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MEDICAL RESEARCH PROGRESS REPORT

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The High Pressure Nervous Syndrome (HPNS) is a condition found in deep diving in excess of 400 feet (13 ATA) whilst breathing oxygen-helium. It is characterized by tremors, an increase in theta activity (4-7 c/sec) in the electroencephalogram (EEG) accompanied by a depression of faster activities and if sufficiently se ere, lapses of consciousness . In animals, convulsions occur, but to date these have not been seen in man .

The HPNS is a complex phenomenon comprised of effects, some of which are a function of the hydrostatic pressure. Others seem due to a complex combination of the two. This paper will describe briefly some of the relevant factors responsible for the HPNS in saturation and excursion diving.

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The High Pressure Nervous Syndrome during Human Deep Saturation and Excursion Diving

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The High Pressure Nervous Syndrome (HPNS) is a condition found in deep diving in excess of 400 feet (13 ATA) whilst breathing oxygen-helium. It is characterized by tremors, an increase in theta activity (4–7 c/sec) in the electroencephalogram (EEG) accompanied by a depression of faster activities and if sufficiently severe, lapses of consciousness (1, 4, 5, 11). In animals, convulsions occur, but to date these have not been seen in man (7).

The HPNS is a complex phenomenon comprised of effects, some of which correlate with the rate of compression and others which are a function of the hydrostatic pressure. Others seem due to a complex combination of the two. This paper will describe briefly some of the relevant factors responsible for the HPNS in saturation and excursion diving.

Saturation dives

Tremors

In 1965, tremors of the hands, arms and torso were reported (2) in subjects compressed at [illegible]-90 ft [illegible] to 600 and 800 ft and quantified by [illegible] ball bearing test which requires subjects to pick up ball bearings with tweezers and place them [illegible] of the same diameter. [illegible] and Schreiner (12) [illegible] also in 1965, observed one [illegible] tremor of both hands and [illegible] the other, tremor of the hands. [illegible] 19) used a "tremograph" to [illegible] with a frequency of 5–8 [illegible] to the upper extremities, [illegible] jaw. Will power [illegible] suppress the tremors to some extent [illegible] they appeared more commonly in dry [illegible] than in the wet, [illegible] the rise in temperature [illegible] compression.

[illegible]

finger. This has permitted also a study of the frequency of the tremor. A useful classification of tremor is that of Brumlik and Yap (8) into Rest Tremor, Postural Tremor and Intentional Tremor which includes normal and abnormal expressions of these.

All normal tremors, on frequency analysis, show a large frequency component between 8–12 c/sec whereas Parkinsons and cerebellar disease has a rest peak frequency of 3–8 c/sec. A postural tremor of 8–12 c/sec, as found with the HPNS, is found also in alcoholism and thyrotoxicosis and during the shivering of cold.

Whilst tremor may not be very incapacitating, it is an important early sign of the HPNS and may be the first warning that the rate of compression for the depth desired is too fast, before other more serious HPNS changes are seen, such as in the electroencephalogram (EEG). To prevent tremors, the deeper the depth the slower must be compression.

Electroencephalogram

Measurement of the EEG without on-line frequency analysis may show little change on visual appraisal unless the HPNS is severe. Graphic representation of on-line EEG frequency analysis, as in the 1500 ft. British experiment (4) especially at depths of 600 ft and greater, with the eyes open, show, however, there is a compression induced rise in theta activity (4–6 c/sec) which once elicited continues for 6 hours, regardless of the fact that compression has ceased, and then falls to more normal values over a further 12 hours. In addition, there may well be a reduction of the remaining EEG activity.

This depression of the electrical activity [illegible] the brain is seen also in [illegible]

Performance

Performance [illegible] tests are not particularly sensitive in identifying the presence of HPNS except perhaps for the ball bearing test. Intellectual tests usually are unaffected. However, when the HPNS is more severe, as during compressions of 40–90 ft/min to 600 and 800 ft, then mental impairment does occur accompanied by dizziness, nausea and sometimes vomiting (2).

The performance decrement normally is the result of the hand tremors and so the reverse of inert gas narcosis with psychomotor tasks most affected and intellectual performance less or not at all (5).

Using tremor, EEG and performance as indicators of the HPNS, the rate of compression in deep saturation oxygen-helium dives has been reduced significantly to ameliorate the signs and symptoms of HPNS found with early 100 ft/min rates (2, 3), to such values as 16.7 ft/min with stages to 1500 ft (4, 5), to the technique of a slower and slower compression speed also with stages to permit adaptation. In the French Sagittaire II experiment to 1640 ft the compression decreased to a final rate of 14 ft/hour. Thus compression profiles to great depths now look like those of decompression.

Excursions

Now it has been observed that decompression from excursion dives permits quite large excursions from a saturation depth without the need for stops (9) and in the same way excursion dives may provide one way to dive deep with fast compressions but without undue HPNS. The technique involves slow compression to a saturation depth, as described previously, followed by a fast compression some hours later to the work depth some 150 ft, or so deeper at rates which would not be possible from the surface. With such techniques it may [illegible] excursions from 1000 ft, to 1100 ft. Whether or not HPNS would result with standard rates of compression of 60 ft/min, however, has yet to be ascertained.

Bennett and Towse (6) studied rates of 100 ft/min with 20/80 oxygen/helium on EEG, tremor and performance at depths to [illegible] ft and noted no HPNS. However, other experiments with compression rates of a similar magnitude to 300 ft, 400 ft and 500 ft with 10/90 oxygen-helium did show some decrement in psychomotor tests as evidenced by the occurrence of tremors (3). Other studies indicated that 50 ft/min to 600 ft breathing 5/95 oxygen-helium will evoke HPNS (1) as indeed will the slower rate of 16.7 ft/min as shown in the first stage of compression to 1500 ft and also in the subsequent compressions after 24-hour stages from 600 ft to 1000 ft, 1000 ft to 1300 ft and 1300 ft to 1500 ft (4, 5) and in direct compression to 1000 ft (10). Indeed even rates as slow as 3.5 ft/min to 800 ft as in the experiment at New London (14) elicited the classic EEG changes of HPNS at 400 ft and deeper.

During the latter study, excursions were made from 800 ft to 1112 ft and 800 ft to 1030 ft at 27 and 28 ft/min respectively. These resulted in weakness and slight tremors but no serious increase in the EEG changes already elicited. A slower rate of 17 ft/min a day later did not produce tremor. Nor did the very similar rate of 16.7 ft/min used by Bühlman et al. (15) in excursions from 1000 ft to 1150 ft. However, the results of the RNPL 1500 ft dive suggest that in some individuals, at least, a rate of 16.7 ft/min from 1000 ft to only 1100 ft and 1360 ft to 1400 ft will cause EEG changes and tremor (4, 5).

Deep Work 1000

In January 1973, at Duke University Hyperbaric Facility during a coordinated experiment by many groups including Harbor Branch, Oceaneering Inc. and University of Florida, known as Deep Work 1000, six men were exposed to 870 ft breathing 0.45 ATA O_2 and the remainder helium.

The descent to 870 ft was very slow, being [illegible] to depth with steps of [illegible] hours 15 minutes at 250 ft, 350 ft, and 450 ft. The night was spent at 450 ft and compression started again next day at 10 ft/min to 600 ft where a six hour 15 minute step was made prior to compression to 870 ft at 2 ft/min.

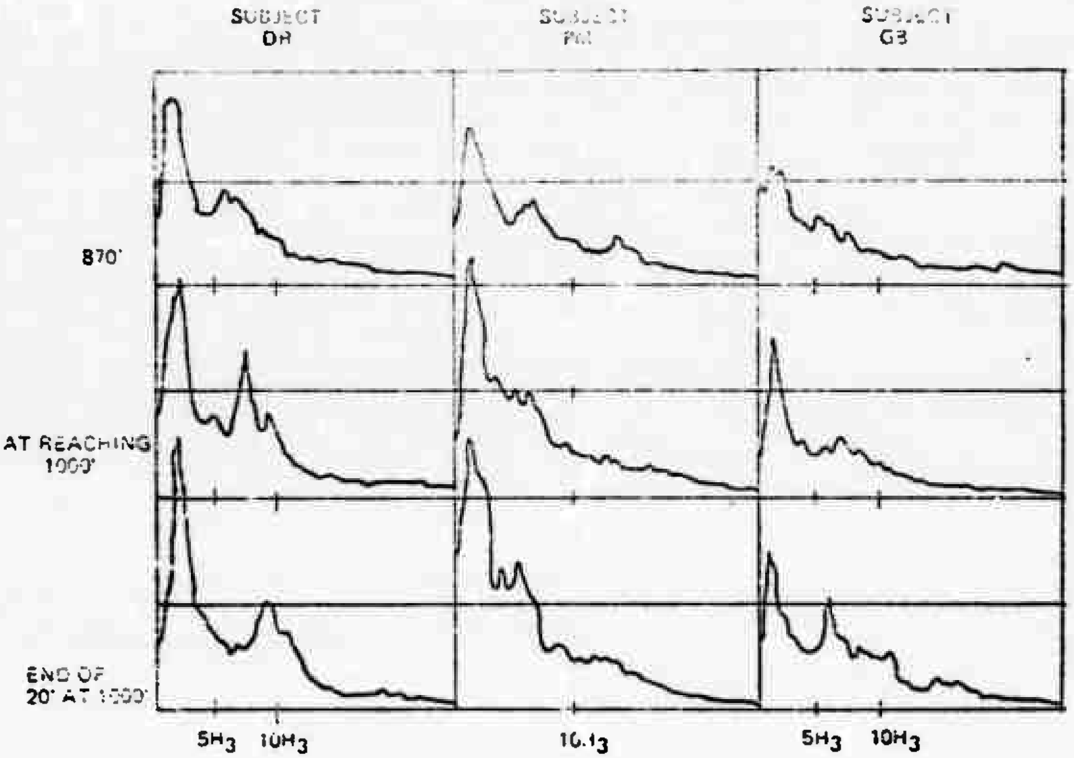

Fig. 1. Intention tremor results after compression from 870 ft to 1000 ft at 100 ft/min. No significant increase in HPNS tremor frequency (8–12 c/sec) may be seen although there are some small increases on reaching 1000 ft especially in subject DR.

Three of the subjects from Oceaneering Inc. made three excursions on separate days from this saturation depth to 1000 ft at 16.7 ft/min, 50 ft/min and 100 ft/min. Measurements were made of intention and postural tremor by [illegible] EEG and performance by the Ball Bearing test, Purdue Peg Board, Arithmetic (68 × 9 [illegible]) and the Wechsler Bellevue Digit [illegible] as [illegible] in the previous saturation dives. In addition, a time estimation study and sleep EEG measurements were made together with study of a pipe puzzle and the Bennett [illegible] test underwater. The performance tests were given on arrival at depth and the last twenty minutes of the two hour exposure.

[illegible] measurements during [illegible]

This peak disappeared during compression when the more usual 10 c/sec peak made its appearance and maybe is a function of tension prior to compression. In the 100 ft/min compression there was again a suggestion of the 5 c/sec peak in the same two subjects. The slight 5 Hz peak again diminished and disappeared as the 1000 ft mark was approached (Fig. 1).

Otherwise the data suggest that there was no consistent significant increase in tremor at any of the three rates of compression.

EEG – Tape recorded EEG samples were fed into a PDP-12 computer for Fourier frequency analysis. Analysis was made in two of the three subjects. The most essential findings were a reduction of all frequency bands at 870 ft and 1000 ft [illegible] compared to baseline values, and [illegible]

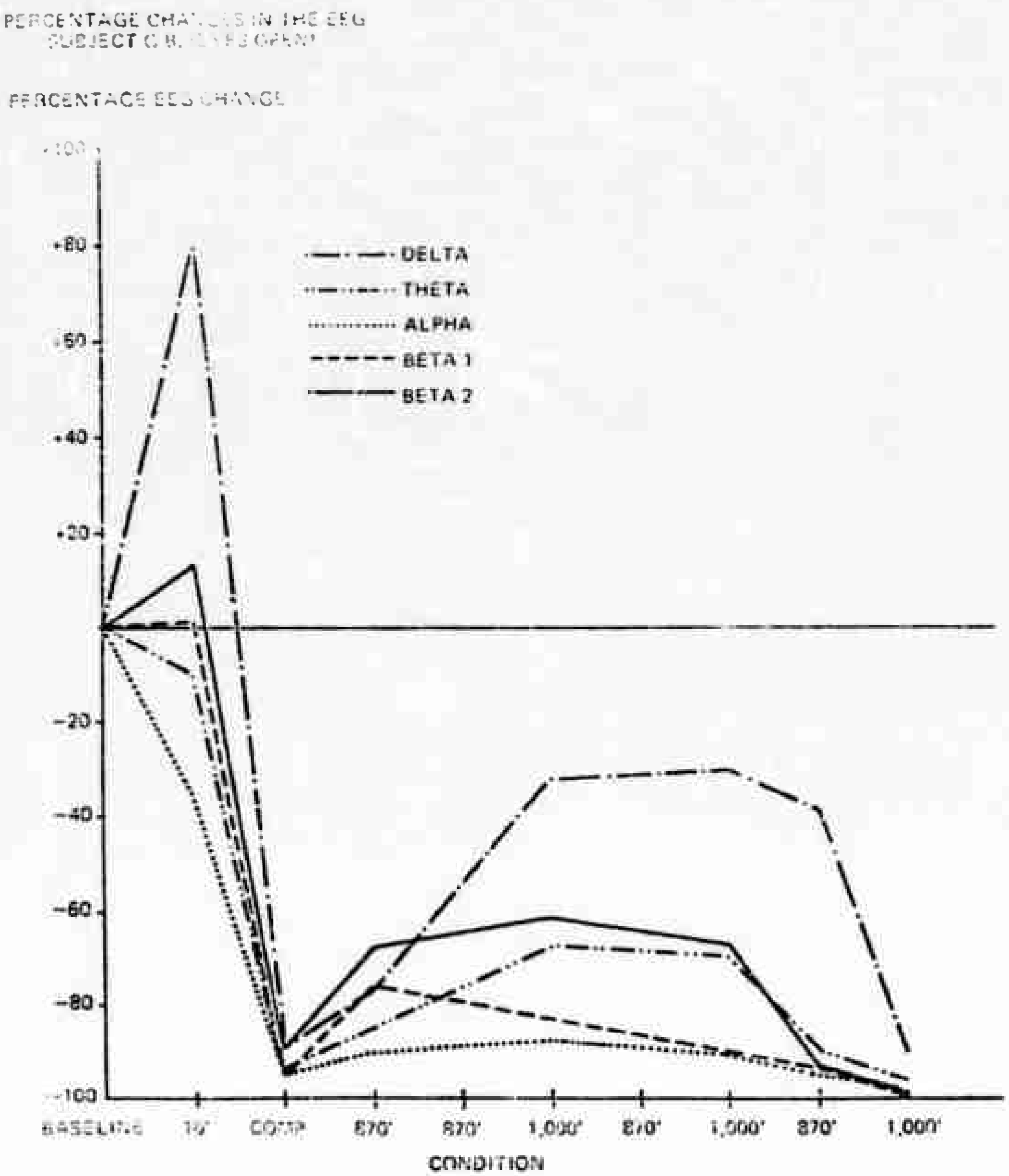

Fig. 2. D[illegible] EEG activity on compression to 870 ft and 1000 ft.

ally in the 60[illegible]–80[illegible] range, but often neare[illegible] 100% in both subjects. Subject G B (Fig. 2) [illegible] during the [illegible] (8–13 c/sec) and delta (2[illegible]) frequencies in isolated instances in the eyes closed condition at 870 ft; no such increases were ever seen in subject G B's profiles. Delta frequencies in general appeared to be more resistant than [illegible] to the depressive effects at [illegible]

[illegible] EEG [illegible] were made in one subject at 870 ft and 7[illegible] ft. These indicated a

Table 1. Performance Efficiency During Deep Work 1000 After Excursion to 1000 ft at 50 ft/min

Test		Predive Test 3	870 ft (Pre-excursion)	Arrival at 1000 ft 50 ft/min	1 3/4 hrs at 1000 ft, 50 ft/min
Ball	Mean	15.67	17.68	16.33	18.00
Bearing	S.D.	±3.79	±1.53	±3.51	±3.61
Peg	Mean	28.67	33.67	30.00	32.67
Board	S.D.	±3.26	±7.23	±4.36	±6.11
Visual	Mean	47.00	48.00	49.3	40.33
Analogy	S.D.	±6.25	±6.56	±5.69	±2.08
Arith.	Mean	11.00	8.67	8.00	10.67
Correct	S.D.	±5.57	±8.96	±8.71	±8.08

decrease in Stage 3 from 5.6% of total at 76 ft. to 2.4% at 870 ft and an abolition of Stage 4 at 870 ft compared with 16.3% at 76 ft. Total sleep time and REM sleep were equal over the two nights. An increase of 8% in Stage 2 at 870 ft means that this stage was increasing at the expense of the deeper sleep stages.

Performance — The ball bearing test indicated a slight but not significant fall of efficiency only during each of the initial tests on arrival at depth, regardless of the rate of compression. None of the other tests, including the underwater pipe assembly and hand tool task indicated a performance decrement (Table 1).

The time estimation task has been shown effective in the analysis of hyperbaric behavior (15, 16).

At times during the 870 ft saturation, marked disruption of the timing behavior was observed in all subjects. When this occurred the 10–20 sec time frame was consistently overestimated with estimation errors increasing by as much as 10–12 sec. Some of the results were [illegible] in other cases poor [illegible] accuracy at the 50 ft [illegible] compression.

Previous research (15) at 300 ft or less has shown that shifts in such timing behavior are to a certain extent dependent on the gas mixture breathed. Compressed air causes an underestimate of time, neon an overestimate and no change with helium. The overestimate in the present study is interesting since it is in a direction opposite to inert gas narcosis. More research is needed to confirm these findings.

Overall these results permit the conclusion that a standard rate of compression of 60 ft/min from a saturation depth of 870 ft to 1000 ft is unlikely to precipitate incapacitating HPNS. Nevertheless extrapolation of this data is not justified for it would seem that the deeper the saturation depth, the slower must be the rate of compression.

It is pertinent that in the 1500 ft RNPL dive, confusion and a sense of impending unconsciousness were experienced by Bevan, at 1535 ft during recompression from 1170 ft in an attempt to relieve vestibular decompression sickness in the other subject (4,5). Although he had spent three days deeper than 1000 ft, he was unable to tolerate, even with a very slow rate of compression which with stages totalled 8 1/2 hours, an excursion of 365 ft from 1170 ft.

The data to date, however, is too small with too few subjects to permit firm statements and it is evident that much more research is required in this critical area, with careful measurement of the PHNS to identify the operationally optimum rates of compression both for deep saturation and excursion diving.

A detailed report of HPNS studies during Deep Work 1000 will appear elsewhere by Bennett, P. B., Bachrach, A.J., Findli[illegible], A., Wilcox, R. and Walsh, J.M.

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