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Intentional tremor on a helium-oxygen chamber dive to 49.5 ATA

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Berghage, T. E., L. E. Lash, W. R. Braithwaite, and E. D. Thalmann. 1975. Intentional tremor on a helium-oxygen chamber dive to 49.5 ATA. Undersea Biomed. Res. 2(3):215-222.–Tremor is a well-recognized manifestation of the high pressure nervous syndrome (HPNS). As such, its measurement and analysis during deep hyperbaric exposures can be an important index of central nervous system integrity. During the U.S. Navy's experimental chamber dive to a depth equivalent to 1600 fsw (49.5 ATA), objective measures of intentional tremor were obtained at several depths. Six subjects were pressurized in 6 days to 49.5 ATA. After spending 7 days at this pressure, they were decompressed in 19 days to the surface. Measures of intentional tremor were obtained predive and at pressure levels of 13.1, 31.3, 49.5, 40.4, and 31.3 ATA using the Naval Medical Research Institute Mark 3 Mod 1 tremor device. Each subject's microtremor was measured while he produced a force of 50 grams and 500 grams against a finger force transducer. Unlike previous studies of HPNS tremor, special attention was given to amplitude rather than frequency analysis. All subjects displayed a marked increase in tremor that interfered with fine motor performance at depths greater than 1000 fsw. A statistically significant increase in signal frequency was also observed.

HPNS
tremor
perceptual-motor performance

Subjective reports of tremor have been recorded on just about every deep helium-oxygen ($He\text{-}O_2$) dive made. Observations made in England, France, and the United States all confirm the existence of a neuromuscular dysfunction termed high pressure nervous syndrome (HPNS) by Brauer in 1968.

Early attempts to quantify the deep-dive tremor involved the use of fine motor dexterity tests such as the ball-bearing test and the Purdue Pegboard (Bennett 1967; Berghage 1968). The first reported use of a finger transducer to measure tremor in a hyperbaric environment can be found in a 1969 Ocean Systems, Inc., Memorandum (Langley 1969). Since this initial report, several investigators have refined both the measurement and analysis of the tremor signal (Bachrach, Thorne, and Conda 1971; Bennett and Towse 1971; Bennett 1972; Bachrach and Bennett 1973; Thorne, Findling, and Bachrach 1974).

Brumlik and Yap (1970) have defined three tremor classifications: *rest* tremor, *postural* tremor, and *intentional* tremor. Intentional tremor, the topic of this paper, is defined as tremor associated with purposeful movement toward a goal, or tremor associated with deliberate neuromuscular control; postural tremor is associated with maintaining static positions against the force of gravity, as with an arm being held outstretched; and rest tremor includes the conditions where the subject is as relaxed as possible.

The refined transducers presently used in the study of HPNS tremor provide a continuous analog signal; both frequency and amplitude of this signal are available for analysis. A review of the definitive paper by Bachrach and Bennett (1973) indicates that most of the effort in tremor analysis has been focused on the changes in signal frequency. Very little attention has been directed toward the equally important signal amplitude. Before today's sophisticated frequency analysis techniques were developed, investigators were attracted to the study of HPNS tremor because of the obvious increase in tremor amplitude. It is surprising, therefore, that more attention has not been directed toward quantification of signal amplitude.

CHAMBER DIVE PROGRAM

In an effort to describe more adequately the characteristics of HPNS tremor and to quantify both frequency and amplitude changes in tremor, the U.S. Navy included the use of an intentional tremor device in its 49.5 ATA (1600 fsw) chamber-dive protocol. This study was part of a coordinated dive program jointly sponsored by the U.S. Navy Experimental Diving Unit, the U.S. Naval Medical Research Institute (NMRI), and the U.S. Navy's Bureau of Medicine and Surgery. The 49.5-ATA chamber dive, during which this data was gathered, culminated a series of chamber exposures that extended over a 12-month period. This series of biomedical and equipment evaluation dives was designed to document the diver's ability to perform useful physical work in the water using U.S. Navy underwater breathing apparatus. To perform these dives safely, extensive neurophysiological and cardiorespiratory monitoring was done in addition to the equipment-evaluation tests, resulting in a rather heavy schedule for the divers. It is within these operational and time constraints that tests had to be scheduled to study the problem of HPNS tremor.

PROCEDURE

TREMOR DEVICE

A detailed description of the NMRI Mark 3 Mod 1 intentional tremor device can be found in a technical report by Tresansky (1973). Basically, the tremor device is an aluminum force lever 7 inches (18 cm) long and 1/2-inch (1.29 cm) square (Fig. 1). Four strain gages attached to the lever in a Wheatstone bridge pattern and powered by a 15-VDC current provide the source for the tremor signal. The signal powers a DC volt meter which the subject tries to maintain in the zero position. Deviations from this zero position are considered tremor. The final output signal that is recorded is a measure of microtremor superimposed upon a neuromuscular visual tracking task. Stephens and Taylor (1974), in a rather unique study of visual feedback and microtremor, found no relationship between the amount of feedback and the tremor signal characteristics. It is therefore reasonable to assume that the results obtained with the NMRI tremor device are a rather pure measure of microtremor and not some function of the visual tracking task.

During the testing period, the subject sat in a chair (Fig. 1) with his arm resting on the table and his index finger inserted into a plastic tube on the end of the force lever. Prior to each testing, the subject calibrated the force transducer by placing a 50-g or 500-g weight on the lever and then zeroed the DC volt meter. Following the calibration procedure, the subject removed the weight, inserted his index finger, and attempted to keep the meter zeroed for 3 min. Both 50-g and 500-g samples were recorded for each subject during each testing period.

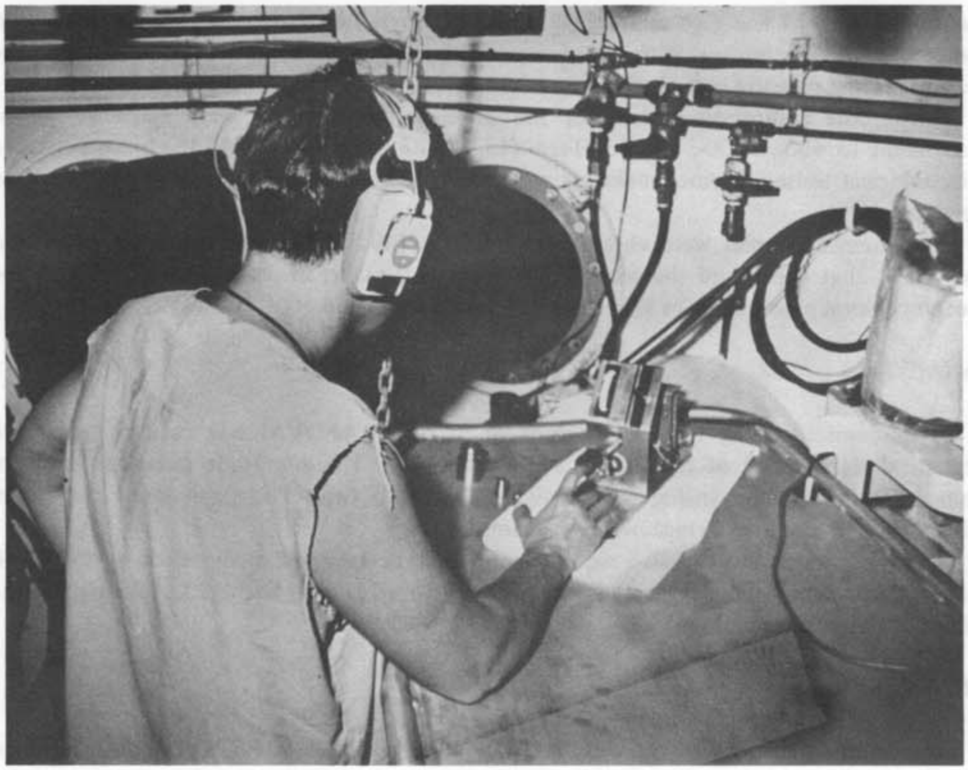

Fig. 1. Experimental subject taking part in the intentional tremor study.

DIVE PROTOCOL

Six U.S. Navy experimental subjects, including two physicians, two diver-trained hospital corpsmen, and two first class divers were compressed to a depth equivalent to 1600 fsw in 6 days. They remained at that depth for 7 days and then were decompressed to the surface in 19 days. The compression-decompression profile for the dive is shown in Fig. 2. Initial

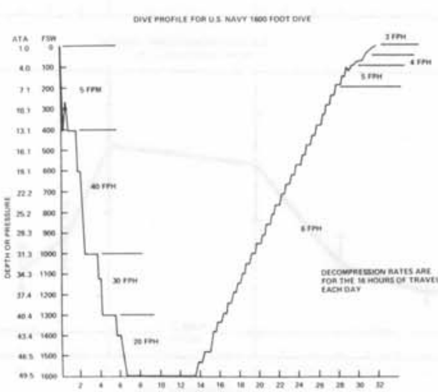

Fig. 2. Dive profile for the record U.S. Navy dive to 1600 fsw.

compression to 14 fsw gage established an oxygen partial pressure of 0.29 ATA. From that point on, compression was with pure helium with oxygen added as needed to maintain the oxygen partial pressure between 0.30 and 0.35 ATA.

During the compression phase of the dive, prolonged stops were made at depths equivalent to 400-, 1000-, and 1300-fsw (13.1, 31.3, and 40.4 ATA) levels for extensive physiological testing. Tremor measures were obtained predive and at the 400- and 1000-fsw levels.

Two tremor samples were obtained at 1600 fsw (49.5 ATA), one when the divers first arrived at that depth and the second just prior to the start of decompression. During the decompression phase, samples were obtained at the 1300- and 1000-fsw levels.

ANALYSIS

A randomized block factorial analysis of variance (ANOVA) was used to assess the statistical significance of the tremor amplitude scores. The amplitude measures were obtained by feeding the analog tremor signal through a Grass Polygraph integrator Model 7PP10B and taking the average of 15 10-s samples.

The tremor signals were also recorded on magnetic tape and analyzed on a PDP-12/40 computer using a frequency analysis program developed by Dr. Michael J. Ackerman at the Naval Medical Research Institute.

RESULTS

The results of the amplitude analysis are graphically shown in Fig. 3. The changes in the tremor signal associated with increased pressure are statistically significant at the $P < .001$ level for both the 50-g and the 500-g samples. The increase in amplitude for the 500-g sample is much more striking and indicates that it is perhaps a more sensitive measure of HPNS.

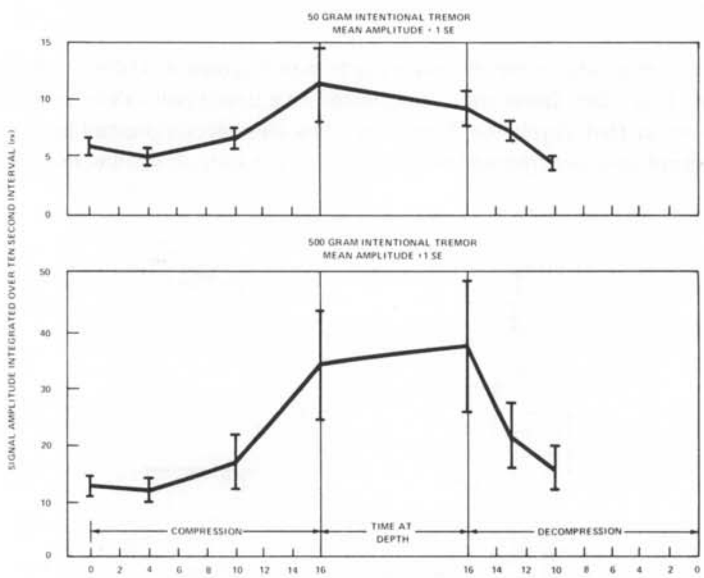

Fig. 3. The relationship between tremor amplitude and ambient pressure.

A detailed analysis of variance of the 500-g results revealed three significant items (Table 1): (a) that exposure pressure or depth has an effect on the amplitude of tremor, (b) there are major individual differences in tremor samples, and (c) there is a significant interaction between exposure pressure and the tremor response of an individual. In other words, there are major differences among individuals and their response to pressure. Some individuals shake violently; others show only minor changes.

TABLE 1

Analysis of variance
summary table

Source	SS	df	MS	F
Depth (D)	5153	1	5153	135.6*
Phase (Ph)†	1	1	1	0.0
Subjects (S)	11979	5	2396	63.1*
S × D	4719	5	943	24.8*
D × Ph	85	1	85	2.2
S × Ph	1060	5	212	5.6
S × D × Ph	600	5	120	3.2
Residual	910	24	38	
Total	24507	47		

*$P < .001$.

†A test of the differences between compression and decompression.

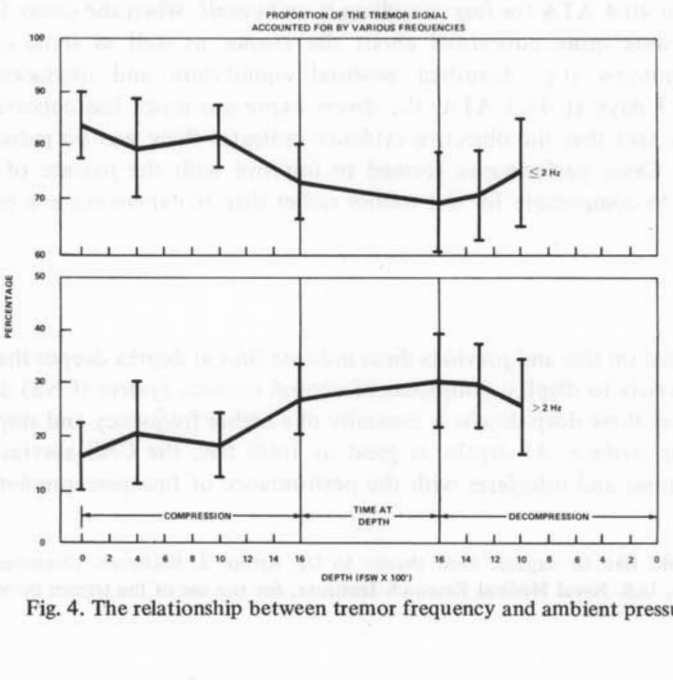

Fig. 4. The relationship between tremor frequency and ambient pressure.

Figure 4 shows the results of the frequency analysis. The shift in frequency is identical for both the 50-g and 500-g samples; therefore, to simplify the figure only the 500-g sample is shown. There is a significant rise in tremor frequency associated with increased ambient pressure. At depths greater than 1000 fsw (31.3ATA), the proportion of the tremor signal that can be accounted for by frequencies less than or equal to 2 Hz is greatly diminished. This result is in keeping with previously reported studies.

The question of adaptation of HPNS while at 49.5 ATA is unresolved. Neither of the two indicators of adaptation, i.e. improvement while at 49.5 ATA and better performance during decompression versus compression, shows any consistent trend. The 50-g samples show improvement while the divers were at 49.5 ATA; yet the 500-g samples show further deterioration. In both cases the changes noted are well within plus or minus one standard error and could very well be due to chance alone. The samples gathered for both force levels during decompression are not significantly different than those gathered during compression at the same pressure levels. Thus, one must conclude that there were no changes in HPNS tremor associated with time under pressure.

DISCUSSION

The tremor signals gathered in this study at various depths were integrated over 10-s periods and the average of 15 of these periods was taken as a measure of the signal amplitude. This technique produced very consistent reproducible results; the authors recommend its use on further studies of this type.

Subjective reports and task performance during this chamber dive confirm the objective tremor measurement results. The subjects reported great difficulty in performing very fine perceptual-motor tasks and physicians well trained in inserting catheters also experienced great difficulty in performing this task at 49.5 ATA. The diving equipment setup and maintenance procedures required almost twice as much time as they did on the surface. The magnitude of the tremor was so great that one of the divers gave up drinking coffee at depths deeper than 40.4 ATA for fear of spilling it on himself. When the divers first reached 49.5 ATA, they were quite concerned about the tremor as well as some of the other physiological symptoms (i.e. disturbed postural equilibrium and increased breathing resistance). After 3 days at 49.5 ATA, the divers expressed much less concern about the tremor despite the fact that the objective evidence indicates there was no reduction in the tremor amplitude. Diver performance seemed to improve with the passage of time. They appeared to learn to compensate for the tremor rather than to experience any physiological adaptation.

CONCLUSION

The data gathered on this and previous dives indicate that at depths deeper than 1000 fsw (31.3 ATA) man starts to display symptoms of central nervous system (CNS) dysfunction. The tremor signal at these deep depths is generally of a higher frequency and amplitude than that found on the surface. At depths as great as 1600 fsw, the CNS aberration reaches significant proportions and interferes with the performance of fine perceptual-motor skills.

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Berghage, T. E., L. E. Lash, W. R. Braithwaite, and E. D. Thalmann. 1975. Le tremblement volitionnel au cours d'une plongée en chambre en mélange hélium-oxygène à 49.5 ATA. Undersea Biomed. Res. 2(3):215-222. –Le tremblement est un signe bien connu du syndrome nerveux des hautes pressions (SNHP)–. Son determination et son analyse au cours des expositions à l'hyperbarie profonde peuvent être un indice important de l'intégrité du système nerveux central. Au cours d'une plongée à 1600 fsw en chambre (U.S. Navy)le tremblement volitionnel a été mesuré objectivement à plusieurs profondeurs.Six sujects ont été comprimés en 6 jours à 49.5 ATA. Après avoir passé 7 jours à cette pression, ils ont été décomprimés jusqu'au surface en 19 jours. Le tremblement volitionnel a été mesuré avant la plongée et à 13.1, 31.3, 49.5, 40.4, et 31.3 ATA par l'instrument du Naval Medical Research Institute (Mark 3, Mod 1). Le microtremblement de chaque sujet a été mesuré pendant qu'il produisait une force de 50 g contre un traducteur de force digitale. En contraste avec les études précédentes du tremblement au cours de l'SNHP, une attention particulière a été prêtée à l'analyse de la fréquence plutôt que de l'amplitude. Chez tous les sujets on a constaté une augmentation importante du tremblement qui a troublé le performance motrice fine à des profondeurs au delà de 1000 fsw. Une augmentation statistiquement significative de la fréquence du signal a été observée aussi.

syndrome nerveux des hautes pressions
tremblement
performance perceptive-motrice

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