Undersea Biomedical Research, Vol. 16, No. 3, 1989

Neuropsychologic effects of saturation diving

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Værnes RJ, Kløve H, Ellertsen B. Neuropsychologic effects of saturation diving. Undersea Biomed Res 1989 16(3):233–251.—Neuropsychologic status of saturation divers was assessed before and after 300–500 msw dives (deep saturation diving—DSD group) and before and after 3.5 yr of ordinary saturation diving (saturation diving—SD group). Average baseline results showed the divers to be slightly superior to nondiving controls. Mild-to-moderate neuropsychologic changes (>10% impairment) were found in measures of tremor, spatial memory, vigilance, and automatic reactivity in 20% of the divers after deep dives (DSD group). One year postdive no recovery was observed except for a vigilance test. In the SD group, 20% of the divers showed >10% impairment after 3.5 yr of ordinary saturation diving. Significant reduction in autonomic reactivity was also found and there was a relationship between low autonomic reactivity before saturation diving and number of >10% impairments. For the whole group (DSD + SD divers), negative correlations were found between saturation experience and results on memory and complex visuomotor tests. Years of diving from first to last examination was positively correlated with number of >10% impairments and with reduction in autonomic reactivity. No similar correlations were found to dive variables after about 3 yr of air diving. The mild-to-moderate changes seen in some divers, therefore, seem to be the effects of saturation diving. Since one deep dive may cause an effect similar to the effect of 3.5 yr of ordinary saturation diving, there is reason to believe that repeated deep diving may lead to more pronounced neuropsychologic impairment.

saturation diving | **neuropsychologic tests**
diving experience | **longitudinal study**
MMPI

A main objective in hyperbaric research has been to study central nervous effects of exposure to high ambient pressure, for the purpose of establishing the optimal combination of compression rate and composition of breathing gas for different depths. However, neuropsychologic and neurophysiologic effects of such hyperbaric parameters as compression, depth, and gas mixture are still debated. Considerable individual variation in response to high pressure has been identified. Furthermore, it is often difficult to discriminate psychologic reactions from primarily neurogenic effects.

Several deep saturation dives performed between 1968 and 1982 showed temporal CNS changes immediately after the dives (1). Given these CNS changes observed

both immediately postdive (1) and during deep saturation dives (2), an important question is whether chronic CNS effects can develop after single or repeated exposures in the same manner as previous findings on diving accidents (3). The term "diving accident" is here defined as episodes with cerebral symptoms during or after the dive, or both. Only one study (4) has evaluated such possible long-term (>1 yr), permanent effects of deep dives (>180 msw) and no such studies have been performed on standard operational saturation diving.

An extensive range of neurobehavioral sequelae of CNS illness in divers was investigated by Værnes and Eidsvik (3). Although it is commonly found that diving-related CNS decompression illness is largely confined to the spinal cord (5, 6), 8 of 9 divers in the accident group showed abnormalities on neuropsychologic tests, indicating dysfunctions of higher CNS functions. These findings are consistent with findings in caisson workers (7, 8), and with the conclusion by Peters et al. (9) that neurologic and psychologic manifestations of decompression sickness or hypoxia or both in divers are more common than previously believed. In contrast to the study by Peters et al. (9), where the IQ level differed 2 SD between control and accident groups, the study by Værnes and Eidsvik (3) indicated that divers with average intelligence may develop specific CNS dysfunctions after severe near-miss accidents. However, data on the differences in autonomic reactivity and memory capacity between the 2 groups questioned whether embolism with multiple lesions could be the only effect of diving accidents. Several of the accident-group divers showed a syndrome of subcortical-limbic dysfunctions analogous to the studies on CNS dysfunctions due to repeated intoxications in man (10). The symptoms and signs were specific memory deficits, and in one case a total Scoville syndrome (11) characterized by retrograde amnesia. Fast habituation of autonomic responses to auditory stimulation, problems with sustained attention, and emotional instability were also characteristic of these patients.

Such symptoms may be considered psychogenic, but the amnesia and loss of autonomic reactivity strongly indicated a neurologic dysfunction. Previous studies in man and animals (11, 12) have shown that the hippocampal and amygdaloid structures share essential functions in memory. Histologic postmortem studies on subjects suffering from memory deficits due to heavy alcohol abuse (Korsakov syndrome) (13) and surgical bitemporal lesions (Scoville syndrome) (11), together with intoxication studies in rats, have shown that the hippocampus-amygdala is particularly vulnerable to change in oxygen level, presumably due to its high metabolic rate. Therefore, the combined effect of emboli with multifocal lesions or a more specific intracellular hypoxic effect on limbic structures, or both, could represent the pathophysiology in a diving accident with cerebral symptoms. The high incidence of neurotic symptoms in divers with a history of decompression illness (14) may be further elucidated in this context.

The transitory findings after deep saturation dives (1), which in some cases were similar to signs and symptoms after severe diving accidents, led to a comprehensive longitudinal study on divers in Norway to analyze possible permanent neuropsychologic changes after saturation diving, and to determine whether such changes were related to dive parameters. A total of 197 saturation divers have been tested. Of these, 82 were examined at least twice. These 82 divers represent a normal distribution of saturation diving experience from 5 to more than 1000 days. This makes it possible to conduct reliable correlation analysis between test results and dive parameters. Ninety divers will be examined a second time in 1988–1989. These 90 divers will serve as a control group since they were tested before the start of saturation diving, i.e., to verify that the divers who have been followed longitudinally do not represent a biased sample regarding neuropsychologic status at the first examination.

Data in the present study were analyzed at three levels: a) general descriptive statistics, b) frequency of mild-to-moderate neuropsychologic changes, and c) the relationship of these changes to diving parameters. Mild-to-moderate neuropsychologic impairment was defined as deterioration of performance on any given test exceeding 10% or more compared with predive-baseline level. An Accident Divers group (AD group) was included as a reference group to compare the substantial impairment often seen in association with accidents with the effects of deep sea dives and repetitious saturation diving.

METHODS

Subjects

A total of 82 saturation divers were studied. In the descriptive analysis and diver-by-diver analysis the total sample of divers was divided into 2 groups: deep saturation divers (DSD group) and saturation divers (SD group), since the DSD group had saturation experience before doing the deep dives.

The average age in the SD group (32 divers) was 29 yr (1 SD = 4.3), and diving experience was 8.5 yr. There was an average of 3.5 yr between the first examination, which was before saturation diving, and the second examination. The divers had an average of 128.7 days (1 SD = 101.9) in saturation at an average depth of 81.9 msw (1 SD = 38.3) between the first and second examination.

The average age in the DSD group (64 divers) was 29 yr (1 SD = 4.9), and diving experience was 9 yr when participating in the deep dives. The deep dives lasted between 18 and 34 days (*see* 15–23), and the participants had a saturation diving experience varying from 5 to over 500 days. Before the deep dive, average saturation depth had been 96 msw. The divers were thoroughly screened regarding neurologic problems before the deep dive.

The average age in the accident divers (n = 9) (AD group) was 35 yr (1 SD = 5 yr), and average diving experience was 9 yr (1 SD = 3 yr). The AD-group results have previously been published by Værnes and Eidsvik (3).

In the correlation analysis of diving experience and neuropsychologic results, the SD and DSD divers were treated as 1 group. In this correlation analysis, results from the *last* examination for all DSD divers and SD divers were compared with the first examination. Therefore, the average age and average diving experience increased to 33 yr (1 SD = 4.7) and 14.2 yr (1 SD = 4.8), respectively, because the majority of deep dives took place between 1980 and 1985. Average saturation experience was 6.2 yr (1 SD = 2.6) with an average of 208 days (1 SD = 188) in saturation. Average diving depth was 87.3 msw (1 SD = 42.0).

Some divers participated in a deep dive after they had been examined before and after 3.5 yr of ordinary saturation diving. The total sum of the DSD group and the

SD group, therefore, exceeds the number of divers included in the correlation analysis.

Instrument description

The following neuropsychologic tests were administered:

Test of adaptive abilities (Halstead-Reitan tests)

The test battery includes a number of tests, briefly described in the following, which have been shown to be particularly sensitive to the organic integrity of the brain (24). The category test is a nonverbal, forced-choice test of abstraction and ability to identify rules and to test out hypotheses. The tactual performance test (TPT) is a complex psychomotor test of tactile-spatial functions in which the patient is blindfolded and asked to place wood blocks of different shapes into corresponding holes on a formboard. Each hand is tested separately (dominant: TPT-D, nondominant: TPT-ND), thus making it possible to identify lateralized dysfunctions in the brain. In addition, "incidental memory" for localization (TPT-L) and form (TPT-M) of the wood block is tested.

The Seashore Rhythm Test measures auditory discrimination and sustained attention and has been shown to be sensitive to temporal lobe dysfunction. The Finger Tapping Test measures motor tempo in the hands (index fingers), thus yielding information which, together with other test results, may be helpful in identifying lateralization of brain dysfunction and localization along the rostral-caudal axis.

The Trail Making Test is a paper and pencil test of psychomotor tempo and ability to carry out planned, sequential behavior (25).

In addition to the tests described above, both an aphasia and apractognosia screening test (Halstead-Wepman) (26, 27) and tests of sensory-perceptive functions (basal visual, tactile, and auditory perception-finger gnosia and stereognostic ability) are evaluated in the Halstead-Reitan test battery. Results from all tests are summarized in the format of an impairment index, ranging from 0.0 (no impairment of cognitive functions measured) to 1.0 (severe impairment).

Tests of motor and sensory functions

Motor tests included tests of motor tempo (Finger and Foot Tapping), motor coordination (Maze Coordination Test), static steadiness (Steadiness Test), kinetic steadiness (Grooved Steadiness Test), and fine manipulative dexterity (Grooved Pegboard Test). Results from motor tests may be helpful both in identifying lateralized cortical dysfunctions and in identifying subcortical lesions. Sensory examination included both basal sensory functions and perception of visual, tactile, and auditory stimuli which were presented bilaterally and simultaneously. In addition, finger gnosia, roughness discrimination, finger-tip number-writing perception, and stereognostic ability were tested. The sensory tests are helpful in identifying cortical dysfunctions that are localized in the parieto-occipital regions.

Intelligence testing

Level of intelligence was tested using the WAIS, yielding a total IQ and a number of subresults. The test consists of 11 subtests, divided into a verbal and performance test. Test results are helpful in identifying general level of intelligence and specific dysfunctions. Discrepancy between the main parts of the tests (verbal vs. performance) may be indicative of lateralized brain dysfunction.

Memory testing

The Wechsler Memory Scale yields a total result (memory quotient) which is directly comparable to WAIS IQ. Discrepancies may indicate specific memory dysfunctions. Warrington's forced choice tests for faces and words (28) are used in the evaluation of possible differences in spatial and verbal memory.

Autonomic reactivity

Skin conductance was used to evaluate the general level of autonomic activity (basal level measured in microohms) as well as responses and habituation to 15 auditory stimuli (1000 Hz, 95 dB, 2 sec sine-wave tones), presented at irregular intervals. These measures have been shown to yield indirect and reliable information about the status of the brain-stem activating system (29).

Personality evaluation

The MMPI (30) long form (566 items) was administered. K-corrected T scores were calculated for the standard validation scales and for the clinical scales of the inventory.

Clinical interview

All divers were interviewed by a clinical neuropsychologist. A standard questionnaire was filled out as part of a semistructured interview in which the following topics were covered: a) education and diver certificates, b) diver experience (i.e., breathing gases, depths, saturation experience), c) bends, d) perceived complaints during and after saturation diving, e) previous hospitalization with focus on head trauma, f) previous CNS-related disease, g) previous reading and writing problems, h) use of medication, alcohol, and other drugs, i) libido, j) marital status, and k) previous diving accidents, if any (detailed description). The background history information was used in the correlation analysis with the neuropsychologic test results.

Procedures

The DSD group of divers participating in the dives between 300 and 500 msw were examined before, immediately after, and 1 yr after the dive. They were later followed up after about 3 yr, according to the same procedures as for the SD group. The SD group was tested before beginning saturation diving, and an average 3.5 yr later.

Each examination started with the clinical interview, performed by the same neuropsychologist for all divers. Experienced test technicians performed testing of all divers. Test results were checked by another technician before filing.

Neuropsychologic evaluation lasted about 5 h, including a half-hour break. The diver could also have extra breaks when requested.

Data analysis

Data analysis was conducted by means of the SPSS statistical package (31, 32). Frequency distributions, *t*-testing for dependent samples, and Pearson's correlations were calculated.

RESULTS

Descriptive analysis of average results

We began with a descriptive analysis of average results for the divers who had performed diving between 300 and 500 msw (DSD group), for the divers with an average of 3.5 yr of saturation experience (SD group), and divers who had been examined after diving accidents with CNS-related symptoms (AD group). The groups were compared with age-corrected normal, nondiving control levels (33).

The average results on verbal IQ (VIQ), performance IQ (PIQ), and full scale IQ (FSIQ) and 1 SD are presented in Table 1. Included are the average results for all divers who were tested before beginning saturation diving. The average IQ levels were slightly better, but within the normal variation range, compared with the normal nondiving population, which here is defined as an IQ level of 100.

The 32 saturation divers (SD group) who were followed longitudinally in this study did not show impaired general intelligence level, as compared with the total group of divers, before they started saturation diving. In other words, the 32 divers did not represent a biased subgroup of our total diving sample. There were no changes in general intelligence level from first to last examination for the SD or the DSD group.

The average results on the tests of Adaptive Abilities are presented in Fig. 1, where the *broken line* represents the level of an age-corrected, nondiving normal sample (33).

TABLE 1

AVERAGE (AND 1 SD) RESULTS ON WAIS, VIQ, PIQ, AND FSIQ FOR THE DSD, SD, ALL DIVERS WHO WERE EXAMINED BEFORE BEGINNING SATURATION DIVING (N = 122), AND AD GROUP OF DIVERS

	VIQ (1 SD)	PIQ (1 SD)	FSIQ (1 SD)
DSD group	106(11)	113(10)	109(9)
SD group	108(10)	110(10)	109(9)
Before Saturation Diving	108(11)	110(11)	109(10)
AD group	104(10)	107(9)	106(9)

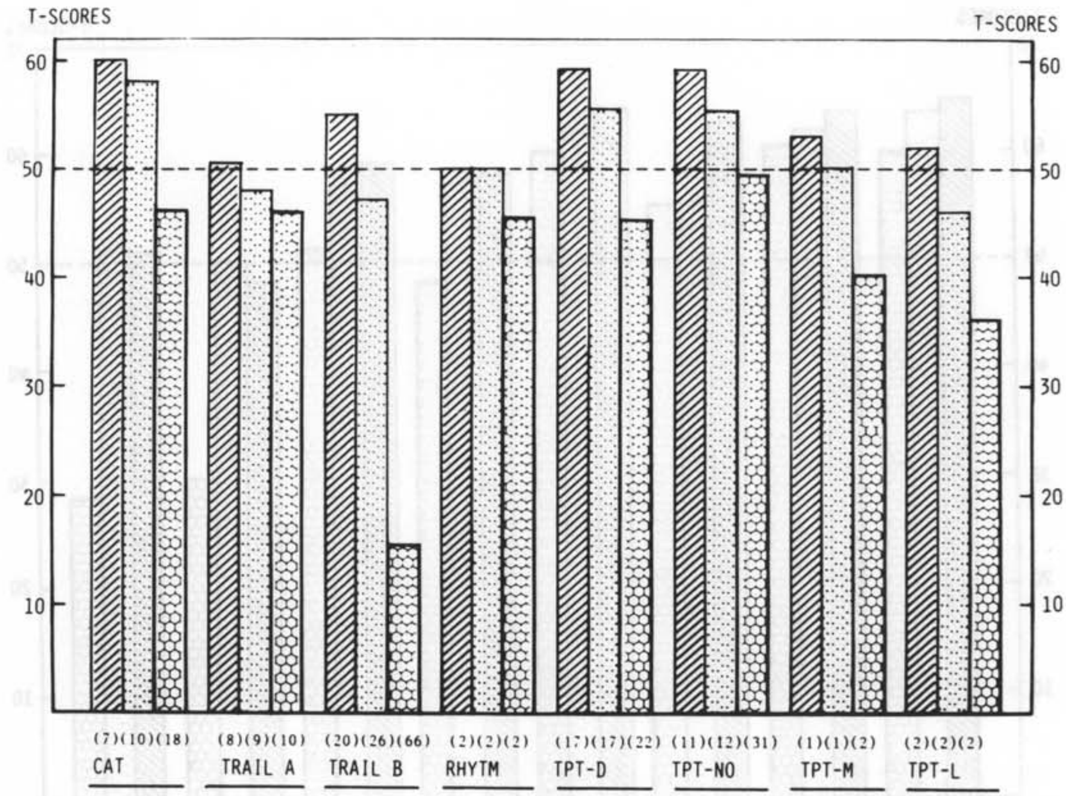

Fig. 1. Scores on selected neuropsychologic measures from the first examination. *Broken line* represents the level of an age-corrected, nondiving normal sample (24). *First bar*—DSD group; *second bar*—SD group; *third bar*—AD group. *Numbers* in parentheses represent 1 SD of average score. *CAT*—category; *TPT*—Tactual Performance Test; *M*—memory, *L*—location; *D*—dominant; *ND*—nondominant.

Figure 1 shows that the two main groups (DSD and SD) performed better than the normal nondiving control on the majority of tests of adaptive abilities. As shown previously (3), the AD group was severely impaired on several of these tests.

The same relationship was found on tests of psychomotor performance such as the Pegboard Test (Fig. 2): While the DSD and SD groups performed at a normal level, the AD group was markedly below the T-score 50. On more basic motor functions, such as hand grip strength, finger oscillation, and steadiness, all 3 groups were in the normal range. The average results on the last examination for the SD and DSD groups were at the same level as the results from first examination.

Neuropsychologic changes (>10% impairment)

Repeated testing of divers made within-subjects analyses on mild-to-moderate changes possible. For the DSD group this involved the results after an average of 3.5 yr with saturation diving compared with the results sampled before beginning saturation diving.

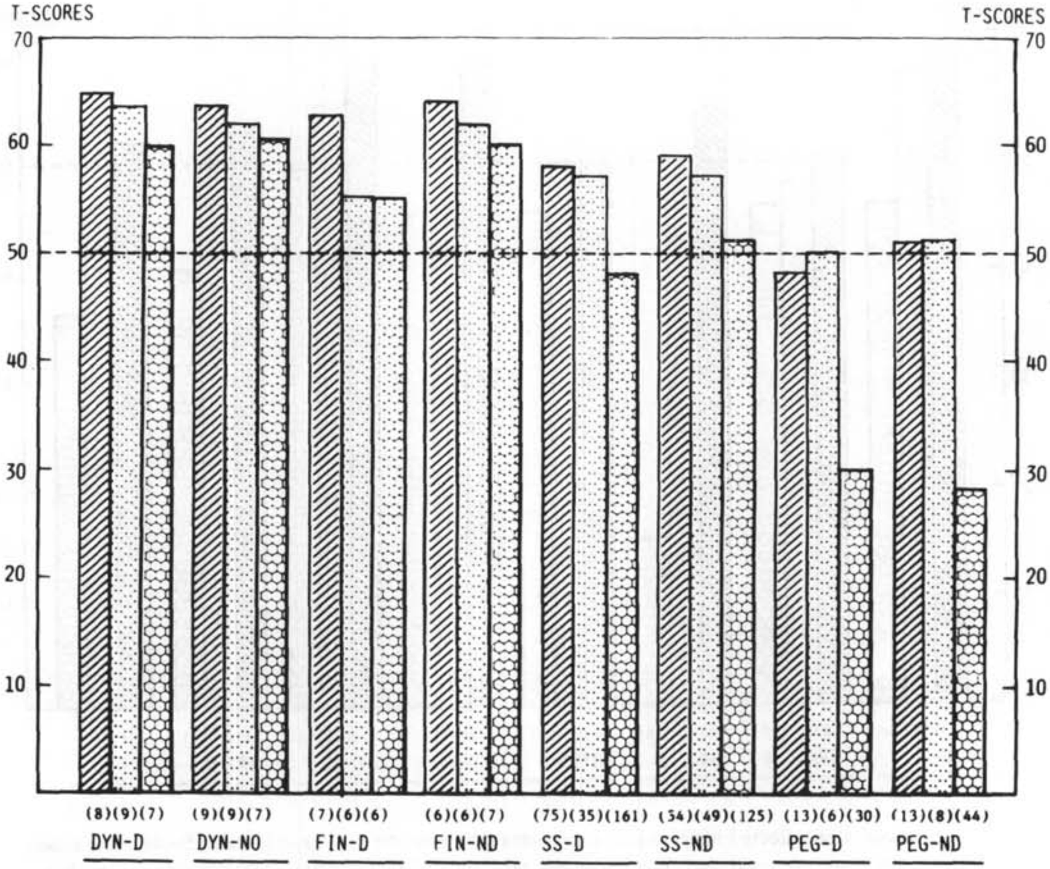

Fig. 2. Scores on motor tests from the first examination. *Broken line* represents the level of an age-corrected, nondiving normal sample (24). *First bar*—DSD group; *second bar*—SD group; *third bar*—AD group. *Numbers* in parenthesis represent 1 SD of average score. *DYN*—dynamometer; *FIN*—Finger Tapping; *SS*—Static Steadiness; *PEG*—pegboard; *D*—dominant; *ND*—nondominant.

The DSD group (>300 msw)

Neuropsychologic data on 64 divers participating in dives between 300 and 500 msw are available for the period 1980–1987. This involved the following dives: Deep Ex I (300 msw, n = 3 on heliox and 3 on trimix 10) (15); Deep Ex II (500 msw, n = 3 on heliox and 3 on trimix 10) (16); Statpipe I (350 msw, n = 6 on heliox) (17); Statpipe II (350 msw, n = 6 on heliox) (18); Fjorddive I (300 msw, n = 8 on heliox) (19); Fjorddive II (300 msw, n = 4 on heliox) (20); Trolldive (450 msw, n = 6 on heliox) (21); OTS-DCIEM dive (360 msw, n = 4 on heliox) (22); and OTS I, II, and III (360 msw, n = 18 on heliox) (23). Only dive results have previously been published on these divers, so this report is the first on postdive follow-up on neuropsychologic status.

Table 2 shows the percentage of divers with impairment of 10% or more on the different neuropsychologic tests. A reduction in Autonomic Reactivity was the most frequently observed change immediately after a deep dive (48%). This was followed

TABLE 2

PERCENTAGE OF DIVERS WITH MORE THAN 10% IMPAIRMENT ON THE DIFFERENT NEUROPSYCHOLOGIC TESTS POSTDIVE AND 1 YR POSTDIVE, COMPARED WITH PREDIVE RESULTS

Test	Postdive	1 yr Postdive
Category	5	2
Tactual Performance Test-dominant	19	9
Tactual Performance Test-nondominant	16	9
Tactual Performance Test-memory	8	7
Tactual Performance Test-location	20	16
Finger Tapping-dominant	8	18
Finger Tapping-nondominant	8	16
Rhythm Test	19	16
Trail B	6	2
Dynamometer-dominant	17	13
Dynamometer-nondominant	14	13
Static Steadiness	27	29
Pegboard-dominant	19	20
Pegboard-nondominant	19	11
Autonomic Reactivity-basal level	48	48

by an increased score on Static Steadiness (27%) and a >10% impairment of spatial memory (TPT-L) in about 20% of the divers. One year postdive, the >10% tremor increase and impaired spatial memory were still present, whereas fine motor dexterity for the nondominant hand was slightly improved. The incidence of >10% reduction of skin conductance basal level was 48% postdive. This percentage was unchanged 1 yr postdive.

The SD group

The results regarding >10% impairment after 3.5 yr of operational saturation diving, compared with presaturation diving results, are presented in Table 3.

As with deep diving, ordinary saturation diving (SD group) caused an increase in tremor (30% of the divers). Furthermore, a high percentage of divers showed a >10% impairment on spatial memory (30%) and reduction in autonomic reactivity (53%). The average basal level before saturation diving was 3.09 microohm (1 SD = 2.90). This corresponds to the average levels for a normal nondiving control group (3.22 microohm) (34). After 3.5 yr with saturation diving, a significant reduction to 1.54 microohm (1 SD = 1.55) was found (t = 2.79, $P < .01$). The incidence of >10% reduction in finger tapping was also high.

Data indicate similar processes in the SD and DSD group, i.e., an effect of saturation diving per se. Analogue test-retest studies on normal nondiving groups, such as policemen (35), have shown an average of 16% improvement between first and second examination. In general, the divers also showed average improvement between first and second examination. However, on tests for memory, sustained attention,

TABLE 3

PERCENTAGE OF DIVERS WHO HAD MORE THAN 10% IMPAIRMENT ON THE DIFFERENT NEUROPSYCHOLOGIC TESTS AFTER 3.5 YR OF SATURATION DIVING COMPARED WITH THEIR RESULTS BEFORE SATURATION DIVING

Test	Percent of Divers
Category	13
Tactual Performance Test-dominant	17
Tactual Performance Test-nondominant	13
Tactual Performance Test-memory	17
Tactual Performance Test-location	30
Finger Tapping-dominant	23
Finger Tapping-nondominant	17
Rhythm Test	17
Trail B	10
Dynamometer-dominant	13
Dynamometer-nondominant	23
Static Steadiness	30
Pegboard-dominant	13
Pegboard-nondominant	17
Autonomic Reactivity-basal level	53

and tremor a great individual variation was observed; between 20 and 30% of the divers showed >10% impairment of specific function as shown on Tables 2 and 3. Two examples comparing the divers and policemen regarding test-retest results can be given: While 20% of the divers showed an impairment of 10% or more on spatial memory, there was a less than 9% chance that the subjects in the test-retest study would show such impairment. Furthermore, 17 to 19% of the divers showed an impairment on the Rhythm Test, but there was less than 2.5% chance in the nondiving test-retest group (35).

Correlation between neuropsychologic status and background information

The correlation analysis between background history information and neuropsychologic test results involved a) analysis of background variables, b) analysis of the neuropsychologic results, c) analysis of relationships between the frequency of >10% changes and background information, d) relationships between personality variables and other data.

Significant correlations were found between having had bends and other CNS-related complaints during diving ($r = 0.42, P < 0.01$). There was a positive relationship between previously experienced head trauma and more bends ($r = 0.28, P < 0.01$), and significant correlations between having CNS-related complaints during saturation diving and having CNS-related complaints on Day 1 at surface after diving ($r = 0.63, P < 0.001$).

Analysis of the neuropsychologic test data revealed four clusters

1. *Cognitive and complex psychomotor performance:* There were significant correlations between the results on Category and Tactual Performance Test ($r = -0.36$, $P < 0.01$), and between Tactual Performance and Trail B ($r = 0.32$, $P < 0.01$).

2. *Impaired fine manual dexterity, increased tremor and impaired tactual performance:* There were significant correlations between Pegboard and Maze Coordination (test of intentional tremor) ($r = 0.41$, $P < 0.001$), and between Tactual Forms and Maze Coordination ($r = 0.30$, $P < 0.01$).

3. *Divers with impaired spatial memory and increased postural tremor:* A significant correlation was found between Forched Choice Faces and Static Steadiness ($r = -0.34$, $P < 0.01$).

4. *Cognitive and complex psychomotor performance and general level of intelligence:* We found significant correlations between WAIS and Trail B ($r = -0.48$, $P < 0.001$), and between WAIS Performance and Tactual Performance ($r = 0.52$, $P < 0.001$). In general the Tactual Performance Test was related both to cognitive variables and to complex motor performance.

Correlations between neuropsychologic status and the background information

The following five clusters emerged:

1. *Diver experience and impaired memory:* There were significant negative correlations between memory performance (Forched Choice Words) and number of days in saturation ($r = -0.37$, $P < 0.01$), and (naturally) with number of years with diving ($r = -0.43$, $P < 0.001$). Digit Recall on Wechsler Memory Test was negatively correlated with number of days in saturation ($r = -0.28$, $P < 0.01$).

2. *Saturation experience-saturation depth and grip strength:* Reduced hand-grip strength, which is one of the most common compression-related symptoms (15–23) was significantly correlated to saturation experience (for the dominant hand $r = -0.35$, $P < 0.01$, for the nondominant hand $r = -0.35$, $P < 0.01$); and to average saturation depth (for the dominant hand $r = -0.34$, $P < 0.01$, for the nondominant hand $r = -0.31$, $P < 0.01$).

3. *Number of years of saturation diving and impaired complex visuomotor performance:* There was a significant correlation to Trail B ($r = 0.35$, $P < 0.01$).

4. *Frequency of CNS-related complaints after saturation diving and impaired spatial memory:* There were significant correlations between this variable and both the Memory ($r = -0.33$, $P < 0.01$) and the Location ($r = -0.31$, $P < 0.01$) variables on the Tactual Performance Test.

5. *Frequency of CNS-related complaints after saturation diving and reduction in complex psychomotor performance:* There were significant correlations with Tactual Performance, total score ($r = 0.31$, $P < 0.01$).

We found no significant correlations between the background variables and the corresponding test results from the first examination [after about 3 yr of air diving and before saturation diving (DS group) and deep diving (DSD group)]. The only finding was a significant correlation between age and intentional tremor ($r = 0.29$, $P < 0.01$).

Degree of neuropsychologic change and background information

When correlating the number of >10% changes from first to last examination with the background information, we found a significant correlation between number of years with saturation diving from first to last examination and number of >10% changes ($r = 0.23$, $P < 0.05$) and with reduction in the basal level in autonomic reactivity ($r = -0.38$, $P < 0.001$); and a significant correlation between reduction in the basal level of autonomic reactivity and average saturation depth ($r = -0.25$, $P < 0.05$).

Another finding was a significant negative correlation between the basal level of autonomic reactivity before saturation diving and number of >10% changes on the neuropsychologic tests after 3.5 yr of saturation diving (the SD group) ($r = -0.41$, $P < 0.03$). This indicates that divers with a low basal level, possibly due to previous CNS injury, show more pronounced neuropsychologic changes after years with saturation diving than divers with normal basal level of autonomic reactivity.

Personality variables, neuropsychologic status, and the background information

The average MMPI profile of saturation divers (and 1 SD) is shown in Fig. 3. The profile is within the normal variation range, but the K, Pd (psychopathic deviate), and the Ma (mania) scales were slightly elevated. This indicates that divers in general were somewhat defensive (K-scale interpretation) (36): scores in this range indicate "persons who are being defensive and unwilling to acknowledge psychological distress," and introvert and risk-taking individualists who object to authority.

In the correlation, analysis, the following clusters emerged:

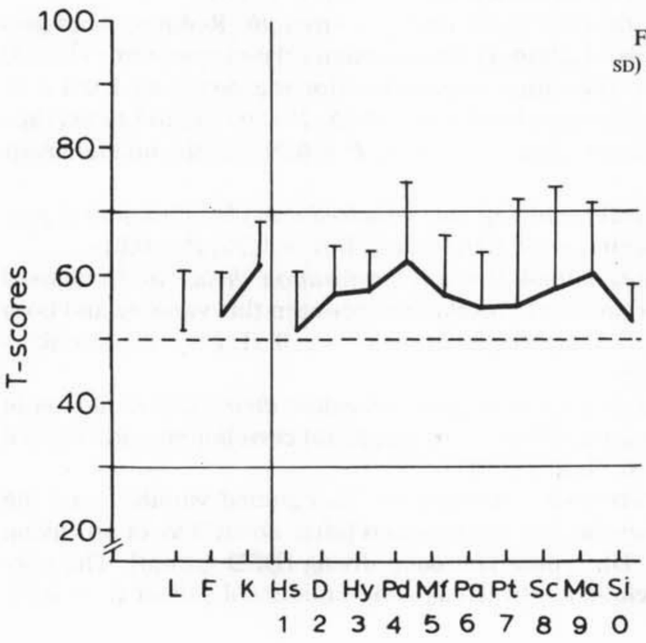

Fig. 3 Average MMPI-profile (and 1 SD) for the saturation divers.

1. *Diving experience and an individualistic-introvert attitude:* There were significant correlations between the Pd scale and saturation diving experience ($r = 0.40$, $P < 0.01$), with average saturation diving experience ($r = 0.40$, $P < 0.01$), with average saturation depth ($r = 0.38$, $P < 0.01$), and having had accidents with CNS-related symptoms ($r = 0.40$, $P < 0.01$).

2. *Divers with prior diving accidents and psychosomatic symptoms:* There were significant correlations between Hs-scale and CNS-related complaints after saturation diving ($r = 0.36$, $P < 0.01$), and with having had bends ($r = 0.36$, $P < 0.01$).

DISCUSSION

The 82 saturation divers performed on average slightly better than their age-corrected, nondiving controls. However, about 20% of the divers showed mild-to-moderate changes in some neuropsychologic functions, both 1 yr post-deep dive (DSD group) and after 3.5 yr of ordinary saturation diving (SD group). Both the frequency of such mild-to-moderate changes (number of >10% impairments) and the individual level of neuropsychologic functions were statistically related to dive variables.

Inasmuch as adequate control groups are very important in such a study, the following 4 "control procedures" were performed: a) Age-corrected, nondiving controls (33); b) divers without saturation diving experience (tested in the present project); c) a nondiving, normal group for analysis of test-retest effect (35), and d) test-retest comparison of the 82 divers.

A tremor increase of more than 10% was the most frequent indicator of CNS changes after a deep dive. Impaired spatial memory and auditory vigilance were also relatively frequent. One year later, the tremor increase and change in spatial memory were still present. A low basal level of autonomic reactivity was also still present 1 yr postdive.

There was further an increase in the percentage of divers showing >10% impairment in finger tapping, dominant and nondominant, 1 yr postdive. At least two explanations are possible: First, the DSD divers performed this test repeatedly during the dives as a part of the HPNS monitoring so the "training effect" could mask the impairment due to diving. Second, the DSD divers performed ordinary saturation diving between the deep dive and the 1-yr postdive testing. As found for the SD group, the further impairment of finger tapping could be an effect of this operational diving.

As for deep diving, ordinary saturation diving also caused increased tremor, impaired spatial memory, and a significant reduction in the basal level of autonomic reactivity. Finding relatively high incidence of neuropsychologic changes after ordinary saturation diving indicates that the "chronic" changes 1 yr after deep dives may well be an effect of repeated saturation diving.

The mild-to-moderate changes observed could be random variations within the group of normal healthy divers. However, the common pattern in test results for SD and DSD groups and the similarity to what previously had been observed among accident divers (3) could possibly indicate specific cerebral processes. Individual variation in neuropsychologic functions such as memory, attention, tremor, and autonomic reactivity was found to correlate with saturation diving parameters.

In the correlation analysis significant negative correlations were found between diving experience (number of days in saturation and number of years performing saturation diving) and memory function. Reduced hand-grip strength, which is one of the common compression-related signs (15–23), was significantly related to saturation experience and saturation depth. The same relationships were found for complex psychomotor performance. Divers who had CNS-related complaints during the immediate postdive period also showed impaired psychomotor performance.

No significant correlations between neuropsychologic status at first examination and the background information were found for the SD group. The change in neuropsychologic status from first to last examination therefore seemed to be related only to the extent of saturation diving activity.

These relationships were further confirmed when correlating the occurrence of >10% changes with diving experience. The reduction in autonomic reactivity was significantly correlated to these changes, and number of years with saturation diving was also significantly correlated with the reduction in autonomic reactivity.

An interesting finding was the significant correlation between low basal level of autonomic reactivity before saturation diving and the occurrence of >10% changes after 3.5 yr with saturation diving. This may indicate that divers with subclinical dysfunction of a mild neurologic nature were more sensitive to CNS changes during saturation diving. This is in accordance with the hypothesis of Aarli et al. (37) that CNS changes after saturation diving may be due to "an unmasking of preexisting subclinical minimal CNS lesions."

The validity of the autonomic reactivity test as a measure of an arousal deficit confirms numerous studies on mild encephalopathy. In clinical assessments of minimal brain dysfunction in children (38) and adults (39, 40), this method has become an important part of neuropsychologic evaluation. The test has also been used in evaluating central stimulants during neuropsychologic rehabilitation (41, 42).

The divers studied showed normal IQ levels, a normal neuropsychologic status and memory functions, and normal personality profiles. The significant correlations between subtle neuropsychologic changes and diving variables therefore indicate that we observed early signs of a possible CNS dysfunction in some divers. Our findings may lead to the hypothesis that repeated deep diving will give more pronounced neuropsychologic changes. This important question will be further analyzed in this longitudinal study when operational diving deeper than 200 msw is conducted. Such deep diving offshore is planned to start in 1989 in the Norwegian sector of the North Sea.

Our findings are in agreement with the results reported by Curley (4) on the U.S. Navy diving experience; no permanent deficits in cognitive or CNS functioning in these divers were detected. However, instead of looking only at average results as in Curley's study (4), an analysis of a possible pattern of the subtle individual variation was conducted. A further difference from the USN study was the correlation analysis including background parameters and dive variables. It was not made clear in Curley's study why such analyses were not performed. Our findings indicate that these subtle variations in test results were not random but related to the extent of saturation diving for some divers. In that respect our findings do not support Curley's statement (4) that "Transient emotional and perhaps cognitive changes may occur, but if present these changes are so subtle as to be undetectable by the current assessment methodology."

Even if the mild-to-moderate changes indicate the start of a pathologic process on subcortical level in some divers (mild encephalopathy) such as a decrease in memory and vigilance, low autonomic reactivity, and increased tremor, the underlying mechanisms are unclear. The degree of individual reaction and the variation in symptomatology indicate that the mechanisms for both the temporal and the subtle permanent changes after saturation diving are very complex. Individual factors, additive factors, and synergistic mechanisms may be involved. When trying to understand such mechanisms the tendency to move back and forth from macro- to microlevels (from results on behavior-clinical symptoms to studies on transmitter changes) is problematic. In Table 4 some of the most important factors for the development of temporal or permanent CNS changes are summarized.

What are the possible mechanisms behind this mild encephalopathy which cannot be detected by standard neurologic examinations? Are there analogous findings in clinical research that could indicate possible pathogenesis? Studies of Alzheimer's disease by George et al. (43) have recently linked the presence of periventricular white matter lesions (PWMLs) to increased motor and gait deficits on neurologic examinations and to altered patterns of glucose utilization as measured by positive emission tomography (44). Several reports have also confirmed the association of PWMLs with computed tomography (CT) that demonstrates small vessel disease in the brain (45, 46). The hyalinosis and white matter rarefaction are consistent with hypertensive encephalopathy (43, 45). As many as 10–30% of cognitively normal elderly study subjects are PWML-affected. This number has been reported on CT and nuclear magnetic resonance (NMR) studies several times (47). Kluger et al. (47) have recently reported that PWMLs in normal subjects are associated with the same subtle deficits as we have found in saturation divers. The performance of 17 cognitively normal elderly subjects (6 with CT evidence for PWMLs in their frontal lobes and 11 without such lesions) were analyzed on cognitive and motor tests. As for our divers, all subjects were within accepted ranges of normality (extensive medical, neurologic, psychiatric, and on cognitive examinations; scores 1 and 2 on the Global Deterioration scale) (48). The group with frontal PWMLs had significant ($P < 0.005$) deficits of motor performance, memory, and vigilance (choice reaction time).

Kluger et al. (47) suggested that the presence of frontal PWMLs in otherwise cognitively normal subjects was associated with subclinical dysfunction. Their findings raise a number of questions. Is the presence of frontal PWMLs partly responsible for the mild encephalopathy syndrome in our divers, analogous to the often reported observation of psychomotor slowing with advancing age? The frequency of about 20% in our divers corresponds to the relative frequency of 10–30% who were PWMLs affected in the Kluger study (47). Do frontal PWMLs herald the subsequent development of a more widespread cognitive decline? A study by Steingart et al. (49) linking the presence of PWMLs with both mild cognitive impairment and motor dysfunction in elderly subjects suggests that the answer to this question is affirmative. Animal studies in which kainic acid was injected into the amygdala have given similar distal cell death in the hippocampus and the periventricular structures (50, 51). It is not known, however, if such lesions in animals can give analogous performance decrements of memory, vigilance functions, and motor activity. As a consequence of the clinical findings reported here, such studies of both chemical lesions and high-pressure exposure have recently started at the University of Bergen and at NUTEC. This research may help clarify some of the questions raised by unmasking the CNS

TABLE 4
POSSIBLE FACTORS FOR THE DEVELOPMENT OF TEMPORAL AND PERMANENT CNS CHANGES AFTER SATURATION DIVING

Environmental Factors	Pathophysiology	Individual Factors	Other Factors
Hydrostatic pressure	Silent bubble	Subclinical defect	Alcohol consumption
O_2/Pressure synergy	Cellular hypoxia	Predisposed sensitivity, to N_2 narcosis, HPNS, etc.	Pattern of alcohol drinking in conjunction with diving
Decompression rate	Transmittor changes		
Compression rate	Reduced cerebral blood-flow	Low stress tolerance	Use of other drugs
Workload-pressure synergy		Marginal intellectual status	

processes that underly the mild, but nevertheless significant, neuropsychologic changes observed in deep sea divers.

Manuscript received August 1988; accepted March 1989.

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