RESEARCH OF EFFECT OF HYPERBARIC PRESSURE ON DYNAMICS AND EFFICIENCY OF COMPLEX MENTAL PROCESSING

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ABSTRACT

The paper presents the experimental plan, methodology and results of research of efficiency and dynamics of complex mental processing in 15 divers (diver demolition specialists) in simulated conditions of diving at the depth not exceeding 30 meters in hyperbaric chamber.

Changes in efficiency (total time) and dynamics (speed, stability and accuracy) of mental processing were determined through 20 measurements (5 measurements per pressure entry ranging from 1- 4 bars) with each examinee, and by means of the following chronometric cognitive tests:

1. test of perception of spatial location of light signal (CRD 311)
2. short-term operational memory test (CRD 324)
3. simple visual orientation test (CRD 21)
4. operational thinking connected with hand and foot coordination (CRD 413)
5. problem solving test (CRD 11)

The research revealed significant changes in processing speed registered at the 2 b pressure (at the simulated 10-m depth) and processing stability at the 4 b pressure (30-m simulated depth) respectively, which affect the mental processing efficiency in general as it decreases abruptly at the 2 b hyperbaric pressure at the simulated 10-m depth, remains unchanged at the 20-m simulated depth and continues to decrease at the 30-m depth.

INTRODUCTORY REMARKS

The study of influence of increased pressure (simulated shallow air-diving) on changes of mental and psychomotoric efficiency of divers and seals is a part of original scientific research within macroproject "Development and Management of Human Resources in the Croatian Military", which has been in progress since 1992 as a part of research of defense strategy of the Republic of Croatia. During thematic workshop "Psychological Functioning Under Extreme Conditions", held during 36th IAMPS, in Split, Croatia, this paper was used to initiate discussion about the problem of influence of extreme conditions, often found in the militaries, on operative capabilities of soldiers, specially on their psychomotoric and mental efficiency.

Nitrogen narcosis is a problem of constant concern for divers and diving physicians. It might seem that really everything has been already said about it, since this phenomenon has been extensively studied, and some extensive reviews are available (1-4). In the diving community it is usually considered that the effects of nitrogen narcosis on performance under the water could be detected at 40 meters and deeper, further impairment occurring with the increase of depth. Behnke and co-workers described performance impairment at 20 meters characterized by euphoria, retardation of the higher mental processes, and impairment of muscular coordination, and at 30 meters as well, characterized by feeling of stimulation, excitement, and euphoria (5). Bennett and co-workers found "...the minimal partial pressure of nitrogen likely to produce an effective deterioration of performance was 3.2 atm (323 kPa), or that in air at 30 m..."(6). Having in mind possible nitrogen narcosis at even shallower depths, Bennett later stated: "No doubt, 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). Since divers, novice and experienced, report from time to time minor psychomotoric problems while air diving in shallow waters, we tested possible nitrogen narcosis effects at 10m, 20m, and 30 m (2.0, 3.0, and 4.0 bars, respectively).

Since most of the similar studies are based on multiple retesting, i.e. on multiple measurement of the same functions the same subjects, in designing such studies special attention should be paid to selection of adequate tests and standardization of experimental conditions, as well as to methodology and analysis of individual differences. There are only few psychological tests applicable for multiple retesting on the same subjects, since the object of measurement changes during the experiment. Many psychological tests that measure capabilities, if used for multiple retesting, become tests of knowledge, thus interindividual and intraindividual variabilities of the results of the measurement diminish.

THE FOCUS OF THIS RESEARCH

The main problem of this research is mental processing efficiency under pressures from 2.0 to 4.0 bars, i.e. understanding changes of total efficiency and dynamical characteristics of mental processing under these circumstances. This makes the frame for the following questions:

- changes of total mental efficiency,
- changes of efficiency of different forms of mental processing, and
- variations of characteristics of dynamics of mental processing,

expressed as indicators of speed, stability, and accuracy of mental processing. Specific objective of this study imposed further problems dealing with the methodology of processing of the obtained data and analysis of the results. Therefore, the paper also deals with the problem of elimination of marked interindividual differences on the level and dynamical characteristics of subjects as well as elimination of effects of exercise in multiple retesting.

METHODS

Subjects

15 healthy male divers, average age of 28.3ą4.6 years, with 5.7ą4.8 years of diving experience, after signing informed consent, participated in the study, previously approved by the appropriate ethical committee.

Apparatus

The experiment was conducted in hyperbaric chamber Draeger-Galeazzi.

Figure 1. Hyperbaric chamber

Performance was tested using battery of computerized tests Complex Reactionmeter Drenovac (CRD-series). Before the experiment, the subjects were trained using CRD-series two hours per day and after three days obtained five results in a row without tendency of improvement. This was considered to be a "stable" result, i.e. "entry level". Amongst hundreds of tests that could be given on CRD-series, only five representative tests (11, 21, 311, 324, and 413) were selected for the study (first digits represent CRD-series instrument number).

Figure 2. Set up of CRD-series instruments inside the chamber.

The sequence of the tests given was from simple to more complicated, i.e. 311, 324, 21, 11, and 413. The goal was to complete any given test as quickly as possible, and with as few errors. Correct hit in every test would automatically results in a new task. We measured total solving time (TT), i.e. total result of mental processing on any given test, minimal single task solving time (TMIN), i.e. maximal speed of mental processing, total "ballast" (TB), i.e. sum of differences between various single task solving times and TMIN, representing "stability" of mental processing, and finally total number of errors (TE), i.e. credibility and accuracy of processing. These parameters could be understood as descriptors of psychomotoric manipulations of certain type or level.

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

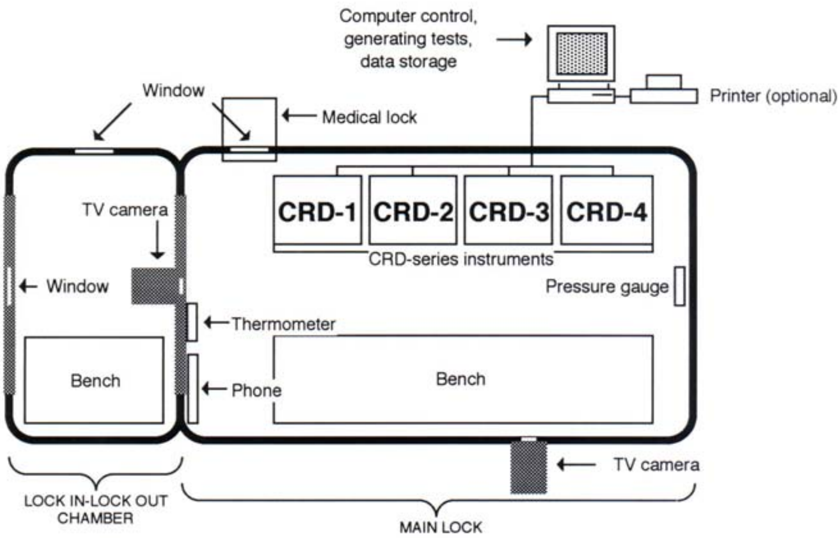
Test 324 was used to measure the ability of actualizing short-term memory. It also consists of 60 single tasks. LEDs illuminate in random order and correct answer is given by pressing the button defined by certain sequence known to the subjects before testing. This position might be left, right or just below the LED. In this experiment the sequence was "left-right-right-below", and the subjects were obliged to actualize this memorized sequence.

Test 21 was used to measure the ability of 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.

Test 11 was used to measure the ability of convergent thinking, i.e. general ability to perform in problematic situations. This function is provoked by constructing and solving simple mathematical tasks. Out of 35, 18 tasks were addition, 17 subtraction. In each of the tasks two LEDs emit at the same time. One of 12 LEDs positioned in the central part of the instrument indicates which numbers in the upper row and lateral columns should be used to construct 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, i.e the result of mathematical operation, in the lower part of the instrument.

Test 413 was used to test the ability of operative thinking or complex psychomotoric coordination (eye-hand). Field "A" of the instrument was used, consisting of four LEDs (upper two for hands, lower two for legs), as well as buttons and pedals. Each of 35 given tasks was a specific command. A combination of two or three LEDs would illuminate at the same time, requiring various combination of hands and legs to be pressed simultaneously for the correct answer.

Figure 3. Hyperbaric chamber and set up of CRD-series instruments inside the chamber (schematic).



Procedure

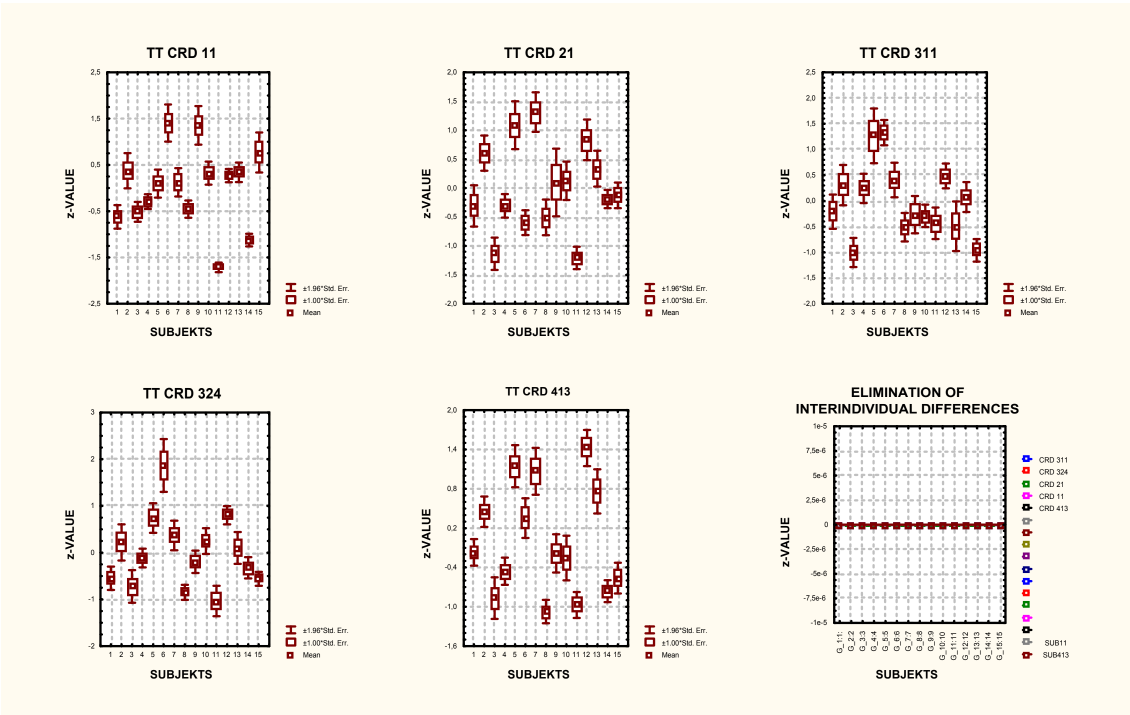
The experiment was conducted in a multiplace hyperbaric chamber (figure 1) by repetitive measuring of the same indicators of mental and psychomotoric functions at 1.0, 2.0, 3.0, and 4.0 bars, respectively, during five consecutive days. The subjects were fully familiarized with the experimental environment during their earlier chamber exposures. During the experiment they were not provided with any feedback about the results of the tests. The testing was commenced five minutes after reaching the pressure. In a group of 8 randomly chosen subjects the testing would begin at the atmospheric pressure, followed by testing at 2.0, 3.0, and 4.0 bars, respectively. Every other day this order was inverted. In the second group consisting of 7 subjects, the subjects were first tested at 4.0 bars, than to 3.0, 2.0, and finally at the atmospheric pressure. Every other day this order was inverted in this group, too. In statistical analysis ANOVA and MANOVA procedures, Median-test, and Kruskal-Wallis test were used. P-values less than 5% were considered significant.

PROCESSING AND ANALYSIS OF RESULTS

Processing of the obtained data was done in three steps. In the first step preliminary analysis of interindividual differences of levels and functional characteristics of mental processing was done, as well as the analysis of changes of these parameters as a function of the experiment.

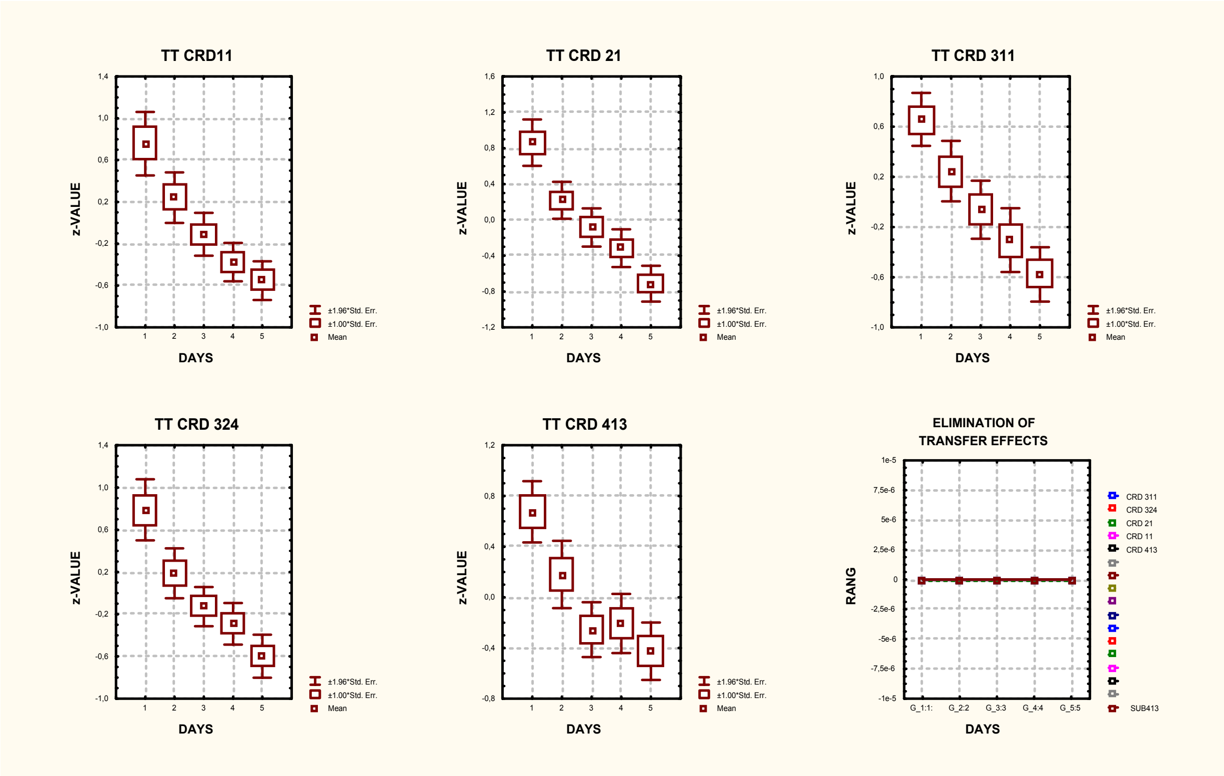
Since significant interindividual differences and significant changes of efficiency and dynamical characteristics of mental processing as a function of duration of the experiment (days) were found, the second step included sorting and transposition of the obtained data, i.e. transposition into standard z-values and sorting into relative rankings. Transformation of the original values into standard z-values was done for every subject individually, and transposition of the original values into relative rankings was done for every subject according to the cycles of the measurement (4 measurements for every "dive"). The effects of these transformations is presented in figures 4 and 5.

Figure 4. Elimination of interindividual differences



Great interindividual differences were noticed in all 5 tests. By transposition into standard z-values, the differences were leveled to "0" (zero).

Figure 5. Elimination of transfer effects.



By transforming the original results into relative rankings significant transfer of experience in solving test problems during the days of the experiment was leveled to “0” (zero).

Only after the elimination of these factors, in the third step non-parametric and parametric statistical procedures were applied in order to analyze the influence of increased pressure on the efficiency and dynamics of mental processing. ANOVA procedures were used to test the significance of differences while solving problems on various CRD-series instruments under various pressures. The results are presented in Table 1.

Table 1. Efficiency of different forms of mental processing under increased pressure.

(ANVAR)	***TESTS***				
	CRD311	**CRD324**	**CRD21**	**CRD11**	**CRD413**
F - test	**4.630**	**.498**	**6.934**	**3.738**	**5.817**
p - level	.004	**.684**	.000	.012	.001
BARS:					
1:2	.014	**.337**	.000	**.164**	**.408**
1:3	.002	**.681**	.018	**.995**	**.138**
1:4	.002	**.286**	**.814**	.054	.015

The function of actual signal localization (CRD-311) changes significantly at 2.0 bars, there are no significant changes in operative memory (CRD-324), simple visual orientation (CRD-21) is significantly changed at 2.0 and 3.0 bars, while more complex mental functions of problem solving (CRD-11) and operative reasoning are significantly changed only at 4.0 bars.

MANOVA procedures were applied to test the significance of changes of mental processing at 2.0, 3.0, and 4.0 bars, respectively, compared to the atmospheric pressure (1.0 bar).

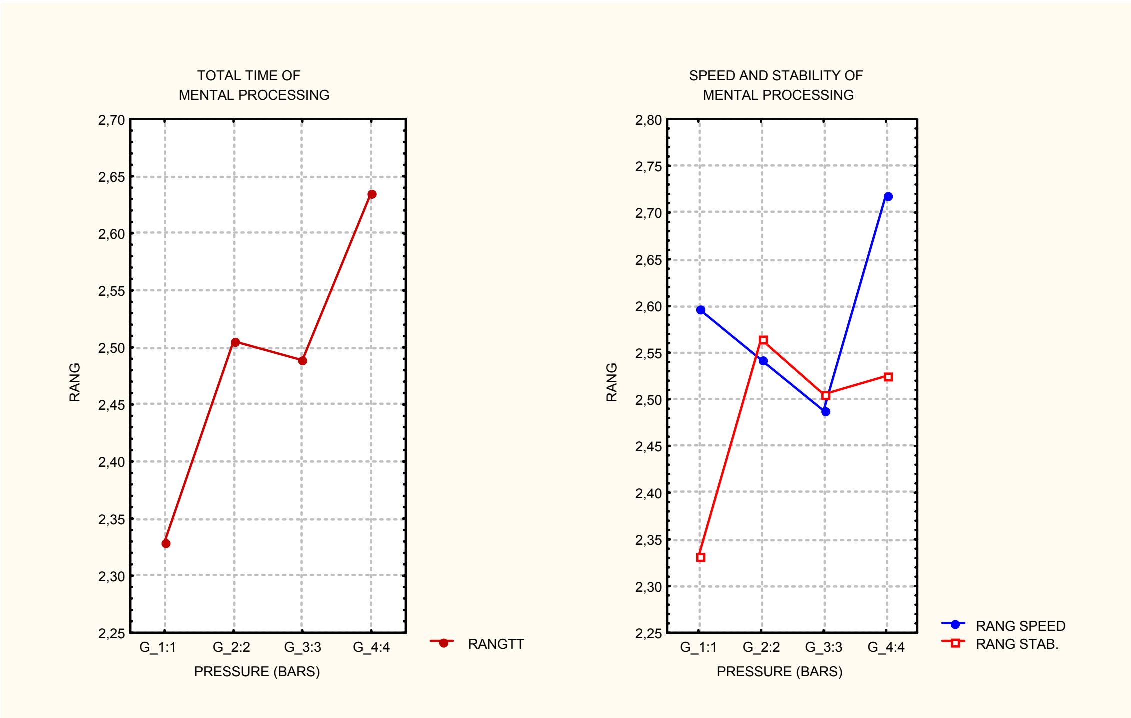
Table 2. Significance of changes of total efficiency of mental processing under various pressures.

(MANOVA)

WILKS LAMBDA	***Rao s R***	***df 1***	***df 2***	***p - level***
.808606	**3.8953**	**15**	**723**	.00000

All the changes were statistically significant. For the further analysis of the relationship between increased pressure and mental processing, additional adaptations of the original data were done. Individual z-values in all 5 CRD-tests were summarized after EVERY sequence of the testing in order to obtain new variables of total mental efficiency (TT) and dynamics of mental processing (TMIN, TB). Also, a new variable of total number of errors was created (TE). Variations of these parameters under various pressures are presented in Figure 6.

Figure 6. Total efficacy and dynamics of mental processing under various pressures



On the graph presented are averages of variations of total mental efficiency expressed as total test solving time of all the tests. This parameter showed deterioration at 2.0 bars already, remained at the same level at 3.0 bars, and was further deteriorated at 4.0 bars. Personal strategy in solving various problems influenced these changes. This is manifested as trend of changing speed (TMIN) and stability (TB) of mental processing.

The deterioration of stability of mental processing was clearly seen at 2.0 bars already, and remained practically unchanged at 3.0 and 4.0 bars. Speed of mental processing was first increased at the pressures of 2.0 and 3.0 bars, then finally decreased at 4.0 bars. Total number of errors was constantly increasing over the range of pressures, although these changes were not statistically significant.

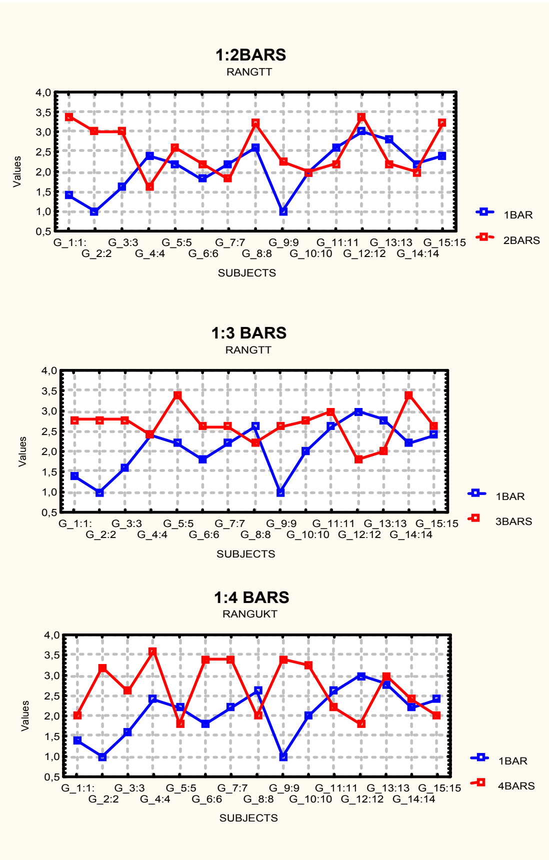
In Table 3 presented are indicators of significance of total mental efficiency and of dynamical characteristics of mental processing as obtained at 2.0, 3.0, and 4.0 bars, respectively, in relation to the same indicators at 1.0 bar.

Table 3. Analysis of total efficiency and dynamics of mental processing under various pressures

(ANVAR)	***INDICATORS*** TT	TMIN	TB	TE
F - test	**4.543**	**2.970**	**3.119**	**.982**
p - level	.004	.031	.025	**.400**
BARS:				
1:2	.035	**.500**	.005	**.731**
1:3	.055	**.177**	.034	**.268**
1:4	.000	**.135**	.019	**.124**

Figure 7 presents differences in individual reacting as changes of total mental efficiency under various pressures for every of 15 subjects.

Figure 7. Comparative presentation of individual mental efficiency under various pressures.



Total mental efficiency varies individually under various pressures, but it is clear that the increase of pressure causes deterioration of mental processing in the majority of the subjects.

Table 4 presents the changes of efficiency of various forms of mental activity and of total mental activity in every subject under the pressure of 4.0 bars compared to 1.0 bar.

Table 4. Efficiency of mental processing at 4.0 bars.
(0 - EQUAL, 1 - BETTER, 2 - WORSE)

SUBJECT	311	324	21	11	413	TOTAL E.M.P.	# FUNKCIONS, DECAY
1	2	2	2	0	0	2	3
2	2	0	1	2	2	2	3
3	2	2	0	1	1	2	2
4	2	1	1	2	1	2	2
5	1	1	2	1	2	2	2
6	2	2	2	2	2	2	5
7	2	2	1	2	0	2	3
8	1	2	2	2	2	2	4
9	2	2	2	2	0	2	4
10	2	2	2	2	2	2	5
11	1	1	1	2	1	1	1
12	1	1	1	1	1	0	0
13	2	2	2	2	0	2	4
14	2	2	2	2	2	2	5
15	1	1	1	1	2	1	1
BETTER	5	5	6	4	4	2	
EQUAL	-	1	1	1	4	1	
WORSE	10	9	8	10	7	12	

The changes of mental activity are presented in this table by the following symbols: “0” - if no changes at 4.0 bars in comparison to 1.0 bar were noticed, “1” - if mental efficiency was better under 4.0 bars compared to 1.0 bar, and “2” - if mental efficiency deteriorated at 4.0 bars compared to 1.0 bar.

In the columns marked with numbers 311, 324, 21, 11, and 413, respectively, indicated is the number of such changes. Changes of total efficiency of mental processing are displayed in the column TOTAL DMP, while the last column contains the number of deteriorated mental functions in each of the subjects at 4.0 bars.

In 11 out of 15 subjects deterioration occurred in total mental efficiency, in only one of the subjects mental activity remained unchanged, while in two subjects amelioration was seen in most of the mental activities.

DISCUSSION

The goal of this research was to explain how mental efficiency changes under pressures of 2.0, 3.0, and 4.0 bars. The results offer several answers. Under the experimental conditions total test solving time was significantly prolongued and stability of mental processing deteriorated. However, some other aspects of the problem should also be stressed out, especially the relationship between efficiency and functional characteristics of mental processing and nitrogen narcosis.

Weltman and Egstrom (7) and Weltman, Smith, and Egstrom (8) considered "perceptual narrowing", not nitrogen narcosis, to be the cause of performance decrement at low pressures. We avoided "perceptual narrowing" in our subjects providing full training of the testing procedure before the experiment, and therefore consider that all the changes noticed in this study could be attributed to the increased nitrogen partial pressure effects. In statistical analysis, the results achieved at 1.0 bar were not considered asymptotic. This was based on report by Moeller and co-workers who found their subjects were more engaged under experimental than control conditions (9). The effects of learning were evident, and this is consistent with findings by Synodinos (10), and Moeller and co-workers (9). However, "learning" in this study could not be attributed to "memorizing", because over the days of the experiment the subjects were always assigned with variation of different tests given on the same instrument. This leads to the conclusion that learning is not affected under low air pressures, but also that some adaptation might have occured over five days of the experiment. However, the evidence for such a conclusion were very weak. According to Franks (11), signal detection tests could be considered the best and the most simple parameters of measuring nitrogen narcosis effect. In our study such a test (311) was the only one showing significant increase ($p<0.001$) of TE over the, but not with pressure increase. We conclude that signal detection tests could not be considered to be the best in describing nitrogen narcosis effects in shallow air diving. Since nitrogen narcotic dose in shallow air diving is definitively very low, more sensitive tests should be used to detect quantitative and qualitative changes of performance. Reports by Whitaker and Findley, about no influence of the order of pressures to which the subjects were exposed to, are consistent with our findings (12). Mathieu and co-workers reported of change in strategy which in their subjects occured at 4.0 bars of simulated air-diving (13). Their subjects had significantly more mistakes on treble crossing test, but the speed was not decreased. On the recognition test, the number of false alarms and correct rejections was unchanged, while the number of hits and misses was significantly decreased. Our results are quite opposite, so some finer evidence of changes in strategy at low air pressures might be necessary in the future. In open water diving there is always negative impact on performance rising from the underwater environment. In hyperbaric chamber, all the changes could be attributed to the increased nitrogen partial pressure effects, provided the subjects were accustomed to the chamber environment and trained to perform in it. We found not only evidence of quantitative narcosis in simulated air-diving to the depths from 10 to 30 meters, but also of changed quality of psychomotoric processing. Therefore, we consider nitrogen narcosis effects at those depths to be not of academic interest only.

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