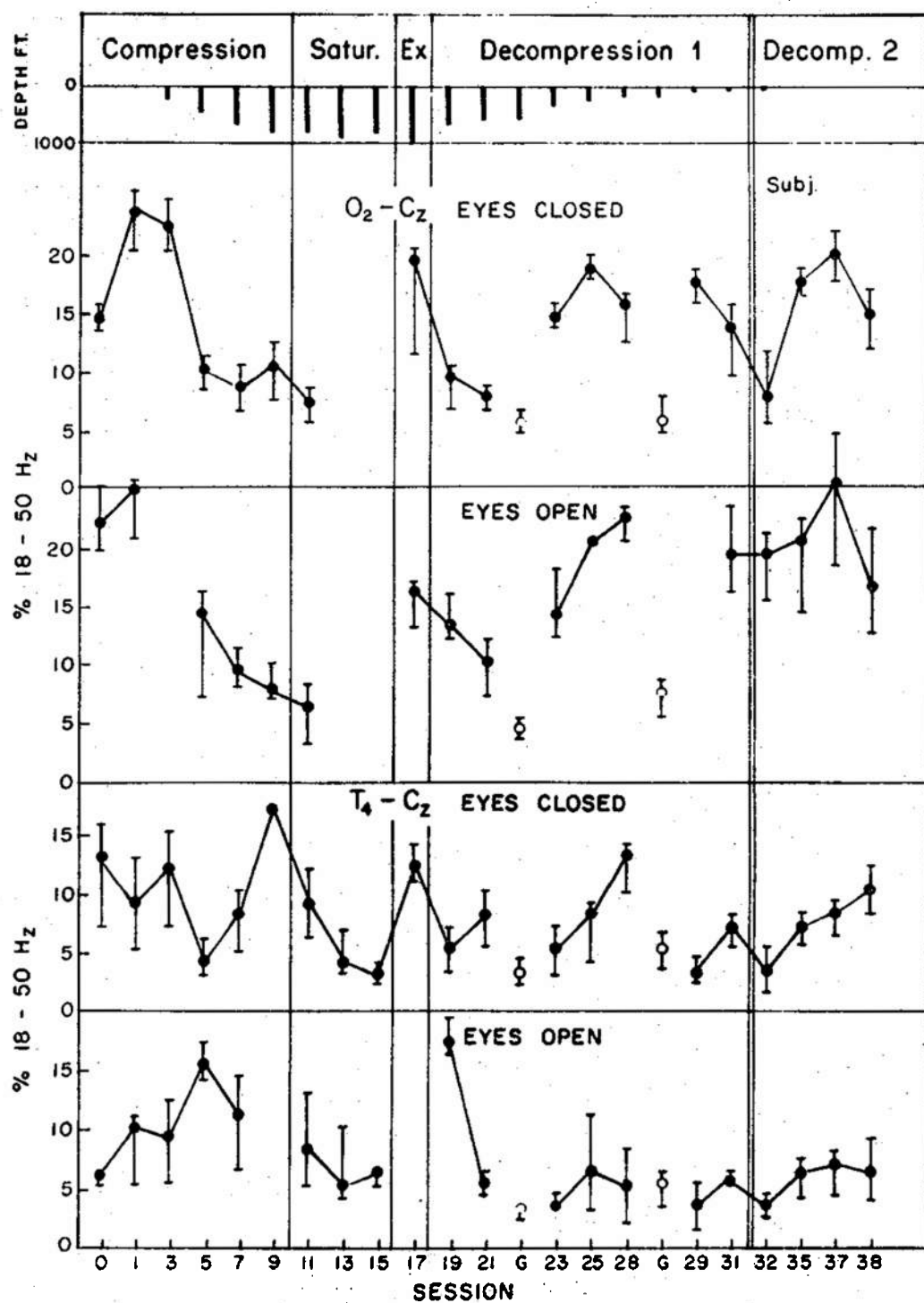


Fig. 10. Subject D. F. Time course of changes in the high frequency band (18-50 Hz) during saturation-diving experiment. Two electrode positions $O_2 - C_z$ and $T_4 - C_z$. Eyes closed and open, marked changes during compression period and during inhalation of nitrogen-oxygen gas mixtures.

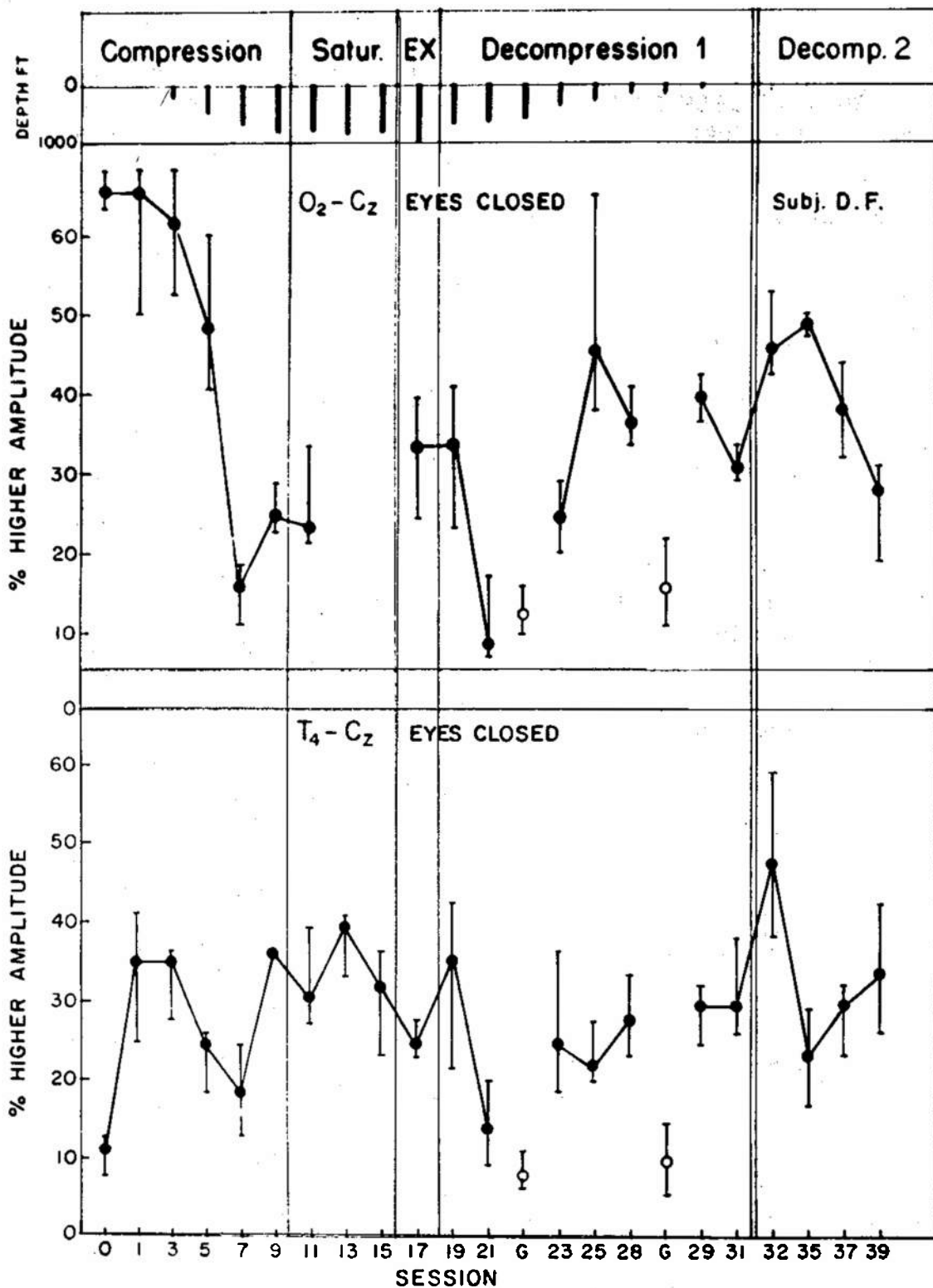


Fig. 11. Subject D. F. Time course of changes in percentage of high amplitudes during saturation-diving experiment. Two electrode positions $O_2 - C_2$, eyes closed. Upper curve exhibits a marked fall in percentage of high amplitude during compression and during inhalation of nitrogen-oxygen gas mixtures.

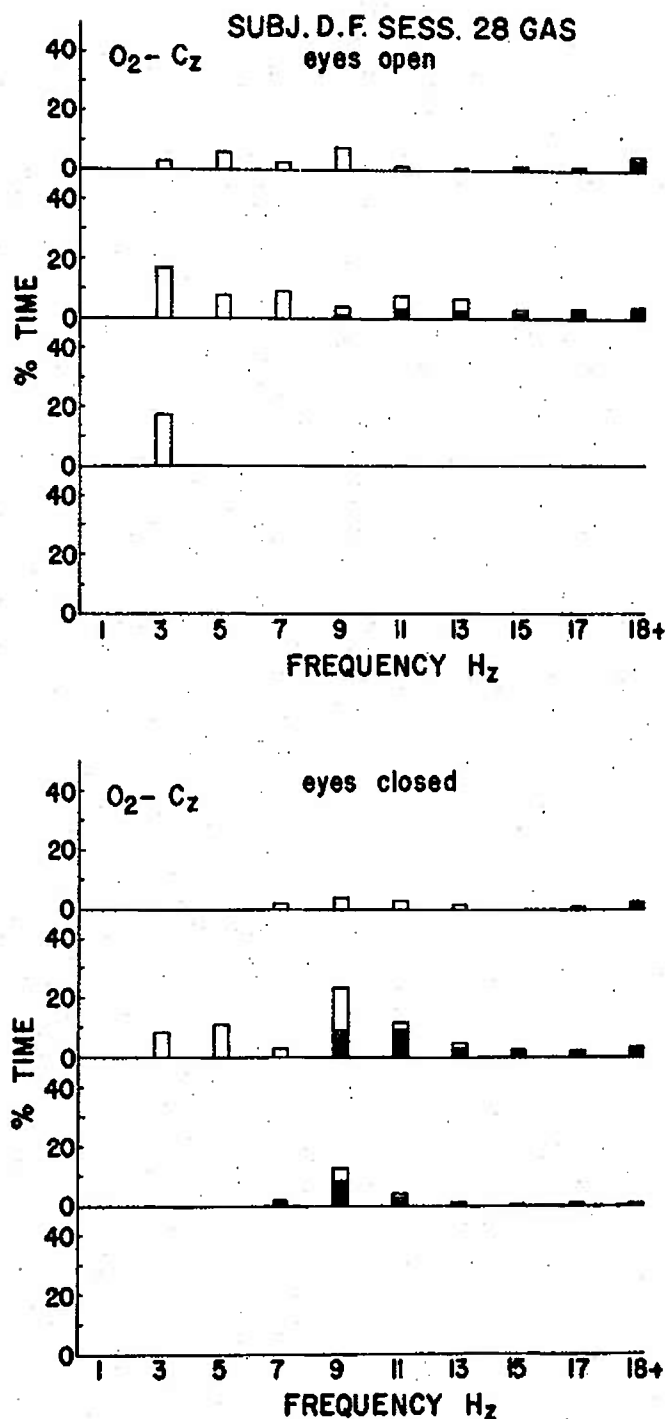


Fig. 12. Subject D.F. Detailed analysis of 20-second period during inhalation of nitrogen-oxygen gas mixtures at a depth of 198 feet. Electrode position $O_2 - C_z$, eyes open. Shift to lower frequencies.

ration excursion dives, and decompression, are discussed separately, since different factors play a role during the different phases, as shown below.

Compression

The initial compression to 800 FSW was carried out at a rate of 3.5 feet/minute. This compression rate was six times faster than the compression rate of 0.5 feet/minute employed in the U.S. Navy-Duke University dive to 1000 FSW (Salzano, et al., 1971)¹³ and the dive to 825 FSW carried out at the U.S. Naval Experimental Diving Unit (Bradley, et al., 1968).²

In all three dives, no symptoms of narcosis, helium tremors or performance deterioration were observed. EEG data were only obtained in our experiment. In spite of the absence of symptoms and performance deterioration, the compression at 3.5 feet/minute produced similar EEG changes in both subjects consisting of: (1) lowering of the mean frequency, (2) decrease of the percentage of fast waves (18 - 50 Hz), (3) decrease in the percentage of large amplitude waves, and (4) increase in the percentage of 6 - 8 Hz waves (theta activity). These EEG changes were more pronounced with eyes open, than with eyes closed.

During the subsequent saturation period at 800 FSW, the EEG changes observed during the compression to 800 FSW were reversed within 14 hours in subject C.D. and 18 hours in subject D.F.

It is therefore concluded that these EEG changes found during the compres-

Table II. Effects of Inhalation of High Nitrogen-Oxygen Mixtures During Decompression From Saturation-Excursion Dives to 1000 FSW

Subject, Conditions	Remarks from Log	
<p><u>Subject, C. D.</u> 1) Session 22G Date 3/15 Time 11:30 Gas Mixtures 3.5 ATA N₂ 1.4 ATA O₂ Depth 500 FSW</p>	<p>rater scores normal</p>	<p>higher mean frequency (Fig. 2) higher mean frequency alpha range (Fig. 3) higher % band higher frequency waves (18-50 Hz) lower % 6-8 Hz (Fig. 4) lower % of high amplitude waves shift to low frequency band 3-5 Hz (Fig. 6) as compared to pre dive EEG pattern (Fig. 5)</p>
<p>2) Session 26G Date 3/16 Time 19:35 Gas Mixtures 3.5 ATA N₂ 1.4 ATA O₂ Depth 300 FSW</p>	<p>slight narcosis some- what more errors in rater score</p>	<p>higher mean frequency (Fig. 2) higher mean frequency alpha range (Fig. 3) higher % band high frequency waves (18-50 Hz) and lower percentage 6-8 Hz (Fig. 4) high % band 0-2 Hz (Fig. 7) and compared with pre dive EEG pattern (Fig. 5)</p>
<p><u>Subject, D. F.</u> 1) Session 21G Date 3/14 Time 22:30 Gas Mixtures 3.5 ATA N₂ 1.4 ATA O₂ Depth 600 FSW</p>	<p>rater score no marked deviation</p>	<p>lower mean frequency (Fig. 8) higher % simple alpha waves (Fig. 9) lower % band high frequency waves (18-50 Hz) (Fig. 10) lower % of high amplitude waves (Fig. 11)</p>
<p>2) Session 28G Date 3/17 Time 15:05 Gas Mixtures 3.5 ATA N₂ 1.4 ATA O₂ Depth 198 FSW</p>	<p>dizziness, more errors in rater score</p>	<p>lower mean frequency (Fig. 8) higher % simple alpha waves (Fig. 9) lower % band high frequency waves (18-50 Hz) (Fig. 10) lower % of high amplitude waves (Fig. 11) shift to lower frequency range (Fig. 12)</p>

sion phase represent a compression syndrome and are produced by the rate change in pressure, rather than by the pressure of helium per se.

This interpretation is supported by observations of clinical symptoms such as helium tremors, arthralgia, "no joint juice" symptoms, vertigo, nausea in all deep dives in which higher compression rates were used. There were EEG disturbances concomitant with such clinical symptoms.

It is noted that the following EEG patterns occurred in our recording:

1. Changes in the high percent and low percent of simple alpha.
2. Higher and lower percent in high amplitude waves.
3. Changes from simple to composite waves.

In our opinion, such patterns are common in EEGs on normal humans and are, within the scope of our present knowledge, of no significance as to abnormal electroneurophysiology.

In the French/American Dive at Comex in 1968, two subjects were compressed continuously to 1170 feet and 1189 feet at a compression rate of 10 feet/minute (Brauer, 1968).³ They observed clinical symptoms such as tremors of the fingers while at rest, muscle jerks, and episodes of somnolence associated with appearance of slow waves in the EEG record (theta activity) and transformation of the waking tracing into a sleep EEG record. The pronounced changes in the EEG

record were easily recognized by visual inspection, and resulted in a decision to stop the dive after four minutes at 1189 FSW.

The authors named the observed clinical symptoms and related EEG changes at the "High Pressure Nervous Syndrome" and suggested that it represented a helium barrier at around 1200 FSW. The effects were first attributed to the high pressure of helium (Brauer, 1968).³

In the British deep dive to 1500 feet in March 1970, an attempt was made to avoid the development of the High Pressure Nervous Syndrome by using a compression profile which included a nearly 24-hour stop at 600 feet, and two 24-hour stops at 1000 and 13000 feet. However the compression rate remained high, 16 feet/minute. The High Pressure Nervous Syndrome was encountered again but in a less dramatic form than at the Comex dive in 1968. Bennett, et al., (1970)¹ reported that the EEG recordings during compression showed a rise in slow frequencies, alpha, 13 - 20 Hz, and 20 - 30 Hz. These changes were observed in one subject at 600 feet and more pronounced in both subjects during the compression from 600 - 1000 feet and were associated with tremors, dizziness, and nausea. The EEG changes were more pronounced with the eyes open.

There is a striking similarity in the changes of the compression electroencephalogram reported by Bennett (1971)¹ and those found in our experiment (Figure 2), although the compression rate in our dive was significantly lower (3.5 feet/minute) and did not result in clini-

cal symptoms such as helium tremors. However, our subjects observed helium tremors at vastly greater compression rates of 27 to 40 feet/minute during short excursion dives to 1112 feet and 1050 feet. Unfortunately, it was not possible to take EEG records during these excursion dives which were carried out in a non-instrument escape chamber.

Bennett, et al., (1971)¹ noted that the theta activity initiated through the compression would first continue to increase during the subsequent saturation period for about six hours and then return to normal levels over the next twelve hours. Thus a period of 18 - 20 hours was required for the EEG activity to return to normal levels which again is in good agreement with the 14 - 18 hour time noted in our experiment.

Bennett (1971)¹ was able to differentiate to a certain extent between the effects of compression (rate changes in pressure) and the effects of pressure per se. He observed a depression of all frequencies other than theta from 1300 feet to 1500 feet, which did not show adaptation.

In November 1970, the Comex group carried out a dive to 1706 feet (Fructus, et al., 1971).⁷ Compared with the early Comex dive in 1968, the compression rate had been considerably reduced. During three periods between 0 - 355 feet, 1150 - 1310 feet and 1510 - 1610 feet, the compression rate was 3 feet/minute and during the rest of the descent 0.6 feet/minute. Tremors appeared between 1000 feet and 1150 feet and were shown to be correlated with an increase in theta activity. By reducing

the compression rate, the occurrence of the High Pressure Nervous Syndrome was postponed to higher pressures and greatly reduced in its severity.

The initial compression rate up to 355 feet corresponds with the compression rate of 3.5 feet/minute used in our experiments, in which we were able to detect through computer analysis, EEG changes at 400 feet, consisting of an increase in theta activity and a decrease in fast frequencies. Because of the similarity of the initial compression rate, it is most likely that the use of a similar method of computer analysis would have demonstrated EEG changes below the reported level of 1,300 feet.

The EEG findings obtained so far in different dives with different compression rates indicate the existence of a compression syndrome, which must be separated from the effects of high pressure per se. The compression effects can be interpreted on the basis of the hypothesis of Kylstra, et al., (1968)¹⁰ which states that osmotic gradients produced by dissolved gases causes changes in the distribution of water which influences physiological functions. Our results indicate that the compression rate during deep dives must be kept under 3.0 feet/minute to avoid the occurrence of symptoms and related EEG changes produced by compression.

Chouteau, et al., (1971)⁵ attempted to quantify the effects of compression rates by calculating the pressure gradients between the inert gas tension in the tissue and the inspired gas. They were able to determine the pressure gradients for a number of different tissues

and particularly the 120 min. half-time tissue in manned dives and in high pressure animal experiments carried out so far.

It was found that maximum pressure gradients above 8 - 10 atm did invariably produce clinical symptoms during compression, while Δp maximum values below 8 - 10 atm did not cause any symptoms.

In both the EDU dives (Bradley, et al., 1968)² and the U.S. Navy-Duke dive (Salzano, et al., 1971)¹³ maximum pressure gradients remained below 8 atm but in our dive reached during the descent 12.0 atm at 600 feet and 13.5 atm at 800 feet. The EEG changes (decrease in frequency) also appeared during descent and disappeared during the saturation period. However, the second diver did not exhibit clinical symptoms during compression, but demonstrated EEG changes similar to the first diver. EEG monitoring can therefore provide a more refined means of evaluating the effects and safety of compression procedures in the absence of clinical symptoms.

Saturation Excursion Diving and Decompression

The two subjects showed a markedly different EEG pattern under normal conditions prior to the dive and responded to the saturation diving and decompression in a different manner. Subject D.F. exhibited an EEG consisting predominantly of a low amplitude—fast frequency pattern, about 20 μV in amplitude; opening or closing of the eyes had little or no effect on the basic pattern. Subject C.D. showed with eyes

closed — a continuous 10 - 11 Hz alpha pattern in the parietal areas with an amplitude from 50 - 70 μV .

During the saturation and decompression periods, subjects exhibited a slight decrease in alveolar CO₂ tension and a marked increase in CO₂ excretion in the urine, which are indicative of hyperventilation (Schaefer, et al., 1970).¹⁴ Only one of the subjects, C.D., showed throughout the saturation and decompression periods a consistent decrease in mean frequency and an increase in percent of 6 - 8 Hz (theta activity) correlated with the CO₂ excretion in the urine. We interpret these changes as being caused by hyperventilation rather than by the effects of pressure per se. These findings underline the importance of hyperventilation in diving which has been stressed by Buhlmann, 1969,⁴ who carefully instructs his divers not to hyperventilate during the dive.

Inhalation of Nitrogen-Oxygen mixtures during decompression

The practice of having divers inhale high nitrogen-oxygen mixtures for short periods during the decompression has been introduced to speed up the elimination of helium and shorten the decompression period (Keller, H. et al., 1966).⁹

Two important observations were made in the EEG recordings during inhalation of nitrogen oxygen mixtures during decompression. In both divers, the inhalation of the same gas mixture produced a markedly greater effect at lower ambient pressure as compared with those seen at higher pressure. During the latter there were no clinical

symptoms of narcosis and no performance deterioration, but slight EEG changes in both cases.

At lower depth, there were clinical symptoms of narcosis, impairment of performance, and more pronounced EEG changes.

At the present time, we do not have an explanation for this difference in the effect of breathing nitrogen-oxygen mixtures at different pressures.

The two divers also showed different EEG changes in response to the inhalation of nitrogen-oxygen mixtures.

Subject C.D. exhibited an increase in mean frequency and in the percentage of fast waves simultaneously with an increase in the low frequency 3 - 5 Hz. This pattern, with an increase of both ends of the EEG spectrum, became more pronounced during inhalation at lower depth.

The other subject D.F. showed a uniform tendency to a decrease in mean frequency, fast frequencies and a general shift to lower frequency bands.

A EEG pattern similar to that observed in the subject C.D. has been reported by Russian investigators (Zaltsmann, et al., 1968)¹⁵ who observed in exposure to nitrogen-oxygen mixtures in dives to 70 - 360 feet an intensification of fast activity on a background of suppressed alpha activity until the alpha disappeared and was replaced by theta activity.

In view of the observed symptoms of narcosis, decrement in performance,

and associated shift of the EEG spectrum to lower frequencies, there is a need to set limits of depths for the use of nitrogen-oxygen mixtures.

Results of this study demonstrated that EEG monitoring provides a refined means of evaluating the effects and safety of compression procedures in the absence of clinical symptoms.

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<p>EEG records were obtained in two Ss during saturation excursion dives to 1000 ft. depth. Computer analysis produced the following findings. During the compression to saturation depth of 800 ft. at a rate of 3.5 ft./min similar EEG changes were observed in both Ss consisted of: 1) lowering of the mean frequency, 2) decrease in the percentage of fast waves (18 - 50 Hz), 3) increase in the percentage of 6 - 8 Hz waves (theta activity). During the subsequent saturation period at 800 ft. the EEG changes observed during the compression to 800 ft. were reversed within 14 hours in S C.D. and 18 hours in S D.F. which indicated that the EEG changes found during the compression phase represent a compression syndrome. During the latter part of the 36 hours saturation period at 800 ft. and the subsequent decompression period S C.D. exhibited a consistent decrease in mean frequency and an increase in percent of 6-8 Hz frequency (theta activity) which appeared to be correlated with an increase in CO₂ excretion in the urine and a decrease in alveolar CO₂ tension suggesting a hyperventilation effect. Inhalation of nitrogen-oxygen mixtures (3.5 Atm N₂, 1.4 Atm O₂) at different depth levels during compression produced in both subjects symptoms of narcosis, performance deterioration and EEG changes (shift to lower frequency ranges or predominance of low frequency bands) at the lower depth level. At greater depth levels no symptoms of narcosis or performance changes were observed but slight changes in the EEG occurred.</p>		

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