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Effect of compression rate on use of trimix to ameliorate HPNS in man to 686 m (2250 ft)

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Bennett PB, Coggin R, McLeod M. Effect of compression rate on use of trimix to ameliorate HPNS in man to 686 m (2250 ft). Undersea Biomed Res 1982; 9(4):335–351.—Previous man dives, in a series designed to evaluate the physiological effects of helium, nitrogen, and oxygen (trimix), investigated the comparative effects of 5% vs. 10% nitrogen with fast compression (12 h 20 min) to 460 m (1509 ft) and subsequent compression over 2.5 d to 650 m (2132 ft). In 1981 three divers were compressed twice as slowly as for these earlier dives to 650 m over a period of 6 d 8 h using 10% N_2 in heliox. An extensive series of studies were made over 4 d 15 h at 650 m before further compression to 686 m (2250 ft) for a stay of 24 h with extensive tests of psychological and neurophysiological performance, pulmonary function, reflex, Doppler, and other studies. High pressure nervous syndrome (HPNS) tremors and EEG theta activity increases were effectively controlled with no nausea, vomiting, or somnolence (microsleep). Some euphoria was present. At 686 m there was a 20% to 30% impairment of concentration and attention; otherwise the physical condition of the divers was fine and they completed all tasks without difficulty. Slow compression prevented the initial large performance decrement of 40% to 50% on Day 1 as found in previous fast-compression dives. Otherwise the performance tests showed much the same decrement of 15% to 20% seen in earlier dives; deeper than 570 m (1870 ft), however, the addition test was worse, with a decrement of 35%. The results are discussed with respect to the previous two dives with faster compression, and the possible nonlinearity of nitrogen antagonism of HPNS is considered.

HPNS	compression	EEG
trimix	nitrogen	pressure
helium	performance	tremor

Signs and symptoms of the so-called high pressure nervous syndrome (HPNS) such as dizziness, nausea, vomiting, postural and intention tremors, fatigue and somnolence, myoclonic jerking, stomach cramping, increased slow waves and decreased fast activity in the electroencephalogram (EEG), decrements in intellectual and psychomotor performance, and poor sleep with nightmares have provided a formidable limitation to man's ability to dive and work in ocean depths much beyond 305 m (1000 ft) (1–4). First discovered in man in 1965 (6) in dives to 183 m (600 ft) (5) and 244 m (800 ft), considerable progress has been made over the last 15 years in understanding the nature of the syndrome and strategies for its control. These strategies and methods to prevent the HPNS include selection of divers, slow exponential compression with stages, excursions from a shallower saturation depth, adaptation with time at depth, and the use of narcotics to antagonize the effects of pressure responsible for the condition (7, 8).

The latter method has been extensively developed at the F. G. Hall Laboratory, where in 1973 the first human deep dives were made with trimix in which nitrogen was added to helium-oxygen. Dives to 229 m (750 ft) and 305 m in 1973 (9) and 1975 (10), coupled with a theoretical model for prediction of the percentage of nitrogen needed to control HPNS (11), suggested that linear addition of 10% nitrogen was optimal.

The practical test of this hypothesis was made at Duke University with trimix 10 (10% N_2/ 0.5 ATA O_2-He) in especially rapid 33-min compressions to 305 m (1000 ft) (10). In the French *CORAZ* series (12) with 9% nitrogen or 4.5% nitrogen in helium-oxygen, dives were made also to 305 m but with a slower compression time of 4 h. Euphoria and narcosis resulted in a preference for helium alone. Since faster compressions produce worse signs and symptoms of HPNS, it is possible that the disparate results are due to the differing compression rates or durations at maximum depths (2 h in the Duke study vs. 32–91 h for *CORAZ*).

To resolve these and other questions the F. G. Hall Laboratory in 1979 initiated a series of deep human trimix dives termed *Atlantis*. These deep dives were planned to determine the correlations between different rates of compression and either 5% or 10% nitrogen utilized to control the debilitating signs and symptoms of HPNS. Only one parameter at a time was to be altered. They were further planned to determine the effects of inspired gas density, hydrostatic pressure, and narcosis on respiratory factors such as dyspnea in deep diving.

Trimix 10 (10% N_2) in Atlantis II ameliorated the unpleasant physical symptoms of HPNS seen in Atlantis I with only trimix 5; an especially rapid compression time of only 12 h 20 mins to 460 m (1509 ft) was used. However, it was not as effective in preventing the initial 50% decrement on compression and 20% decrement at 460 m in intellectual and psychomotor performance similar to those seen with trimix 5 in Atlantis I (13). The question was therefore asked: Would a slower rate of compression with trimix 10 be more effective in prevention of these decrements in performance? Or would this, like the *CORAZ* series, result in euphoria, lassitude, and signs and symptoms of narcosis?

In connection with the effects of rate of compression, and reinforcing the need to look at this component in Atlantis III, were the results of a further trimix 10 dive listed as 12 B and made in England in October 1980 at the Admiralty Marine Technology Establishment Physiology Laboratory [AMTE(PL)]. This was modeled on the Atlantis II experiment at Duke in March 1980; but from 420 m (1378 ft) to 668 m (2192 ft) the two divers were compressed at a rate more than 2.5 times faster than for Atlantis II (Fig. 1). The divers appeared to be fine on arrival at 668 m, but after about 4 h they became incapacitated, experiencing vomiting, lassitude, and semiconscious states. Their signs and symptoms were not directly comparable to the HPNS as seen with oxygen-helium alone and as noted also by Rostain et al. in the *CORAZ* series (12). Nevertheless, the one difference between the English dive and Atlantis II was the faster compression rate at depths greater than 420 m.

METHODS

Subjects

Atlantis III therefore was planned with trimix 10 but with compression rates twice as slow as those for Atlantis I and II (Fig. 1), using one volunteer subject from Atlantis I (LW), one from Atlantis II (SP), and one new subject (EK) so as to permit comparison with the previous studies. Physical details of the five subjects used in the Atlantis series dives are given in Table 1.

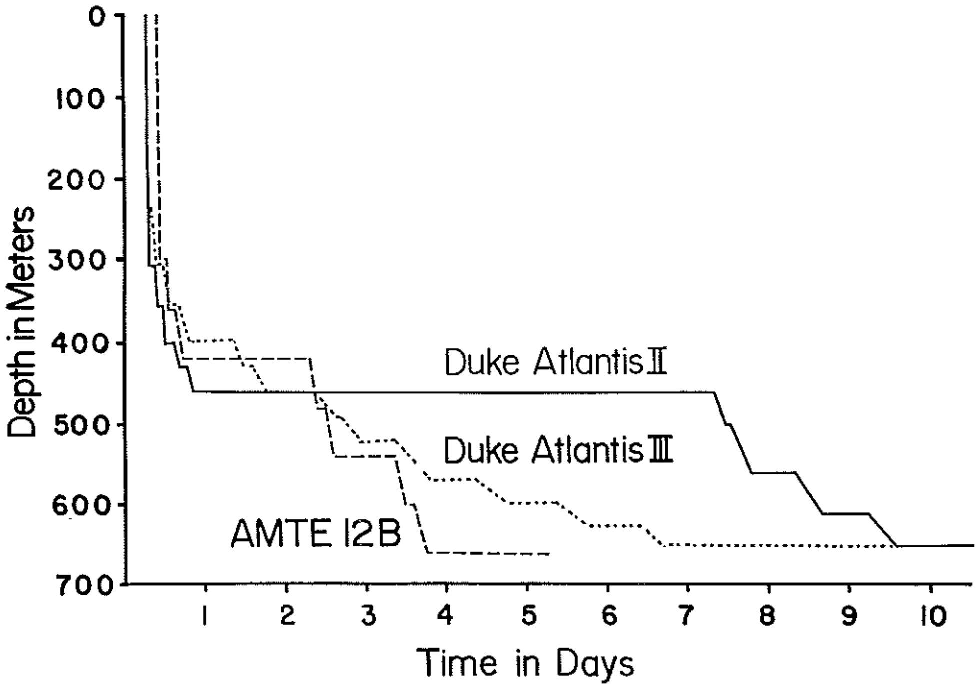

Fig. 1. Compression profiles for Duke University Atlantis I in 1979 to 460 m (1509 ft, same as Duke Atlantis II), Atlantis II in 1980 and III in 1981 to 650 m (2132 ft), and the Admiralty Marine Technology Establishment (Physiological Laboratory) in 1981 to 668 m (2192 ft).

Dive profile

The Atlantis III profile is shown in Fig. 2. Compression to 400 m (1312 ft) started January 23, 1981, at 08:30 a.m. After an overnight stage of 14 h 20 min the compression was continued so that a total compression time of 6 d 8 h 20 min was taken to reach 650 m (2132 ft). A period of 4 d 15 h 40 min was spent at 650 m to permit an extensive test battery of psychological and performance tests plus extensive pulmonary, hematological, and neurophysiological studies not discussed in this paper. After nearly 5 days at 650 m the divers were compressed at 0.05 m/min to 686 m (2250 ft), where a period of 24 h was spent with further extensive physiological tests as above.

TABLE 1
SUBJECTS IN ATLANTIS I, II, AND III DIVES

Subject	Age, yr	Height, cm	Weight, kg	VC, liter BTPS	1 ATA: MVV_{15}, liter/min^{-1} BTPS	1 ATA: $\dot{V}max_{O_2}$ liter/min^{-1} STPD	Atlantis Dive No.
WB	25	183	71	6.23	253	3.10	I, II
SP	24	185	87	7.36	244	3.14	II, III
DS	40	175	79	4.87	195	3.60	I, II
LW	30	173	77	5.20	230	2.95	I, III
EK	24	183	74	6.13	214	3.20	III

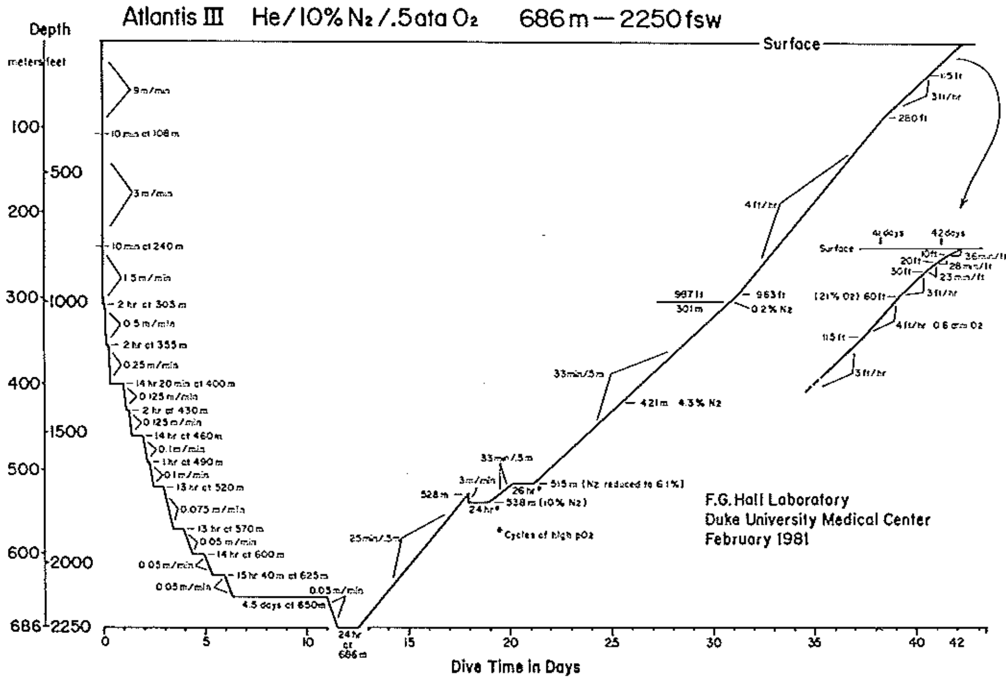

Fig. 2. Dive profile for Atlantis III January–March 1981.

On Day 12, at 12:30 p.m., decompression was initiated using initial linear rates of 25 min/0.5 m. This was modified because of mild elbow bends (EK), and knee bends (SP) in two of the divers, and the nitrogen was slowly decreased from 10% at 538 m (1765 ft) to 6.1% at 515 m (1689 ft) over 26 h (rate 33 min/0.5 m) and was further decreased slowly over the subsequent decompression to 301 m (987 ft), at which depth the nitrogen was 0.2%. Decompression was then continued at a rate of 4 ft/h, which was further slowed to 3 ft/h from 85 m (280 ft) as shown in Fig. 2. The divers emerged from the pressure chambers on March 6, 1981, after 43 days of confinement.

Performance test battery (60 min)

To eliminate learning factors so far as possible, training twice per day at the performance test package was initiated from December 1, 1980.

The same performance test battery, lasting 1-h or longer, was given at each stage during compression, at maximum depth on arrival, and every 4 h during Day 1 except for sleep time. On Days 2–4 a test battery was given at the start of each day.

The performance test battery chosen has been used widely elsewhere in HPNS studies and during the previous Atlantis dives at the F. G. Hall Laboratory (13). It consisted of tests of cognitive memory and of motor and neurophysiological function to determine the presence of HPNS or nitrogen narcosis, or both.

Signs and symptoms questionnaire. A checklist questionnaire asked questions about signs and symptoms of HPNS or narcosis and the occurrence of arthralgias, dyspnea, etc.

Tremor. Postural tremor was measured over 1 min with a Grass SPA transducer (Grass Instruments, Quincy, MA) attached with a rubber band to the middle finger of the subject, and the output was displayed on a Grass electroencephalograph. The recordings were made when the subject was sitting with the hand outstretched and the elbow resting on his chair. Subsequent frequency analysis was made into 5 frequency bands as for the EEG (1 min). Tremor is a diagnostic sign of the presence of HPNS rather than narcosis.

Ball bearing test. In 1 min the subject had to pick up ball bearings one at a time with forceps and place them in a tube of almost the same diameter. The score was the number of ball bearings in the tube in 1 min. This test (1 min) of fine psychomotor and visual coordination is sensitive to HPNS rather than nitrogen narcosis.

Purdue peg board. Pegs and washers had to be assembled correctly on a board. Each unit to be assembled consisted of one peg, a flat washer, a thick washer (¼-in.), and a further flat washer. Time for the test was 1 min and the score was the number of pieces assembled. This is a test of psychomotor performance and is especially sensitive to the motor effects of HPNS.

Bennett hand-tool test. A 9 × 18-in. board had vertical end pieces 9 in. high. Each end piece was drilled with 12 holes (3 rows of 4), and one end was fitted with combinations of nuts, bolts, and washers. Each row contained bolts of a common size but different in size from those of the other rows. Wrenches and screw drivers were provided, and the task was to unfasten each of the assemblies and transfer it to the other side of the test board. Score was the total time required. The test is a standardized measure for gross motor proficiency in the use of wrenches and screw drivers under changed environmental conditions and is especially sensitive to the motor effects of HPNS.

Arithmetic. Sheets of 66 addition sums were presented for 5 min and the subjects were required to answer as many as possible. The test quantifies short-term memory and cognitive function and is sensitive to nitrogen narcosis to a greater extent than to HPNS.

Number similarities. The subjects were presented with 40 sets of paired numbers and were given 1 min to mark the nonidentical pairs:

670824317	X	690284317
724767	____	724767

Digit span test. Series of 8 digits were presented biaurally and the subject had to write them down after 5 s. This is a test of memory and is especially sensitive to nitrogen narcosis.

Stroop color and control. The duration of the control task was 1 min and of the color task was 1 min. In the control condition the 5 color names—green, red, blue, brown, and yellow (written in *black*)—were randomly mixed up in a row. One of the color names appeared before the row, and the task was to cross out that color name in that row. There were 34 test rows per sheet. In the color condition the 5 color names (written randomly in the 5 colors, but not in their own color) were randomly mixed up in a row. One of the color names appeared before that row (not written in its own color) and the task was to cross out the particular color name (irrespective of its ink color) that represented the color of the preceding word (irrespective of its color name). The test is sensitive to nitrogen narcosis and to HPNS to a lesser degree.

AB sentence checking. The subject worked through sheets of 64 statements per sheet saying whether the written statement was true or false. Each statement referred to the position of letters A and B and was followed by either AB or BA; the subject compared the statement with the order and ticked either true or false: e.g., B follows A-AB. The test was allotted 2 min and is especially sensitive to nitrogen narcosis.

Electroencephalogram. Electrodes were attached at the vertex and occipital area for monopolar recordings of the EEG. Measurements were made on a Brush (Brush Instruments, Cleveland, OH) 6-channel polygraph with on-line frequency analysis and using a Nihon-Kohden (Tokyo, Japan) EEG frequency analyzer MAF 5 in the activity bands 2–4 Hz (delta), 4–8 Hz (theta), 8–13 Hz (alpha), 13–20 Hz (beta), and 20–30 Hz (beta). Measurements were made with eyes shut 3 min before each compression phase and for at least 3 min on arrival. Theta activity is expected to increase due to HPNS but not with nitrogen narcosis.

Test administration

The procedures for application of the tests have been discussed in detail previously (13). However, the tests were given at the same time of day and in a fixed order, with the subjects sitting at a table. As controls, four complete sets of test scores were obtained from 3 days predive and on the morning of the dive but before compression. These were averaged to provide a mean control score on the surface for each subject. Performance data during the dive were then expressed as the percentage of change in mean score from this mean surface control score.

RESULTS

Subjective impressions

As with Atlantis II, the trimix 10 was very effective in controlling the adverse symptoms of HPNS, enabling the divers to reach a depth of 686 m (2250 ft) and spend 11 days at depths greater than 600 m (1969 ft). Symptoms such as nausea, vomiting, postural tremors, somnolence, and lapses of consciousness were effectively controlled. One of the 3 divers (EK), however, exhibited inappropriate behavior and euphoria during the compression to 600 m, but this decreased as the depth and time of dive further increased. During the early compression the other divers also noted nausea, faintness, dizziness, fatigue, and "internal" tremor that were especially marked between 50 and 200 m (164 and 656 ft) when the chamber temperature rose toward 39°C as a result of a technical fault with the chillers. These quickly disappeared as the fault was rectified and the chamber cooled.

At 460 m (1509 ft) on Day 2 the subjects felt a little tired and noticed the presence of slight euphoria. Subject LW commented on how well he felt compared with the same depth in Atlantis I. Poor sleep was experienced due to personal temperature perceptions of "feeling cold," although raising the temperature even 0.5°C above 32°C would result in feeling "too hot."

On Day 4 a depth of 570 m (1870 ft) was reached. Subject LW was symptom free except for mild nausea in the early morning. Indeed all subjects every evening seemed to be more alert and in better condition than in the morning. Subject SP also was fine but a little tired. Subject EK was now showing signs of euphoria and disorientation, as referred to earlier.

On Day 7 at 650 m (2132 ft) the divers were subjectively less tired, more functional, and in even better condition than at that depth in Atlantis II. Except for continued sleep problems and some impairment of concentration and attention span, the subjects' physical condition was excellent. Subject SP reported, "I have locked out in the wet feeling worse than this." LW reported, "No problem locking out provided I had a heated suit." There was no dyspnea present, appetite was good, and meals were eaten well.

During Days 9, 10, and 11, when the arduous exercise studies were performed, lack of good sleep continued to be a problem and the subjects said they felt "cloudy" and had difficulties in concentration. Nevertheless, all the divers continued to function well and satisfactorily performed all the tests required, including the placing of 3 arterial catheters and the complex pulmonary function and exercise studies. They were eating normally and morale was good. Subject EK improved steadily as the depth and time of the dive increased, acting more appropriately with much less euphoria and disorientation.

A depth of 686 m (2250 ft) was reached on Day 12 after 12 h of compression from 650 m. LW said, "The day felt like (compression) Days 5, 6, and 7" (i.e., no problems). He felt well acclimatized but "slow." Subject EK reported no problems and he appeared increasingly more confident. Subject SP was tired and slow after a poor night's sleep that may have been partly due to his exceptional work of 240 W for 5 min on the bicycle ergometer during the previous day.

In general the divers were in a fit condition and able to perform effectively all the tasks required of them, including venipuncture, withdrawing blood into interlocked syringes, pipetting and centrifuging before sample lockout, performance tests, neuropsychological tests, reflex tests, EEG, complex respiratory experiments with arterial catheterization, and all routine and nonroutine operations. All planned test data were obtained. It was demonstrated that men can function quite well to pressure equivalent to 686 m. However, sensitive tests of performance, hematology, psychology, pulmonary function, and neurophysiology did reveal changes, some of which will be discussed in other papers. The performance, EEG, and tremor data are considered here.

Tremor

Two of the subjects (SP and EK) showed only very minor changes in the accelerometer results (Fig. 3). The third diver showed levels 150%–200% greater than controls. The tremors, however, could not be seen when the subjects held out their hands for inspection, although subtle small increases in the accelerometer readings can be seen in the direct measurements (Fig. 4).

Psychomotor performance tests

The mean raw data and standard error of the mean for the ball bearing, peg board, and hand-tool tests are given for the 3 subjects in Table 2. Due to the bulk of the data in 47 tests, the results at a number of critical depths during the compression and time at depth have been selected. All of the data are plotted as the mean percentage change from surface control data (Fig. 5). The tests show an average decrement of some 20% from about 400 m (1312 ft) and deeper, which is no worse at 650 or 686 m. The ball bearing test showed a greater decrement during the days of the lung function studies, probably because of the long and arduous work of this project and the fatigue it induced. It is significant that the larger decrements in psychomotor tests seen in Atlantis I and II, such as in the hand-tool test during the first hours of compression, were not present with the slower compression of Atlantis III (Fig. 6). On decompression, the tests returned linearly with decreasing pressure to slightly better than normal results by test 47 at 27 m (89 ft).

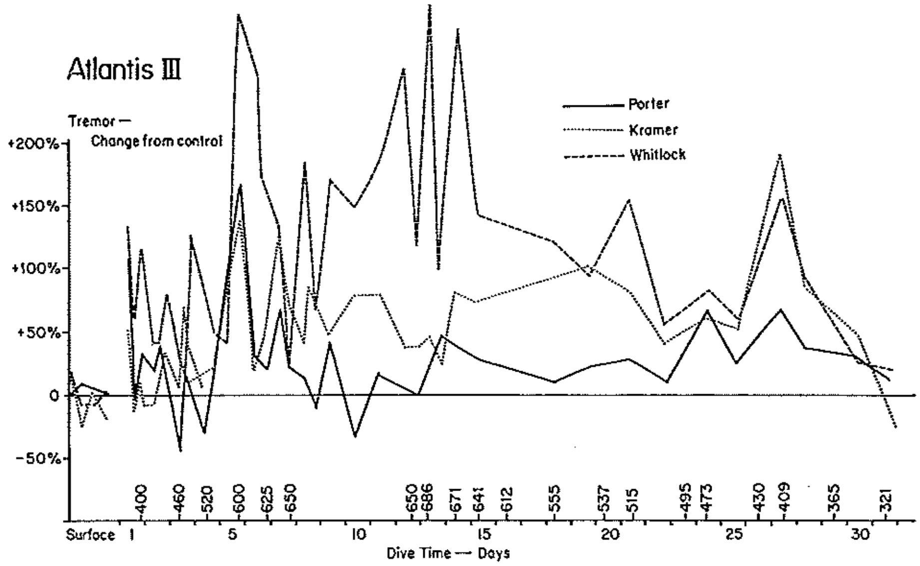

Fig. 3. Percentage change from surface controls in postural tremor for each of the three divers.

Intellectual, cognitive, and memory tests

In Table 3 the raw data are presented in the same format as for the psychomotor tests, and the mean percentage changes from surface controls until decompression are shown in Fig. 7. This composite information illustrates that, except for the "addition correct" test, after the compression to 650 m the majority of tests showed a decrement of around 20%. In fact, the decrements at 650 m and 686 m were often less than those seen during the first few days of

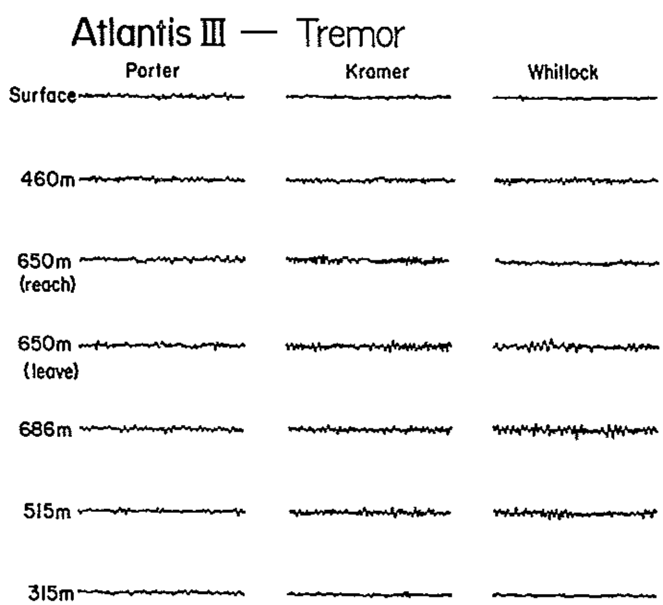

Fig. 4. Postural tremor recordings from an accelerometer on right middle finger of each of three divers. Compression to 686 m (2250 ft) resulted in very little change.

TABLE 2

MEAN TEST SCORES AND SEM FROM PSYCHOMOTOR TESTS AT SELECTED DEPTHS

Test No.	Depth, m	Ball Bearing	Peg Board	Hand Tool
Control	Surface	20 ± 0.3	58 ± 2.7	145 ± 3.7
3	305	17 ± 0.3	50 ± 4.0	178 ± 11.7
4 (p.m.)	400	14 ± 2.7	43 ± 3.0	177 ± 3.5
5 (a.m.)	400	16 ± 0.5	50 ± 4.2	180 ± 3.0
7 (p.m.)	460	15 ± 1.7	50 ± 2.0	168 ± 6.9
8 (a.m.)	460	15 ± 1.2	48 ± 3.7	167 ± 6.4
12 (p.m.)	570	15 ± 1.3	51 ± 0.5	182 ± 11.5
13 (a.m.)	570	15 ± 1.5	47 ± 3.5	181 ± 4.0
14 (p.m.)	600	13 ± 2.7	46 ± 3.8	167 ± 6.0
15 (a.m.)	600	15 ± 2.3	49 ± 1.7	183 ± 5.5
18 (p.m.)	650	15 ± 1.7	48 ± 1.8	174 ± 13.6
19 (a.m.)	650	14 ± 0.5	49 ± 2.0	181 ± 7.0
20 (p.m.)	650	16 ± 1.8	50 ± 0.7	181 ± 2.2
24 (a.m.)	650	16 ± 0.9	46 ± 1.9	181 ± 7.5
25 (p.m.)	686	15 ± 0.6	49 ± 2.3	171 ± 2.6
26 (a.m.)	686	16 ± 0.3	46 ± 3.0	164 ± 2.5
27 (p.m.)	686	15 ± 0.7	44 ± 2.3	164 ± 7.1
40	315	18 ± 2.0	54 ± 1.5	147 ± 0.7
47	27	22 ± 1.2	61 ± 1.2	135 ± 2.7

Total number of tests, 47.

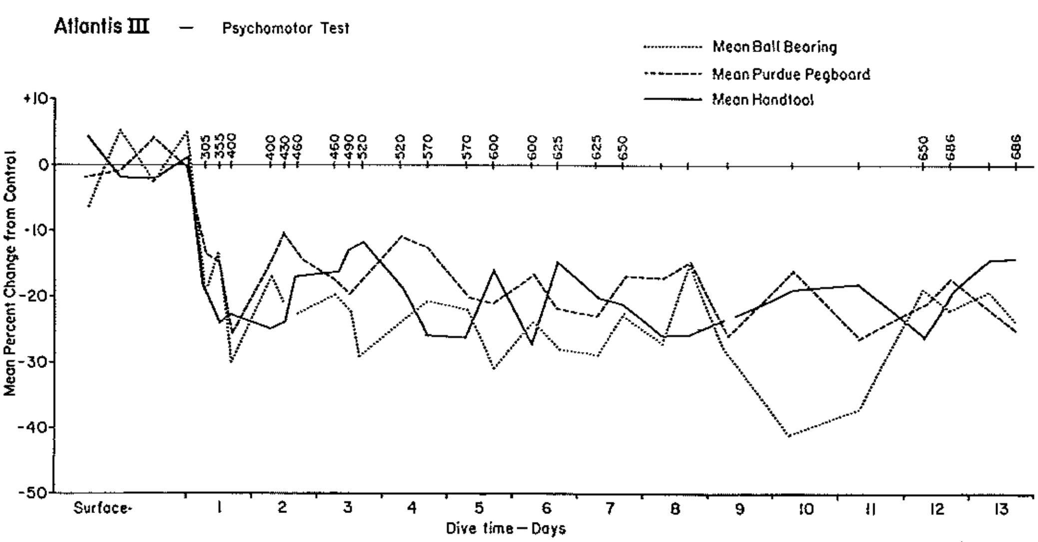

Fig. 5. Mean percentage change from surface controls in the three divers' psychomotor tests of performance at various depths during compression and during the 4 days at 650 m (2132 ft) and 1 day at 686 m (2250 ft).

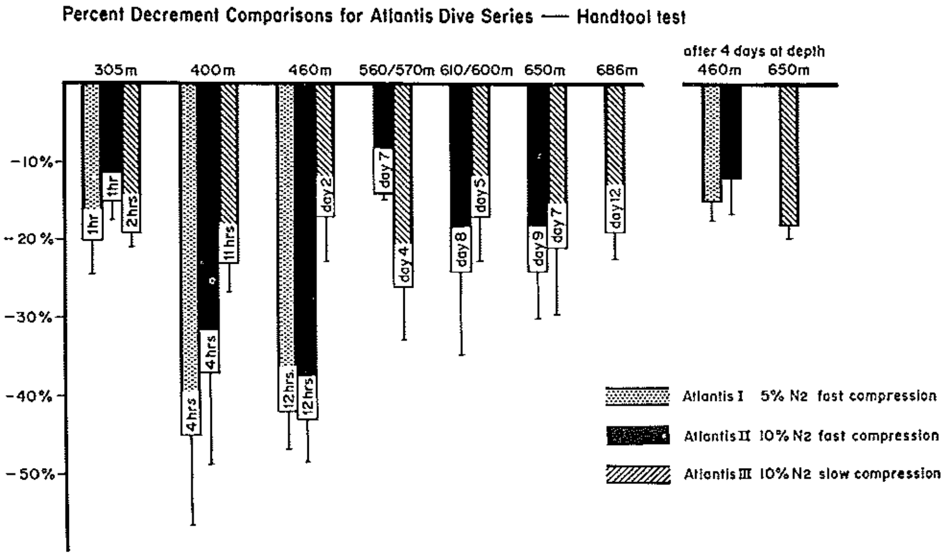

Fig. 6. Mean percentage decrements and SEM of three subjects' efficiency at the hand-tool test for Atlantis I, II, and III. Larger decrements during compression for Atlantis I and II are not seen in Atlantis III.

compression. As with the psychomotor tests, the larger decrements in tests of cognitive function (as much as 50% in arithmetic during compression in Atlantis I and II) were no longer seen with the slower compression of Atlantis III (Fig. 8). Further, at depths greater than 560–570 m (1837–1870 ft) the performance at the addition test especially (Fig. 8) showed a greater decrement than the other tests of intellectual function (Fig. 7). During decompression the results slowly returned to normal as the pressure decreased, until at 27 m they were within normal limits. Although there was some variability in susceptibility between the subjects, which is echoed in the SEM data, their results were surprisingly similar and consistent, with decrements commonly between 10% and 20%.

Electroencephalogram (EEG)

The EEG data were recorded during the performance package and separated on-line into 5 frequency bands: delta (2–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta 1 (13–20 Hz), and beta 2 (>20 Hz). Figure 9 shows the percentage changes from controls at the surface in theta activity during the experiment. Subject EK, who showed inappropriate behavior during compression, had a relatively small increase in theta of between 100% and 140% from 400 m to 686 m, whereas the other two divers were virtually unaffected throughout. Other slow-wave activity was affected similarly. On the other hand, all three subjects showed a decrease in alpha and faster activities (Fig. 10).

DISCUSSION

Atlantis I and II in 1979 and 1980 were designed to evaluate the effects of either 5% or 10% nitrogen in heliox, using mostly the same divers and an especially rapid compression time of 12 h 20 min to 460 m (1509 ft). The experiments showed, with two of the same divers, that at this rapid rate of compression 10% nitrogen was more effective than 5% nitrogen in ameliorating

TABLE 3

MEAN TEST SCORES AND SEM FROM INTELLECTUAL, COGNITIVE AND MEMORY TESTS AT SELECTED DEPTHS

Test No.	Depth, m	Arith. Correct	Arith. Attempt	AB Correct	AB Attempt	Num. Sim. Correct	Num. Sim. Attempt	Digit Span	Control Stroop	Color Stroop
Control	Surface	31 ± 3.3	33 ± 4.5	53 ± 4.4	54 ± 5.0	28 ± 1.2	29 ± 1.5	188 ± 27.5	65 ± 3.8	70 ± 3.5
3	305	24 ± 4.1	31 ± 2.7	39 ± 5.2	46 ± 2.5	23 ± 1.2	25 ± 0.9	177 ± 23.0	52 ± 3.2	55 ± 5.0
4 (p.m.)	400	26 ± 2.9	32 ± 3.5	42 ± 0.9	48 ± 3.1	23 ± 1.7	27 ± 2.2	184 ± 23.6	48 ± 4.0	55 ± 6.1
5 (a.m.)	400	23 ± 4.5	28 ± 3.4	38 ± 4.0	41 ± 5.0	26 ± 0.6	27 ± 0.0	184 ± 22.1	53 ± 0.7	60 ± 5.5
7 (p.m.)	460	26 ± 3.5	31 ± 3.0	41 ± 3.5	45 ± 4.0	25 ± 0.6	26 ± 1.0	175 ± 14.7	54 ± 0.9	60 ± 1.7
8 (a.m.)	460	25 ± 3.7	31 ± 2.5	40 ± 6.1	43 ± 7.6	26 ± 0.6	26 ± 0.7	185 ± 18.7	56 ± 3.5	62 ± 3.6
12 (p.m.)	570	26 ± 4.0	36 ± 3.8	40 ± 3.2	45 ± 3.1	26 ± 1.3	26 ± 1.3	173 ± 22.6	56 ± 0.7	64 ± 2.0
13 (a.m.)	570	24 ± 5.8	30 ± 5.3	39 ± 2.6	42 ± 1.8	21 ± 0.9	23 ± 0.3	176 ± 16.2	54 ± 1.0	61 ± 2.5
14 (p.m.)	600	20 ± 6.9	28 ± 4.9	37 ± 1.5	43 ± 1.0	22 ± 1.5	23 ± 2.3	177 ± 12.5	56 ± 3.2	56 ± 3.8
15 (a.m.)	600	24 ± 5.4	31 ± 4.1	43 ± 3.2	48 ± 1.2	22 ± 0.6	23 ± 0.3	172 ± 26.7	54 ± 2.4	60 ± 3.8
18 (p.m.)	650	22 ± 6.1	29 ± 4.7	43 ± 2.6	47 ± 2.2	23 ± 0.3	24 ± 0.9	165 ± 15.6	54 ± 2.7	58 ± 5.9
19 (a.m.)	650	17 ± 6.4	25 ± 4.4	39 ± 5.1	44 ± 4.7	22 ± 1.5	23 ± 1.0	159 ± 22.0	53 ± 3.8	59 ± 3.3
20 (p.m.)	650	22 ± 2.1	29 ± 3.2	39 ± 7.3	43 ± 4.7	22 ± 0.3	24 ± 0.3	167 ± 12.1	54 ± 2.9	59 ± 2.4
24 (a.m.)	650	22 ± 4.5	27 ± 3.6	36 ± 4.4	40 ± 3.6	22 ± 0.7	23 ± 0.0	155 ± 20.5	54 ± 3.8	59 ± 4.6
25 (p.m.)	686	20 ± 4.7	25 ± 4.2	39 ± 8.0	40 ± 7.4	21 ± 2.2	22 ± 1.5	166 ± 21.8	51 ± 4.9	57 ± 6.1
26 (a.m.)	686	22 ± 3.2	26 ± 3.3	33 ± 2.3	35 ± 1.5	22 ± 0.3	23 ± 0.3	161 ± 25.8	50 ± 1.5	58 ± 5.0
27 (p.m.)	686	23 ± 6.7	29 ± 4.0	39 ± 6.8	41 ± 7.4	23 ± 1.2	24 ± 1.8	157 ± 23.8	53 ± 4.1	63 ± 2.7
40	315	30 ± 4.1	32 ± 4.0	44 ± 4.1	48 ± 4.3	26 ± 1.3	27 ± 0.9	195 ± 24.6	60 ± 1.5	66 ± 2.6
47	27	33 ± 4.2	35 ± 4.4	48 ± 2.7	49 ± 3.0	28 ± 1.0	28 ± 0.7	189 ± 24.6	68 ± 2.6	70 ± 3.1

Total number of tests, 47. Number of subjects, 3.

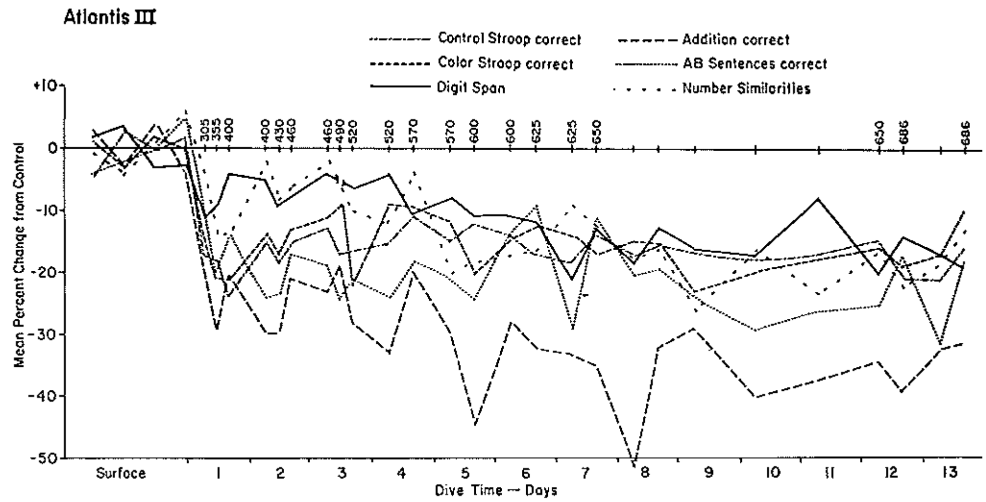

Fig. 7. Mean percentage change from surface controls in the three divers' performance at various tests of intellectual function at stage depths during compression and during the 4 days at 650 m (2132 ft) and 1 day at 686 m (2250 ft).

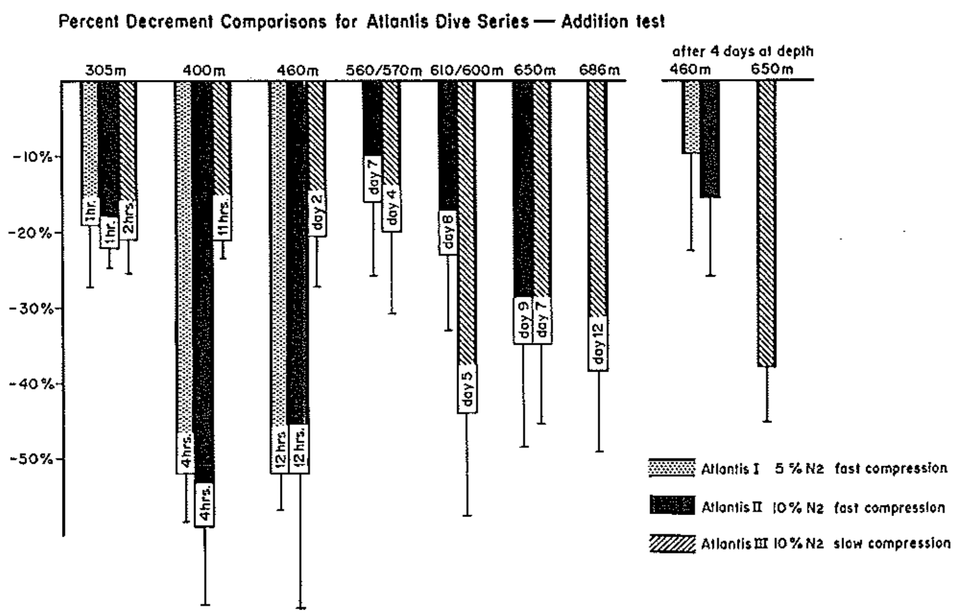

Fig. 8. Mean percentage decrements and SEM of 3 subjects' efficiency at the addition test for Atlantis I, II, and III. As with Fig. 6, larger decrements during compression at 400 m (1312 ft) and 460 m (1509 ft) are not seen with the slower compression of Atlantis III. Performance appears to deteriorate at greater depths than 560 to 570 m (1837–1870 ft).

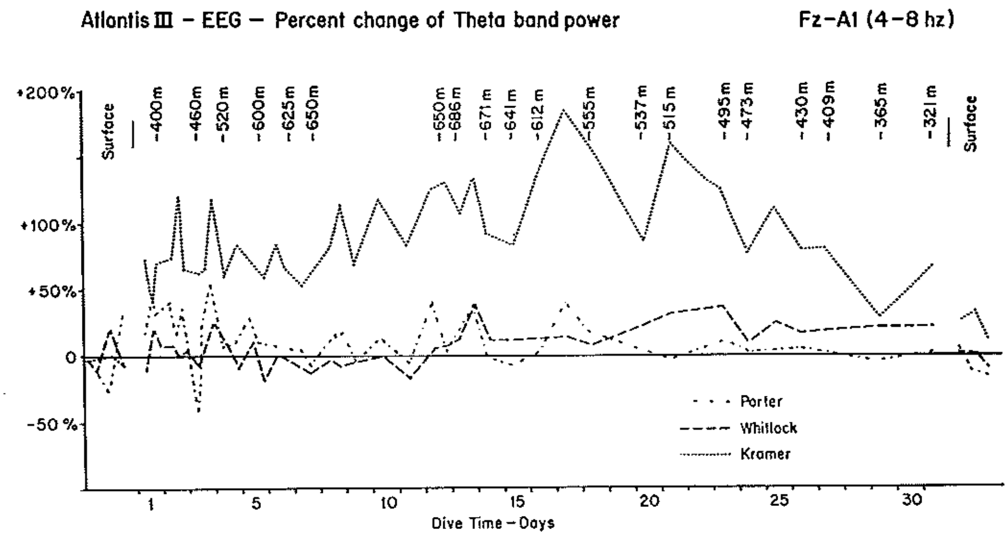

Fig. 9. Percentage change from surface controls of individual EEG theta activity. Two subjects show little change, while one is affected to a relatively minor degree compared with oxygen-helium dives to 600 m (1969 ft). (See Ref. 4.)

unpleasant signs and symptoms of HPNS such as tremors, nausea, vomiting, fatigue, and somnolence.

It is apparent in the present study (Atlantis III, with one diver from Atlantis I, one from Atlantis II and one new diver) that again the overt signs and symptoms of HPNS were prevented by use of trimix, but there was evidence, in one subject especially (the new diver), of the presence of nitrogen narcosis. Nevertheless the divers were able to function very well at their diverse and complex tasks.

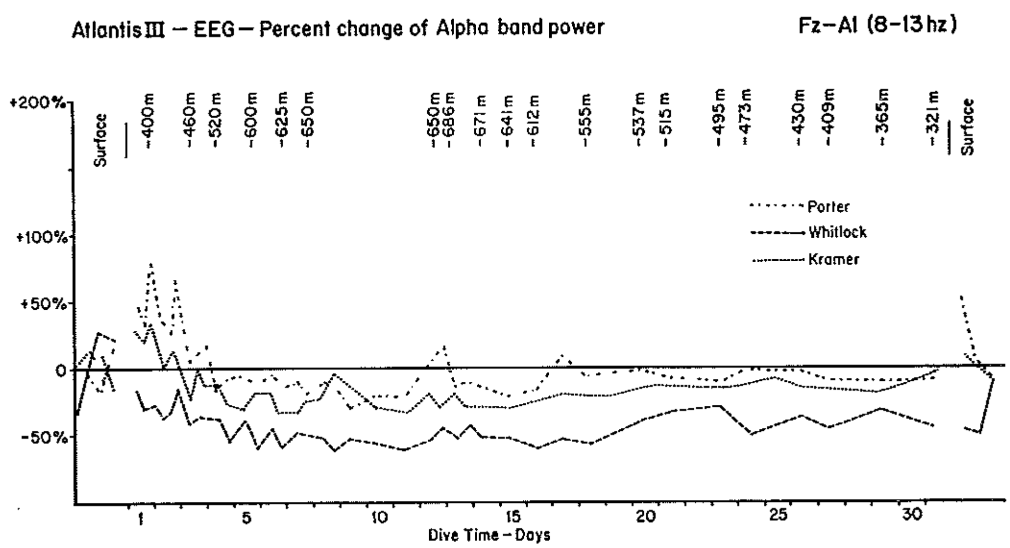

Fig. 10. Percentage change from surface controls of individual EEG alpha activity. Alpha activity is suppressed.

The performance tests for Atlantis I and II showed remarkably little difference in their results, in spite of the obvious subjective improvement in the divers during Atlantis II. The tests of intellectual performance for Atlants I and II (13), depending on the test, showed initial decrements during compression of between 20% to a maximum of 50%, which recovered over the subsequent days to decrements of from 10% to 20%, respectively (Fig. 8). Psychomotor tasks (13) were affected in a similar manner (Fig. 6).

Significantly, as seen in Figs. 6 and 8, this initial compression-related decrement was not seen in the present experiment. However, the steady-state decrement of 20% in most performance tests was still present.

Thus the slower rate of compression was effective in reducing the decrement in performance seen during the rapid compression of Day 1 in Atlantis I and II. The steady-state 20% decrement, which remains from about 400 m (1312 ft) and which was no worse at 686 m (2250 ft), is presumably due to either the presence of the nitrogen or the hydrostatic pressure.

Recent Norwegian studies (14) in which performance was compared in 6 divers at 300 m (984 ft), 3 of whom breathed trimix 10 and 3 heliox, confirmed the effectiveness of 10% nitrogen in preventing HPNS but indicated the presence of narcotic effects of nitrogen.

It is very probable that much of the 20% decrement in performance in the present study is due also to the presence of the nitrogen. For example, the divers' handwriting in their log books at 650 m and 686 m was larger than at the surface, as is commonly seen in nitrogen narcosis.

Further, at depths deeper than 570 m (1870 ft) the addition test of cognitive function, unaffected in the 460-m heliox dive by Bennett and Towse (15) in 1970, showed the greatest performance decrement accompanied by some euphoria and lassitude. This test is commonly affected by nitrogen narcosis (16). This is similar to the French *CORAZ* dives to 300 m with 4-h compression (12) compared to the Duke 300-m fast 33-min compressions (10). It implies that at slower rates of compression, which result in less-severe HPNS, 10% nitrogen is too high and may result in some signs of nitrogen narcosis in sensitive subjects, such as in the case of subject EK.

It appears that nitrogen is not directly antagonizing HPNS but that nitrogen and pressure are interacting in a complex manner to produce a picture of divers able to carry out a considerable amount of useful work with little or no tremors, nausea, or somnolence but with some slowing of ability, poor concentration, and feelings of well-being. A lower nitrogen percentage, such as 5%, may well reduce these latter effects.

The inference that a slow compression with only 5% nitrogen is the most suitable technique for deep diving is in agreement with previous work by Rostain et al. (17), Naquet and Rostain (18), and Rostain et al. (19) with baboons and man. The baboon work identified the need for regular addition of nitrogen throughout compression, as utilized in all the Atlantis dives, and showed the efficacy of nitrogen in preventing the tremors especially and in retarding convulsions to 1100 m (3609 ft). These new techniques were employed with divers to 400 m (1312 ft) (Janus IV) in 1976 (17, 18) by compressing two groups of 4 men in 24 h to 400 m with 4% trimix (1.6 b) and in 1979 with 8 divers (18, 19) in a dive to 450 m (1476 ft) with a slower compression of 38 h and an increased nitrogen percentage of 4.8% (2.2 b). Both dives used exponential compressions with stages as for Atlantis III and several days at depth to dissociate the compression and hydrostatic pressure effects.

It is pertinent that no euphoria was seen with this lower nitrogen percentage, but the more rapid compression than Atlantis III did induce fatigue and EEG modifications resembling microsleep.

The possibility that at great depths less than 10% nitrogen might be preferable was considered in the original paper defining linear addition of 10% nitrogen as the optimal concentration (11).

Henry's law as utilized in the calculations cannot be applied without corrections at very high pressures. Thus a nonlinear function may indeed be more correct, and less than 10% nitrogen may be optimal at pressures greater than 560 m (1837 ft). Further, in 1979 Smith et al. (20), using the righting response of mice, showed that pressure reversal for nitrogen, but not all anesthetic gases, was curvilinear rather than linear.

In 1981, Norwegian studies (21) comparing heliox with trimix 10 at 500 m (1640 ft) also provided further indications of the risk of nitrogen narcosis in agreement with their earlier 300 m (984 ft) study (14). The experiment also identified the considerable significance of human variability and acclimatization to effective performance. On the other hand, the dives with heliox produced tremors and myoclonic jerking but without the narcosis. It seems reasonable therefore for safe and effective deep dives to 500 m or more to select the least-susceptible divers, to use slow exponential compression rates with stages to reduce compression effects, and to use trimix 5 so as to reduce the tremor, myoclonus, and possibly nausea too, without inducing undue nitrogen narcosis.

In this regard Rostain et al. (22) have reported that by using such techniques, effective work is possible at 450 m (1476 ft). Entex 5, an extension of their 1979 study (18, 19, 23) compressed four divers in 38 h with nitrogen at 4.8% in heliox to 450 m for 12 days. Tremor was increased only by 50% to 100% and maximum EEG increases of 300% to 400% from control values were noted. Performance tests indicated decrements of 10% to 15% on arrival followed by recovery to 7.5% to 5% one day later. Whether these methods will be as effective at 650 m or 686 m remains to be determined.

These deep French trimix dives showed no paroxysmic EEG activity as reported in the *CORAZ* experiments and none were seen in the present study. This suggests that trimix is not, as was thought after the *CORAZ* study and from the electroencephalographic point of view, more adverse than heliox. Indeed the EEG data in Atlantis III, as with Entex 5, showed much less theta activity than was seen in the heliox-only slow 8-day compression of Physalie, and 6- and 12-day compression of Sagittaire IV (4). For example, the latter dive produced increases in theta activity of as much as 2000%–4000% compared to no increase in two of the Atlantis III divers and only 100%–140% in the other.

The problem of difficulty with sleep, a factor well known in deep oxygen-helium dives, however, is not resolved by trimix, although the number of nightmares is markedly decreased. The problems of disturbed nights and inability to obtain a deep stage of sleep undoubtedly leads to an accumulative sleep debt. In multiday studies at depth this can prove to be a problem and can add an important component to the ability to perform effectively. Yet there is no clear indication of this in the present data. Indeed, the performance tests at 686 m on the last day were, in general, less affected than during the 4 days at 650 m. Because it is of definite concern to the divers and can result in fatigue not related to that generated by HPNS, future studies of this kind do need to give consideration to how better sleep may be effected. This may be either through more effective personal temperature control or by pharmacological means.

We wish to express our sincere appreciation for the dedication, courage, endurance and diligence of the 3 divers, Steve Porter, Len Whitlock, and Eric Kramer, and the standby diver Maret Maxwell, and to the technical staff of the F. G. Hall Laboratory for their skilled operation of the chambers and life-support systems during the 43 days at depth and the intensive predive preparation.

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Bennett PB, Coggin R, McLeod M. Effet de la vitesse de compression dans l'utilisation du trimix pour l'amélioration du SNHP chez l'homme jusqu'à 686 m (2250 pieds). Undersea Biomed Res 1982; 9(4):335–351.—De Précédentes plongées humaines, au cours d'une série destinée à évaluer les effets physiologiques de l'hélium-azote-oxygène (trimix), ont permis de comparer les effets de 5% d'azote et ceux de 10%, en compression jusqu'à 460 m (1509 pieds) d'abord rapide (12 h 20 min), puis en compression jusqu'à 650 m (2132 pieds) en 2 j 1/2. En 1981, trois plongeurs ont été comprimés jusqu'à 650 m deux fois plus lentement que dans ces précédentes plongées, en 6 j 8 h, avec 10% d'azote dans l'héliox. Une vaste série d'études fut effectuée sur 4 j 15 h à 650 m avant de pousser la compression jusqu'à 686 m (2250 pieds) pour un séjour de 24 h, avec tests approfondis des performances psychologiques et neurophysiologiques, de la fonction pulmonaire, examens Doppler et autres. Les tremblements du SNHP et les accroissements d'activité EEG théta ont été efficacement maîtrisés avec aucune nausée, vomissement, ou somnolence (micro-sommeil). Il y avait une certaine euphorie. A 686 m, il y avait une diminution de 20% à 30% de la concentration et de l'attention, mais en dehors de cela la condition physique des plongeurs était grande et ils ont effectué toutes les tâches sans difficulté. La compression lente a evité l'important abaissement initial de 40% à 50% des performances du jour 1, comme il avait été trouvé dans les plongées à compression rapide précédentes. Par ailleurs les tests de performance ont bien montré la même diminution de 15% à 20% observée dans les précédentes plongées, excépté que plus profond que 570 m (1870 pieds) les résultats obtenus au test des additions étaient plus mauvais avec une baisse de 35%. Les résultats sont discutés en tenant compte des deux précédentes plongées à compression plus rapide et l'idée est avancée d'une non linearité de l'action antagoniste de l'azote sur le SNHP.

SNHP	compression	EEG
trimix	azote	pression
hélium	performance	tremblement

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