# Change in strategy of solving psychological tests: Evidence of nitrogen narcosis in shallow air-diving.

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Petri NM. Change in strategy of solving psychological tests: Evidence of nitrogen narcosis in shallow air-diving. Undersea Hyperb Med 2003; 30(4): 293-303 - The depths from 10 to 30 m are usually not considered narcotic in scuba air-diving, and evidence of psychomotor disturbances attributable to nitrogen narcosis at these depths is weak and contradictory. 15 experienced male divers were tested in a chamber at 1, 2, 3, and 4 bars over five consecutive days using a battery of computer generated psychological tests-Computerized Reactionmeter Drenovac (CRD-series). Total test solving time, minimal single task solving time, total "ballast" time, and total number of errors were recorded. Nitrogen narcosis effects were evident at all hyperbaric pressures with marked performance differences among subjects. MANOVA revealed significant effects of nitrogen partial pressure for groups of the same variables as follows: total test solving time ($p<0.001$), total "ballast" time ($p<0.001$), and total number of errors ($p=0.038$), but not for minimal single task solving time. ANOVA showed significant effects of pressure only on tests of visual discrimination of signal location (total test solving time: $p=0.012$, total "ballast" time: $p<0.001$), simple convergent visual orientation (total test solving time: $p=0.012$), and convergent thinking (total test solving time: $p=0.002$, total number of errors: $p=0.049$). The order of the pressure exposures had no influence on subject performance. Impaired psychomotor processing found during air exposures from 2 to 4 bars suggests that nitrogen narcosis at depths usually considered safe from its effects might be a problem in underwater operations that require accuracy, speed, limited time of performance, and complex psychomotor skills.

*diving, nitrogen narcosis, performance, psychology, perception*

## INTRODUCTION

Narcosis from elevated nitrogen partial pressures has been a concern of the diving community for more than 150 years. Nitrogen narcosis has been studied extensively, and excellent reviews are available (1-4). The term describes a group of signs and symptoms characterized by deteriorating intellectual and neuromuscular function, and disturbed mood and behavior. Its cause is complex and not attributable to a single factor. Divers usually think that nitrogen narcosis affects performance starting at 5 bars, with further impairment as depth increases. Behnke and co-workers described performance impairment at 3 bars characterized by euphoria, retardation of higher mental processes, and impairment of muscular coordination. At 4 bars, they described feelings of stimulation, excitement, and euphoria (5). These findings were almost forgotten until Cousteau "rediscovered" nitrogen narcosis in 1953, naming it "*l' ivresse des grandes profondeurs"* or rapture of the deep (6). Poulton later also suggested that mental impairment could occur at pressures considerably less than 4 bars (7). Bennett and co-workers found deterioration of performance at 4 bars but not at lower pressures (8). Considering possible nitrogen narcosis at even shallower depths, Bennett later stated: "...there are very sensitive tests which, under the right conditions, will show evidence of quantitative narcosis, but it would seem that such evidence is but of academic interest..." (1).

Little attention has been paid to nitrogen narcosis effects in shallow air-diving, especially compared to similar effects in deep diving. In a 1983 publication of the Undersea and Hyperbaric Medical Society, 473 abstracts dealing with nitrogen narcosis in diving had been collected since 1935 (9). According to a review by Biersner, only 27 of them could be considered relevant to air-diving (10). His conclusion was based on an analysis of testing techniques, data presentation, subject characteristics, performance of control measurements, experimental design, immersion effects, neurophysiological effects, and some mixed effects. Only three of the 27 papers deal with simulated shallow air-diving; at 2 bars (8), 4 bars (8,11), and 4.2 bars (12). Four other papers deal with immersion experiments; at 4 bars (13-15) and at 4.3 bars (16). One paper dealing with nitrogen narcosis in simulated shallow air-diving (4 bars) was published in 2000 (17), making only eight relevant reports since 1935. They span a period of almost 40 years (1962 - 2000) and reflect an older philosophy of the narcosis problem, questions unanswered at the time, and a different approach to psychological methodology. Because such differing methodologies were used, comparisons of most of the results are difficult or impossible. Tests that were applied included sorting of playing cards (8), conceptual reasoning (11), light signal reaction time (11,12), mirror drawing (12), short term memory (13), learning abilities (13), manual dexterity (11,13,14), sentence comprehension (13,14), intelligence (13,14), simple arithmetic operations (13,14), mental abilities (11,12-15), digit copying (15), simple motor abilities (16), visual performance (16), recognition memory (17), and working speed (17). In all the papers, impaired performance, at least to some degree, was reported. Because some studies found significantly different outcomes on similar tests, it seemed prudent to check the (non)importance of nitrogen narcosis in shallow air-diving in a study designed to include the most important descriptors of psychomotor performance, such as working speed, credibility, accuracy, stability, short term memory, long term memory, and behavior in complex situations.

Nitrogen narcosis in air-diving has rarely been checked with computerized tests, but when it was, only at pressures above 4 bars (18-21). Previous studies in which the Computerized Reactionmeter Drenovac (CRD-series) was used confirmed its sensitivity and ability to detect even minor psychomotor performance changes (22-31). The CRD is a battery of psychological tests based on a novel theoretical concept (32). It has not been used to date to study nitrogen narcosis but an unpublished pilot study revealed psychomotor changes in air at 2 bars. Since divers, both novice and experienced, report occasional psychomotor problems at various levels while air-diving to depths even shallower than 30 m, nitrogen narcosis effects were tested at 2, 3, and 4 bars in order to clarify the characteristics and relevance of possible psychomotor changes to diver safety and work outcome.

## METHODS

### Subjects

15 healthy male divers, average age of 28.3 ± 4.6 years, with 5.7 ± 4.8 years of diving experience, after signing informed consent, participated in a study pre-approved by the institutional review committee.

### Psychological Testing

CRD-series consists of software and four computer-supported work instruments. Before the experiment, the subjects were trained to use the instruments, repeating tests for three consecutive days, two hours a day, in the same hyperbaric chamber used later for the experiment. The subjects were considered to have reached "stable" entry level results when they obtained five results in a row on each test, without a trend for improvement. Among 38 standard tests available on the CRD-series, five representative tests (11, 21, 311, 324, and 413), covering a broad spectrum of mental and psychomotor processing, were selected for the study. The sequence of testing was from the most simple to more complicated, i.e. 311, 324, 21, 11, and 413. The goal was to complete each test as quickly and with as few errors as possible. If the subject gave an incorrect response, an error was counted, and the test would not proceed until the correct response was given.

Measured were total test solving time (TT), minimal single task solving time (TMIN, i.e. maximal speed of mental processing), total "ballast" time (TB, sum of differences between various single task solving times and TMIN, representing "stability" of mental processing), and total number of errors (TE, i.e. credibility and accuracy of mental processing). TT could be understood as an outcome of psychomotor changes, while TMIN, TB, and TE as descriptors of psychomotor manipulations of a certain type or level undertaken to keep TT values as close to surface controls as possible. At each pressure, the subjects were always assigned with a different variation of any test given on the same CRD-series instrument.

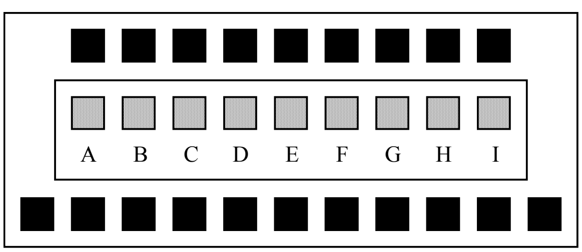


**Figure 1**. Instrument CRD-3, simplified (black squares: buttons, gray, squares: light-emitting diodes, LEDs). It was used to test the ability of visual discrimination of signal location (test 311) and the ability of short-term memory actualization (test 324). LEDs illuminate in random order, and correct answer is given by pressing the button below the corresponding LED (test 311) or in a defined sequence memorized by the subjects before testing (test 324). A correct hit automatically results in a new task.

Test 311, consisting of 60 single tasks, was used to measure visual discrimination of a signal location. Light-emitting diodes (LEDs) illuminate in random order, and the correct answer is given by pressing the button below the corresponding LED.

Test 324, consisting of 60 single tasks, was used to measure short-term memory actualization. LEDs illuminate in random order and the correct answer is given by pressing the buttons in a defined sequence memorized by the subjects before testing. The sequence of buttons in this experiment was “left-right-right-below”, and the subjects were required to actualize this previously memorized sequence.

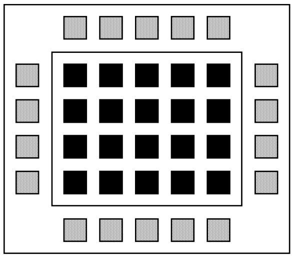

**Figure 2.** Instrument CRD-2, simplified (black squares: buttons, gray squares: light-emitting diodes, LEDs). It was used to test the ability of simple convergent visual orientation (test 21). LEDs illuminate simultaneously; the first either in the left or in the right column, the second either in the upper or in the lower row. A correct answer is given by pressing the button at the intersection of the two LEDs, which automatically results in a new task.

Test 21 was used to measure simple convergent visual orientation. In each of 35 single tasks, two LEDs illuminate simultaneously; the first either in the left or in the right column, the second either in the upper or in the lower row. The correct answer is given by pressing the button at the intersection of the two LEDs.

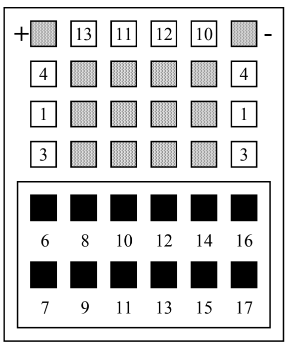


**Figure 3.** Instrument CRD-1, simplified (black squares: buttons, gray squares: light-emitting diodes, LEDs). It was used to measure the ability of convergent thinking, i.e. constructing and solving simple mathematical tasks (test 11). In each of 35 single tasks, two LEDs emit at the same time. One of 12 LEDs positioned in the middle of the instrument indicates which numbers in the upper row and lateral columns to use to construct mathematical problem. The second LED illuminates either in the right or the left upper corner, and indicates to use either addition or subtraction. A correct answer is given by pressing the corresponding button in the lower part of the instrument, which automatically results in a new task.

Test 11 was used to measure convergent thinking, i.e. general ability to perform in problem situations, such as constructing and solving simple mathematical tasks. 18 tasks were addition, and 17 were subtraction. In each of the tasks, two LEDs emit at the same time. One of 12 LEDs positioned in the middle of the instrument indicates which numbers in the upper row and lateral columns should be used to construct the mathematical problem. The second LED is one of the two in upper corners, and indicates which operation to use. The correct answer is given by pressing the corresponding button in the lower part of the instrument.

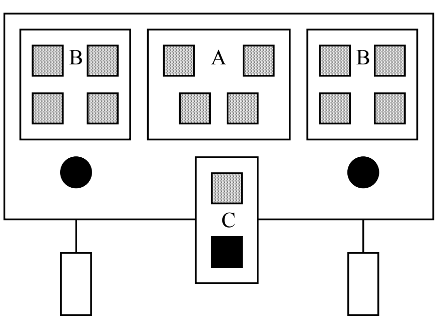


**Figure 4.** Instrument CRD-4, simplified (black circles: buttons, white rectangles: pedals, gray squares: light-emitting diodes, LEDs). It was used to test the ability of operative thinking or complex psychomotor eye-hand coordination (test 413). Upper two LEDs in the field “A” require a response by hands (buttons), lower two by feet (pedals). Each of 35 single tasks is a different combination of two, three or four LEDs that illuminate at the same time, requiring various combinations of buttons and pedals to be pressed at the same time to give a correct answer, which automatically results in a new task.

Test 413 was used to test operative thinking or complex psychomotor coordination. The instrument consists of four LEDs, buttons and pedals. In this experiment, only field “A” was used. Upper two LEDs require a response by hands (buttons), lower two by feet (pedals). Each of 35 single tasks is a different combination of two, three or four LEDs that illuminate at the same time, requiring various combinations of buttons and pedals to be pressed to give the correct answer.

### Experimental setting

The experiment was conducted in a multiplace hyperbaric chamber by repetitive measurement of the same indicators of mental and psychomotor functions at 1, 2, 3, and 4 bars, respectively, during five consecutive days. The subjects were familiarized with the environment during numerous earlier exposures and trained to perform on CRD-series. During the experiment, they were not provided with any feedback about the results of the tests in order to avoid possible motivation decrement (33). The testing was commenced five minutes after reaching a certain pressure since full saturation of the brain with nitrogen could have been expected to occur after that time (34). In a group of 8 randomly chosen subjects, the testing would begin at atmospheric pressure, followed by testing at 2, 3, and 4 bars, respectively. In the second group, the subjects were first tested at 4 bars, then at 3 and 2 bars, and finally at atmospheric pressure. This sequence was inverted every other day in both groups.

### Statistics

MANOVA and ANOVA procedures were used for statistical analyses. P-values less than 5% were considered significant and were checked by a post-hoc LSD test.

## RESULTS

Marked differences in performance were noticed among the subjects, both at 1 bar and at pressures above atmospheric. Therefore, for the purpose of statistical analysis, all the results were converted to z-values. MANOVA revealed significant effects of increased air pressure for groups of the same variables on all five tests, as follows: TT ($p<0.001$), TB ($p<0.001$), and TE ($p=0.038$), but not for TMIN. ANOVA showed significant effects of increased air pressure only on the tests 311, 21, and 11. The results (mean values ± SD) are presented in Tables 1 to 3. P-values less than 0.05 are indicated with an asterisk.

**Table 1.** ANOVA results of tests of visual discrimination of signal location (test 311).

| | | | |
|---|---|---|---|
| Total test solving time | 26.001 ± 2.177 [s] | F=3.334 | p=0.019* |
| Minimal single task solving time | 0.271 ± 0.061 [s] | F=2.552 | p=0.055 |
| Total “ballast” time | 9.825 ± 3.071 [s] | F=7.096 | p<0.001* |
| Total number of errors | 0.479 ± 1.004 | F=1.531 | p=0.206 |

In test 311, post-hoc LSD test of TT revealed significantly impaired psychomotor performance at 2 bars ($p=0.032$), 3 bars ($p=0.003$), and 4 bars ($p=0.038$) compared with atmospheric controls. TB was impaired significantly at 2 bars ($p=0.004$), and 3 bars ($p<0.001$), but not at 4 bars. There was also a significant improvement of TB at 4 bars compared with 3 bars ($p<0.001$). In test 21, post-hoc LSD test of TT revealed significantly impaired psychomotor performance only at 2 bars ($p=0.015$) compared with atmospheric controls. In test 11, post-hoc

LSD test of TT revealed significantly impaired psychomotor performance only at 4 bars (p=0.024) compared with atmospheric controls, and at 3 bars (p=0.028) compared with 2 bars. TB was significantly impaired only at 4 bars (p=0.012) compared with atmospheric controls, but there was also significant impairment of TB at 3 bars (p=0.018) and 4 bars (p<0.001) compared with 2 bars. TE was significantly higher at 4 bars (p=0.006) compared with 2 bars.

**Table 2.** ANOVA results of test of ability of simple convergent visual orientation (test 21).

| | | | |
|---|---|---|---|
| Total test solving time | 28.903 ± 3.763 [s] | F=3.740 | p=0.011* |
| Minimal single task solving time | 0.587 ± 0.085 [s] | F=0.496 | p=0.684 |
| Total "ballast" time | 8.504 ± 2.765 [s] | F=0.889 | p=0.447 |
| Total number of errors | 0.667 ± 0.924 | F=1.349 | p=0.258 |

**Table 3.** ANOVA results of ability of convergent thinking test (test 11).

| | | | |
|---|---|---|---|
| Total test solving time | 75.419 ± 16.888 [s] | F=5.106 | p=0.002* |
| Minimal single task solving time | 1.274 ± 0.261 [s] | F=0.743 | p=0.527 |
| Total "ballast" time | 31.713 ± 13.081 [s] | F=4.730 | p=0.003* |
| Total number of errors | 1.803 ± 1.846 | F=2.635 | p=0.049* |

Figures 5, 6, and 7 demonstrate interactive changes of TT, TMIN, TB, and TE, respectively, showing manipulations the subjects were undertaking as pressure increased to preserve working speed, stability, and accuracy. The changes were neither regular nor uniform in a sense of impaired performance, but rather complex ways of preserving TT values as close to the controls as possible. The subjects did not manage to preserve TT surface values at 2, 3 and 4 bars, respectively, on test 311, and at 3 and 4 bars on test 11. As for test 21, at 4 bars they performed paradoxically even better than at atmospheric pressure (Fig. 7). Although similar manipulations were observed for tests 324 and 413, neither change was statistically significant.

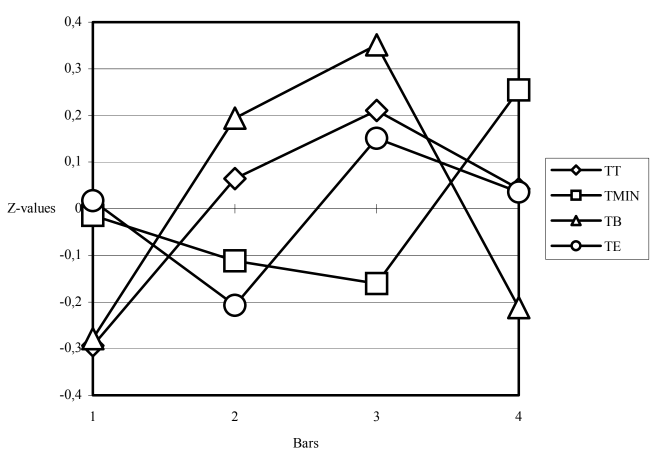


**Figure 5.** Changes of descriptors of psychological manipulations on visual discrimination of signal location (test 311) at the pressures of 1, 2, 3, and 4 bars (TT: total test solving time, TMIN: minimal single task solving time, TB: total "ballast" time, TE: total number of errors). Statistically significant impairment, compared with 1 bar controls, were found for TT at 2 (p=0.032), 3 (p=0.003), and 4 bars (p=0.038), and for TB at 2 (p=0.004) and 3 bars (p<0.001).

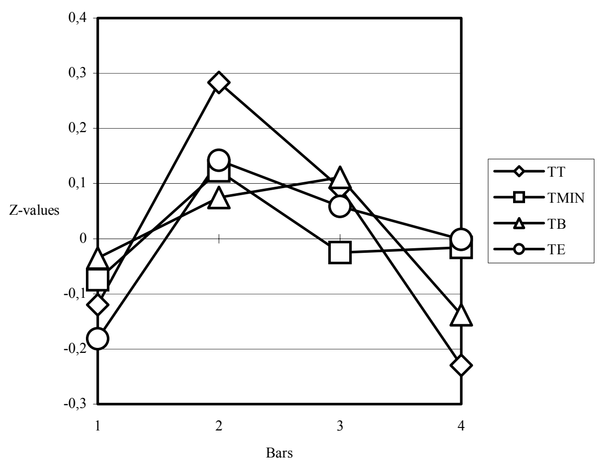


**Figure 6.** Changes of descriptors of psychological manipulations on simple convergent visual orientation (test 21) at pressures of 1, 2, 3, and 4 bars (TT: total test solving time, TMIN: minimal single task solving time, TB: total "ballast" time, TE: total number of errors). Statistically significant impairment, compared with 1 bar controls, was found only for TT at 2 bars (p=0.015).

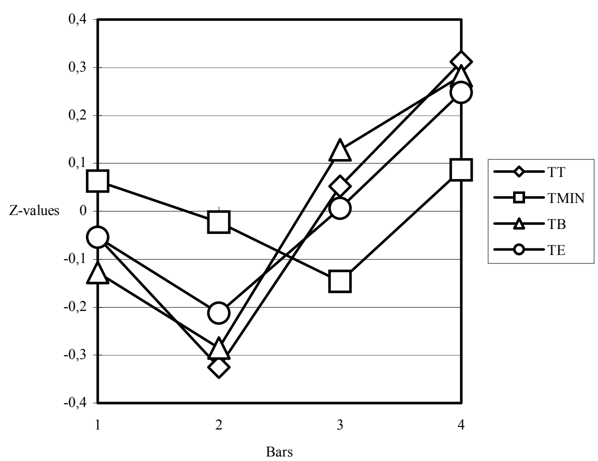


**Figure 7**. Changes of descriptors of psychological manipulations on ability of convergent thinking (test 11) at pressures of 1, 2, 3, and 4 bars (TT: total test solving time, TMIN: minimal single task solving time, TB: total "ballast" time, TE: total number of errors). Statistically significant impairment, compared with 1 bar controls, were found at 4 bars for TT (p=0.024) and TB (p=0.012).

## DISCUSSION

Both quantitative narcosis and impaired quality of psychomotor processing were found in this study expressed by a change in the strategy of solving various psychological test problems, but this did not impair psychomotor performance at all the pressures above atmospheric. No clear dose-response changes were found, as might have been expected with increased nitrogen dose. Strategy changes were evident in working stability (TB), speed of performance (TMIN), and various numbers of errors (TE). This suggests that the subjects were influenced by nitrogen narcosis at low air pressures, but were also able to compensate for it at the same time. In solving various psychological problems, their general approach was to work slower and at a more stable pace. At some pressures, they were even more successful performing in such a manner (Fig. 5 to 7). These conclusions are generally compatible with the results of earlier studies despite dissimilar methodology of studies performed in simulated (8,11,12,17) and real shallow air-diving (13-16).

In 1962, in a study today considered a classic, Kiessling and Maag (11) found at 4 bars worse light signal reaction time by 21%, reasoning ability by 33%, and manual dexterity by 8%.

The present study used much more sensitive measurements of reaction time (test 311), reasoning ability (test 11), and motor dexterity (test 413), but failed to confirm similar performance decrement. The differing results of the two studies could be explained by different training of the subjects and different methodology. In 1963, Frankenhaeuser and co-workers (12) tested signal reaction time at 4.2 bars of air pressure, but found no statistically significant changes in comparison with atmospheric controls. This is not consistent with the findings in the present study in which decrement on test 311 was already present at 2 bars. In 1967, Bennett and co-workers used the playing cards sorting test and found no statistically significant changes in total test solving time and in the number of errors at 2 bars. At 4 bars, the number of errors was increased 18% compared with surface controls (8). None of the tests used in the present study is similar to the playing cards sorting tests, so the results can be compared only at a level of general compatibility of conclusions.

In 1971, Baddeley studied simple motor abilities at 4.3 bars in divers who were assigned to insert various screws into adequate perforations. Total test solving time was 16% longer compared to surface controls (16). In 1972, Davies and co-workers conducted a more complex study in divers breathing air at 4 bars. Tests of short term memory, learning abilities, and words comprehension did not show statistically significant changes compared with surface controls. Ability to perform simple mathematical operations was 16%, logical understanding of sentences 17%, and Bennett manual dexterity test 18% worse compared to 1 bar (13).

In 1976, Synodinos applied the digits copying test and mental abilities test on the surface, at 0.3 bars, and at 4 bars on 16 subjects split into two groups exposed to air pressure in inverted sequence. The results for the entire group were significantly worse at 4 bars compared with the surface and 0.3 bar controls. The author concluded that the degree of nitrogen narcosis was influenced by the sequence of pressures, and that tasks should be trained in shallow water before accomplishing them at actual depths (15). In 1976, Osborne and Davis tested divers at 4 bars. A simple mathematics operations test showed a 33% decrement, and a sentence comprehension test 16% (14). Davies and co-workers (13), Osborne and Davis (14), Synodinos (15), and Baddeley (16) tested divers in immersion using different tests than those of the present experiment, so the results can be compared only with utmost care. However, all the studies showed impaired performance at increased pressure, as did this one.

More recently, Sparrow and co-workers (17) reported a change in the strategy of solving test problems in their subjects at 4 bars of simulated air-diving. Using the recognition memory test, they found that the sensitivity index was invariant, but the criterion (beta) became stricter under hyperbaric pressure. For speed test, the results showed a progressive increase of error rate under pressure with time, but the working speed was constant. Oppositely, in the present study no progressive increase of number of errors and no constant working speed were found.

Weltman and Egstrom (35) and Weltman and co-workers (36) considered "perceptual narrowing", not nitrogen narcosis, to be the cause of such performance decrements. This might actually have occurred in some earlier studies because of experimental design issues. In this study, "perceptual narrowing" was avoided by providing the subjects with training in the testing procedures before the experiment until they reached stability. In open water diving, there is always an additional impact on performance arising from the underwater environment, such as cold, drag, noise, low visibility, anxiety, etc. In a dry chamber, the experimental situation is free of such stress factors, so all changes can be attributed to nitrogen narcosis effects, provided the subjects are accustomed and trained to perform in such an environment.

Some of the paradoxical results obtained in the present study could be explained by the effects of learning, consistent with findings of Synodinos (15) and Moeller and co-workers (37). However, "learning" in this study could not be attributed to "memorizing", since the subjects were always assigned new variations of tests, both during training and the experiment. Learning was not affected under low air pressures, but some "adaptation" might have also occurred over the five days of the experiment. However, the evidence for such a conclusion is very weak. It is also possible that our subjects were, at some stages of the experiment, more engaged under pressure than under control conditions, i.e. performed more successfully under the pressure than on the surface. This "paradox" was previously reported by Moeller and co-workers (27).

According to Franks (38), signal detection tests could be considered the best and simplest parameter for measuring nitrogen narcosis effects. This study suggests the same thing. Although no increase of TE was found with pressure increase on the signal detection test (test 311), an impairment of TT was already present at 2 bars (p=0.032), indicating that such tests are sensitive enough even at low pressures (Figure 5). This conclusion does not support earlier findings suggesting that simple mental functions deteriorate under nitrogen narcosis later than more complex ones (16,39). All CRD-series tests applied in the present study proved to be sensitive enough to detect psychological changes at pressures of 2 to 4 bars, despite a low nitrogen narcotic dose. The sequence of pressures to which the subjects were exposed had no influence on performance, consistent with the findings of Whitaker and Findley (40).

It could be argued that in experiments such as this, the percentage of nitrogen should be decreased in the control group as pressure increases in order to exclude the effects of pressure as a physical variable. This was not considered necessary and the subjects served as their own controls. It is well established that the narcotic effect of a gas depends on its partial pressure and chemical properties. At 2 bars, compressed air is minimally narcotic, at 10 bars it is very narcotic, while a mixture of 20% oxygen and 80% helium is not. There is a significant body of evidence that indicates increased nitrogen tensions cause narcosis (1-4).

The results suggest that nitrogen narcosis in shallow air-diving (10 to 30 m) might be a problem in some underwater operations that require accuracy, speed, limited time of performance, and complex psychomotor processing.

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### REFERENCES

1. Bennett PB. Inert gas narcosis. In: Bennett PB, Elliott DH, editors. The physiology and medicine of diving. London (England): WB Saunders; 1993. p. 170-193.
2. Fowler B, Ackles KN, Porlier G. Effects of inert gas narcosis on behavior - a critical review. *Undersea Biomed Res* 1985; 12:369-402.
3. Adolfson J. Human performance and behaviour in hyperbaric environments. Stockholm (Sweden): Almquist & Wiksell; 1967.

4. Bennett PB. The aetiology of compressed air intoxication and inert gas narcosis. Oxford (England): Pergamon Press; 1966.
5. Behnke AR, Thomson RM, Motley EP. The psychologic effects from breathing air at 4 atmospheres pressure. *Am J Physiol* 1935; 112:554-558.
6. Cousteau JY. Le monde du silence. Paris (France): Hachette; 1957. p. 83.
7. Poulton EC, Catton MJ, Carpenter A. Efficiency of sorting cards in compressed air. *Br J Ind Med* 1964; 21:242-245.
8. Bennett PB, Poulton EC, Carpenter A, Catton MJ. Efficiency at sorting cards in air and at a 20 per cent oxygen-helium mixture at depths down to 100 feet and in enriched air. *Ergonomics* 1967; 10:53-62.
9. Anonymous. Nitrogen narcosis: A bibliography with informative abstracts. Bethesda (MD): Undersea Medical Society; 1983.
10. Biersner RJ. Assessment of the narcotic effects of nitrogen. In: Hamilton RW, Kizer KW, editors. Nitrogen narcosis. Proceedings of the 29th Undersea Medical Society Workshop. Bethesda (MD): Undersea Medical Society; 1985. p. V-1-17.
11. Kiessling RJ, Maag CH. Performance impairment as a function of nitrogen narcosis. *J Appl Psychol* 1962; 46:91-95.
12. Frankenhaeuser M, Graff-Lonnevig V, Hesser CM. Effects on psychomotor functions of different nitrogen-oxygen gas mixtures at increased ambient pressure. *Acta Physiol Scan* 1963; 59:400-409.
13. Davis FM, Osborne JP, Baddeley AD, Graham IMF. Diver performance: nitrogen narcosis and anxiety. *Aerosp Med* 1972; 43:1079-1082.
14. Osborne JP, Davis FM. Diver performance: Nitrogen performance and anxiety. In: Drew EA, Lythgoe JN, Woods JD, editors. Underwater research. New York (NY): Academic Press; 1976. p. 217-24.
15. Synodinos N. Selective impairment by nitrogen narcosis of performance on a digit-copying and a mental task. *Ergonomics* 1976; 19:69-80.
16. Baddeley AD. Diver performance. In: Woods JD, Lythgoe JN, editors. Underwater science: An introduction to experiments by diver. London (England): Oxford University Press; 1971. p. 33-67.
17. Sparrow L, Mathieu D, Wattel F, Lancry A, Neviere R. Effects of breathing air at 4 atm abs: evidence for a change in strategy. *Undersea Hyperbaric Med* 2000; 3:125-130.
18. Linnarsson D. Mode of action of inert gases during mild narcosis in man. In: Reinertsen RE, Brubakk AO, Bolstad G, editors. Proceedings of the 19th Annual meeting of EUBS on diving and hyperbaric medicine. Trondheim (Norway): European Underwater and Baromedical Society; 1983.
19. Östlund A, Sporrong A, Linnarsson D, Lind F. Effects of sulphur hexafluoride on psychomotor performance. *Clin Physiol* 1992; 12:409-418.
20. Östlund A, Linnarsson D, Lind F, Sporrong A. Relative narcotic potency and mode of action of sulfur hexafluoride and nitrogen in humans. *J Appl Physiol* 1994; 1:439-444.
21. Carter RC. Video-games as performance tests. In: Hamilton RW, Kizer KW, editors. Nitrogen narcosis. Proceedings of the 29th Workshop of the Undersea Medical Society. Bethesda (MD): Undersea Medical Society; 1985. p. VI:1-9.
22. Bobic J, Pavicevic L, Gomzi M. The difference in complex psychomotor reaction time between patients with and without signs of cerebral circulatory disorders. *Coll Antropol* 2002 Dec;26(2):515-520.
23. Prpic-Majic D, Bobic J, Simic D, House DE, Otto DA, Jurasovic J, Pizent A. Parental education as a confounder in the assessment of low level lead effect on psychological functions in children. *Cent Eur J Public Health* 2000 Jul;8 Suppl:69.
24. Bobic J, Pavicevic L. Complex reaction time and EEG characteristics in alcoholics. *Arh Hig Rada Toksikol* 1996; 47:351-357.
25. Bobic J, Pavicevic L. [Critical value of psychological measurement instruments for evaluation of work disability in older alcoholics.] *Lijec Vjesn* 1987 Jun;109(6):199-202. (in Croatian)
26. Bobic J, Pavicevic L, Drenovac M. The difference between alcoholics and their healthy equivalent parts - psychological approach. *Stud Psychol* 1995; 37(5):351-356.
27. Drenovac M, Zajc M. [The efficiency of cognitive functions across different age groups.] *Covjek i promet* 1992; 18(1):27-32. (in Croatian)
28. Drenovac S, Drenovac M. [Fluctuations of working efficiency of railway traffic dispatchers on mental and psychomotor tasks during day and night 12-hour shift.] *Covjek i promet* 1989; 15(3):115-127. (in Croatian)

29. Radonjic V, Kafol R, Ercegovac D, Kocijancic R, Neskovic N. [Neurophysiologic, psychomotor and psychologic indicators in workers after long-term exposure to cholinesterase-inhibiting insecticides.] *Arh Hig Rada Toksikol* 1985; 36:355-364. (in Croatian)
30. Drenovac M, Drenovac S. [Working shift and changes of working abilities of trainmen on diesel and electric locomotives.] *Covjek i promet* 1976; 2(3):223-229. (in Croatian)
31. Spoelders-Claes R, Coetsier P. Research note on a new electronic psycho-diagnostic system: The Complex Reactionmeter Drenovac Testbattery. Ghent (Belgium): State University of Ghent, 1976.
32. Drenovac M. [CRD-series of psychodiagnostic tests.] Zagreb (Croatia): Agencija za komercijalnu djelatnost; 1994. (in Croatian)
33. Fowler B, Ackles KN. Narcotic effects in man of breathing 80-20 argon-oxygen and air under hyperbaric conditions. *Aerosp Med* 1972; 43:1219-1224.
34. Bennett PB. The electrical activity of the brain and inert gas narcosis. In: The aethiology of compressed air intoxication and inert gas narcosis. Oxford (England): Pergamon; 1966. p. 69-72.
35. Weltman G, Egstrom GH. Perceptual narrowing in novice divers. *Human Factors* 1966; 8:499-506.
36. Weltman G, Smith JE, Egstrom GH. Perceptual narrowing during simulated pressure chambers exposures. *Human Factors* 1971; 13:99-107.
37. Moeller G, Chattin C, Rogers W, Laxar K, Ryack B. Performance effects with repeated exposures to the diving environment. *Appl Psychol* 1981; 4:502-510.
38. Franks NP, Lieb WR. Stereospecific effects of inhalation general anesthetics isomers on nerve channel ions. *Science* 1991; 254:427-430.
39. Biersner RJ, Hall DA, Linaweaver PG, Neuman TS. Diving experience and emotional factors related to the psychomotor effects of nitrogen narcosis. *Aviat Space Environ Med* 1978; 49:959-962.
40. Whitaker LA, Findley MS. Nitrogen narcosis measured by dual-task performance. *J Appl Psychol* 1977; 62:735-746.