BEHAVIORAL EFFECTS OF NITROGEN NARCOSIS IN THE RHESUS MONKEY

by

Raymond T. Bartus, Ph.D.

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NUMBER 755

Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF51.524.004-9015DA5G.07

Transmitted by:

Jo Ann S. Kinney

Jo Ann S. Kinney, Ph.D.
Head, Vision Branch

Reviewed and Approved by:

Charles F. Gell

Charles F. Gell, M.D., D.Sc.(Med)
SCIENTIFIC DIRECTOR
NavSubMedRschLab

Approved and Released by:

R. L. Sphar

R. L. Sphar, CDR MC USN
OFFICER IN CHARGE
NavSubMedRschLab

SUMMARY PAGE

THE PROBLEM

To utilize a tightly controlled primate testing situation to investigate the specific behavioral impairments caused by nitrogen narcosis.

FINDINGS

Significant deficits were observed in the monkeys' performance which suggest that nitrogen narcosis impairs mechanisms necessary for extracting and utilizing information in the environment.

APPLICATION

Complete knowledge of the specific types of behavioral mechanisms that are effected by nitrogen narcosis will enable accurate and reliable predictions to be made on the degree to which various complex Navy tasks will be affected. The results of this investigation contribute toward this end.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit MF51.525.004-9015DA5G. The present report is Number 7 on this work unit. It was submitted for review on 10 July 1973, approved for publication on 12 September 1973 and designated as NavSubMedRschLab Report No. 755.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

Rhesus monkeys performed highly trained visual discrimination problems while breathing air at normal pressure or the sea water equivalent of 200 feet. A significant drop in performance was observed at 200 feet depth with greatest deficits occurring on the most difficult discrimination problems. This impairment was partially alleviated by allowing the monkeys to view the stimuli longer before making their choice responses. These deficits were interpreted as specific impairments in mechanisms necessary for processing visual information.

BEHAVIORAL EFFECTS OF NITROGEN NARCOSIS IN THE RHESUS MONKEY

INTRODUCTION

It has long been recognized that when air is breathed under pressure, certain behavioral and physiological changes occur which impair performance. These changes are thought to result from the influence of the high partial pressure of nitrogen in the compressed air, and are therefore collectively defined as "nitrogen narcosis" (Miles, 1965). Despite the presence of considerable interest and effort concerning the causes and effects of nitrogen narcosis, relatively little research has been directed toward defining and quantifying the specific underlying behavioral mechanisms that are effected. Most tasks performed by divers involve several levels of behavioral processing, including stimulus information input and analysis, various associative or memory processes, and one or more response output mechanisms. When all these types of tasks are utilized in narcosis investigations, it becomes quite difficult to isolate any one of several variables as contributing more than the others to the final performance impairment observed. At the same time, it can be argued rather strongly that only after attempts are begun to define and quantify the specific effects of nitrogen narcosis, will we be able to sufficiently understand it, so that programs can be developed to effectively cope with its effects.

For these reasons, the following research attempted to utilize a non-human primate testing situation which potentially offers the experimental precision and control necessary to isolate various behavioral mechanisms. As an initial attempt toward the goal of definition and quantification, impairments on the ability to process and utilize visual stimulus information were investigated.

METHOD

Subjects

Four wild-born male Rhesus monkeys (M. Mulatta) were used from the colony established at NavSubMedRschLab, Groton.

Apparatus

The apparatus, shown in Fig. 1, is the Automated Primate Discrimination Apparatus (APDA) which has previously been described in detail by LeVere and Bartus (1969). Briefly, the APDA utilizes a two-choice discrimination paradigm and requires the monkey to initiate each trial by placing his face into an observation window, which automatically turns on two visual stimuli. While continuing to look toward the stimuli he must execute a choice response by pulling one of two response levers associated with each of the stimuli. If a correct lever is pulled, the monkey is reinforced with a 300 mg banana-flavored or whole-diet monkey pellet. If the response is incorrect, no reinforcement is obtained. The spatial position of the correct stimulus is ran-

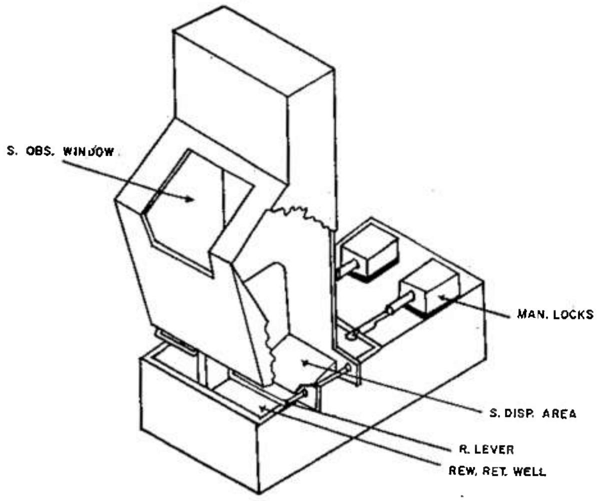

Fig. 1. Schematic diagram of APDA: The Automated Primate Discrimination Apparatus.

domly determined via a 10,000 cps oscillator. However, a correctional procedure is used, so that the correct stimulus remains on the same side until the monkey finally makes a correct choice response; after that time, a new spatial position is randomly determined. The trials are subject-paced in that the next trial can be initiated as soon as the previous trial is completed.

The duration that the stimulus is presented during each trial can be controlled by the experimenter, thus enabling him to manipulate the amount of stimulus information available on each trial. In the current studies, two different values were used: either a 50 msec flash of information was automatically presented as soon as the monkey initiated the trial, or the stimulus information was continuously presented as long as the monkey continued to keep his head in the observation window.

Stimuli

The stimuli were derived from two IEE rear-projection readout displays, located approximately 4" below the observation window in a plane perpendicular to the monkey's line of view, and separated from each other by 1". Each stimulus subtended a visual angle of approximately 9.7° x 15.7°, and the visual angle for the entire two-cue discrimination display was approximately 23.75° x 15.7°.

The particular discrimination problems were obtained by selecting three different stimuli from each of three visual dimensions: brightness, color, and pattern. Two different discrimination problems were given on each visual dimension; one relatively easy and the other more difficult. One of the three stimuli of each dimension served as the correct cue (S^D) for both discrimination problems in that dimension, while the other two stimuli served as incorrect cues (S^Δ).

The three brightness cues that were used were white (S^D), gray (difficult S^Δ) and black (easy S^Δ). For the color discrimination, the stimuli were green (S^D), blue (difficult S^Δ), and red (easy S^Δ), and the patterns used were a "nine" (S^D), an inverted "nine" (difficult S^Δ) and an inverted "seven" (easy S^Δ).

Thus, the level of difficulty was predicted a priori on the basis of the physical characteristics of the stimuli. This distinction was later confirmed by the actual number of trials taken by each monkey to initially master each discrimination problem. In summary, six different discrimination problems were used, involving two levels of difficulty for each of three visual dimensions. This experimental arrangement therefore allowed flexible manipulation of various stimulus parameters without requiring confounding changes in other task parameters, such as psychomotor coordination, feedback, reinforcement, etc.

PRELIMINARY DIVES

Due to the profound lack of information regarding the use of non-human primates in behavioral hyperbaric research, a series of pilot dives was run to provide data concerning the most general, overt effects of narcosis in Rhesus monkeys. Four monkeys were adapted to the restraint of a primate chair, and then pressurized in a dry chamber to a sea-water-equivalent of 300 feet, with observation stops at 0, 50, 200, 250, and 300 feet. The monkeys were observed at each pressure level, and subjective evaluations of their general arousal level, alertness, appetite, etc., were recorded.

It was observed that although all monkeys appeared severely disturbed by the noise, pressure, and/or heat at the start of the dive, they all appeared to calm down reasonably well when each pressure level was reached. At 300 feet (as well as the more shallow depths) all monkeys appeared alert, exhibited a startle reflex to a loud bang, accurately oriented toward the noise, readily ate reinforcement pellets when dispensed to them, and in all other observable meassures, appeared normal. Although one of the monkeys seemed totally disinterested in the food during a major part of the dive, he immediately began picking up and eating the food when the internal temperature of the chamber was reduced by venting in fresh, compressed air. In summary then, no obviously overt behavioral effects were observed which could be attributable to they hyperbaric air.

Because of this lack of effects at 300 feet, it was decided to dive the monkeys to this depth again and obtain actual measures of their performance on the APDA. Two different monkeys were run at this depth, and it was found that they simply refused to work for the food reinforcement, despite the fact that they performed accurately and quickly in the chamber, with the same noise level, temperature, etc, when at normal atmospheric pressure. Furthermore, a lack of appetite, *per se*, did not seem to provide an adequate explanation for this effect, for the monkeys readily accepted the reinforcement pellets at 300 feet when delivered to them by the experimenter; the problem was that they would not *work* for them. This observation, however elementary, serves to reiterate recurrent criticisms of drawing conclusions about the degree of narcosis from subjective appraisals, and reemphasizes the importance of the dependent measure chosen, as well as the need to objectively quantify the specific effects of nitrogen narcosis.

EXPERIMENTAL DIVE

On the basis of these preliminary data, it was decided to dive the monkeys to the more shallow depth of 200 feet. Before the actual experiment was initiated, however, all monkeys were first trained to a 95% or better "first-choice-correct" criterion on each of the six discrimination problems, with the stimulus information available throughout the trial. After completing this pretraining exercise, they were all retrained to 95% correct with only 50 msec of information available per look. They were then overtrained with this same brief stimulus presentation, during which time their performance asymptoted at near-perfect levels.

The experimental procedure utilized a randomized treatment X subject factorial design, consisting of three separate dives for each monkey. Each of the six discrimination problems was administered for 15 trials during each dive. Two of the dives were to actual depths of 200 feet, but differed in the duration the stimuli were presented each trial. During one set of dives, only a 50 msec flash of stimulus information was presented per look, but during the other dives, the stimuli remained on as long as the monkey kept his head in the observation window. The third dive was a simulated control in which 50 msec of information was given at normal atmospheric pressure. To simulate an actual dive, compressed air was passed through the chamber as in the other dives, but was also simultaneously vented out, so that no pressure could build up within the chamber. The duration of each dive was 20 minutes (excluding decompression time), with the testing session beginning five minutes after 200 feet (or its simulation during the control dives) was reached.

RESULTS

The monkeys' performance, measured in terms of the percentage of correct responses, is shown in Fig. 2 for all three dive conditions. Decrements in performance are evident for both dives to 200 feet, as compared with the surface control, with greatest effects occurring on the dive condition with the shortest stimulus presentation. These data were analyzed statistically using a three-way analysis of variance, which verified a significant dive effect ($F = 12.85$, $p < .01$). Individual t tests also confirmed that the monkeys performed considerably worse at depth as compared with the surface, when the stimulus information was presented for 50 msec ($t = 5.57$, $p < .01$, 2-tailed), and that when additional (continuous) stimulus information was made available throughout the discrimination trial, performance showed a significant im-

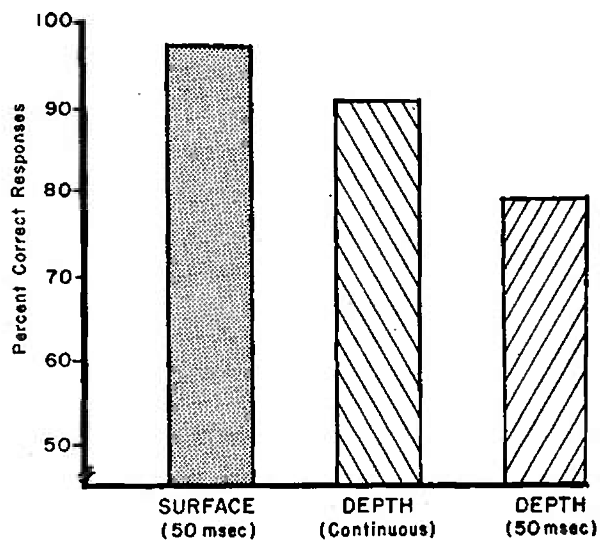

Fig. 2. Mean percentage correct on three dive conditions.

provement at depth (t = 3.45, p <.01, 2-tailed). However, the performance on this condition remained impaired relative to performance at normal atmospheric pressure with 50 msec stimulus information (t = 3.12, p <.01, 2-tailed).

In addition to their overall performance at depth, the data were analyzed for the effect of depth on problem difficulty. These results, shown in Fig. 3, indicate greater differences in problem difficulty as the result of nitrogen narcosis. The analysis of variance confirmed a significant problem difficulty effect (F = 4.79, p <.025). Individual t tests indicated that although no difference in performance existed on the easy vs difficult problems on the surface (t = 2.00, p >.05, 2-tailed), performance on the difficult problems suffered significantly more at depth with continuous information (t = 2.71, p <.05, 2-tailed). This effect was of even greater magnitude and more reliable with only 50 msec information available at depth (t = 3.06, p <.02, 2-tailed).

Finally, none of the interactions was found to be sufficiently reliable by conventional standards (p >.05) and no consistent differences in performance occurred with respect to the visual dimension. The latter result suggests that the effect of hyperbaric air does not selectively influence performance on one visual dimension more than another.

As a supplementary index of narcosis, the total amount of time the monkeys looked in the observation window before each response was measured. Although no inter-problem differences were apparent in this measure of response latency, a significant overall effect due to pressure did occur as shown in Fig. 4. This effect is evidenced by a significant increase of more than 50% in the "looking time per observing response" in narcotic monkeys (t = 3.06, p <.01, 2-tailed).

Finally, a sharp overall increase in the total running time also occurred under pressure, even when the greater number of incorrect responses made at

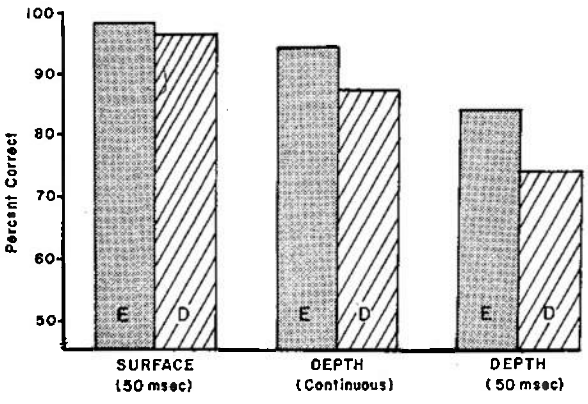

Fig. 3. Mean percentage correct on easy (E) vs. difficult (D) problems during each dive condition.

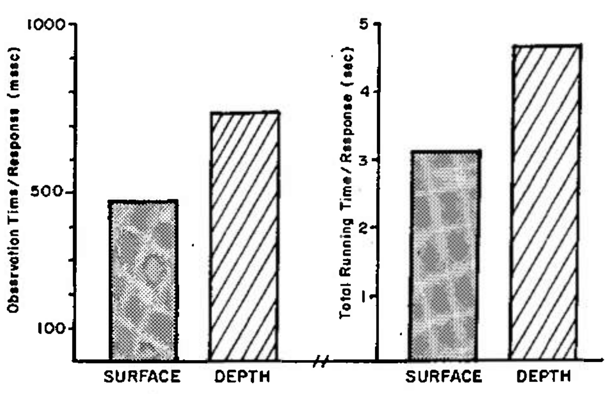

Fig. 4. Response times on surface vs. depth with 50 msec information presented per look.

200 feet was taken into account, as shown in Fig. 4 ($t = 3.83$, $p < .01$, 2-tailed).

DISCUSSION

The results of this investigation demonstrate that those mechanisms responsible for the processing of visual information are impaired under conditions of hyperbaric air. The evidence supporting this conclusion includes (a) performance on highly trained visual discrimination problems suffers serious deficits at 200 feet, (b) the impairment is significantly greater when the visual discrimination is more difficult to make, (c) greater time was spent in looking at the stimuli per response under pressure, suggesting that more time may have been necessary to process the visual information, and (d) the degrees of impairment can be significantly decreased by increasing the stimulus presentation time prior to when the choice response is made.

These results are in essential agreement with predictions which might be made on the basis of recent neurophysiological recordings. This evidence indicates that nitrogen narcosis is responsible for significant decrements in the amplitude of the averaged visual evoked response in man (Kinney & McKay, 1971), cats (Bartus, 1973), and rats (Ferris & Strauss, 1973). The present findings therefore suggest a certain degree of closure in that both behavioral, as well as neurophysiological decrements occur in sensory processing as the result of narcosis.

This, of course, is not to suggest that the effects of nitrogen narcosis are limited to the visual system, or even to sensory processing in general. To the contrary, certain tasks, such as differential schedules of reinforcement (Walsh, Thomas, Thorne, & Bachrach, 1972), mental arithmetic computations and counting backwards (Miles. & McKay, 1959; Adolfson, 1967; Case & Haldane, 1941) have shown reasonable deficits, and yet require little apparent sensory processing in order to be performed successfully. Furthermore, some of the data reported here with regard to significant increases in total running time per response, and the monkey's refusal to work at 300 ft, suggest that a more general dysfunction, perhaps related to systems involved with motivation or arousal, may also be involved. Thus, any conclusion implying that the impairments resulting from nitrogen narcosis are limited to the sensory systems would probably be inaccurate.

However, the point remains that certain impairments do occur which can be most easily explained in terms of specific deficits in information processing capacities. Acceptance of this conclusion further enables one to account for a considerable amount of data demonstrating narcotic impairments in a variety of testing situations (Shilling & Willgrube, 1937; Kiessling & Maag, 1962; Adolfson & Fluur, 1967; Fluur & Adolfson, 1966; Poulton, Catton & Carpenter, 1964; Bennett, Poulton, Carpenter & Catton, 1967; Baddeley, de Figueredo, Hawkswell-Curtis & Williams, 1968; Behnke, Thomson & Motley, 1935).

Although the tasks used in these studies are often quite different, they share a common attribute of requiring information from the environment to be processed in order to achieve task success.

Finally, the data reported here are in general agreement with those authors that contend that increased task complexity (measured in terms of problem difficulty) is correlated with the degree of narcotic impairment (Kiessling & Maag, 1962; Baddeley, et al, 1968). In the present situation, even though all monkeys were trained to near-perfect levels of performance on all tasks in normal atmospheric pressure, and other behavioral variables were presumably controlled, differential effects of the narcosis still occurred with respect to task difficulty.

Burns (1971) has recently suggested that due to confounding effects of motor requirements, past differences reportedly due to task complexity may in fact be attributable to differential influences on pscho-motor coordination. However, the present results provide strong evidence that the effects on motor coordination may not be solely or perhaps even primarily, responsible for the greater deficits observed on the more difficult tasks. The present data also suggest that the increased effect of narcosis need not depend on the task being qualitatively more complex in terms of the number of different behavioral mechanisms presumably needed to perform them, as has been suggested (Kiessling & Maag, 1962). That is, in the present research, significantly greater deficits occurred when the task was made quantitatively more difficult, simply by manipulating the visual information. Although additional research is required, it is conceivable that differences in task difficulty may be the primary reason why some authors find impressive narcotic effects at certain depths, while others report little or no effect (see Fowler, 1972).

In summary, the major findings of this investigation indicate that nitrogen narcosis impairs the ability to process and utilize visual information from the environment. These deficits are even greater when the task is made more difficult, but the effects can be partially alleviated by providing additional information before a choice response must be made. Although certainly not conclusive at this point, the results of this study, nevertheless, offer some direction for future research, and should enhance the probability of successfully predicting the types of tasks that might be most seriously affected by nitrogen narcosis.

Although one must always be objectively cautious of implementing the results of animal research in programs concerned with human behavior, certain applications of this research are nevertheless apparent. For example, when possible, protocols should be arranged so that tasks requiring the extraction of stimulus information from the environment are avoided in conditions of nitrogen narcosis. In many situations this may not be feasible, but in such cases it may still be possible to minimize the detrimental effects of narcosis. For example, when diving work schedules are planned, large increase in work time should be allotted over what is normally necessary to successfully complete the task at surface. Not only will more time be required because of a general decrease in work rate, but each time information must be extracted from the environment, one can expect a further requirement of additional time. Also, these data suggest that the narcotic effect of hyperbaric air may be overcome by providing the divers with as much supplementary or redundant environmental information as possible. Although this additional information may appear unnecessary and quite useless in normal circumstances, under conditions of nitrogen narcosis, it could conceivably result in the difference between task success and failure.

REFERENCES

Adolfson, J. Human performance and behavior in hyperbaric environments. Stockholm: Almquist & Wiksell, 1967.

Adolfson, J. & Fluur, E. Hearing discrimination in hyperbaric air. Aerospace Med 38, 174-175, 1967.

Baddeley, A. D., de Figueredo, J. W., Hawkswell-Curtis, J. W., & Williams, A. N. Nitrogen narcosis and performance under water. Ergonomics 11, 157-164, 1968.

Bartus, R. T. Nitrogen narcosis and its effect on the visual evoked response in the cat. Naval Submarine Medical Center, Groton, Conn. NSMRL Rep. No. 757, 1973.

Behnke, A. R., Thomson, R. M. & Motley, E. P. Psychologic effects from breathing air at four atmospheres pressure. Am J Physiol 112, 554-558, 1935.

Bennett, P. B., Poulton, E. C., Carpenter, A. & Catton, M. J. Efficiency at sorting cards in air and a 20 percent oxygen-helium mixture at depths down to 100 feet and in enriched air. Ergonomics 10, 53-62, 1967.

Burns, J. D. Hyperbaric gas effects on critical flicker frequency in the Rhesus monkey. Physiol and Behav 7, 151-156, 1971.

Case, E. M. & Haldane, J. B. S. Human physiology under high pressure. J Hygiene 41, 225-249, 1941.

Ferris, S. H. & Strauss, M. Nitrogen narcosis at 300 feet in rats: effects on EEG and visual evoked responses. Naval Submarine Medical Center, Groton, Conn., NSMRL Rep. No. , 1973 (in press).

Fluur, E. & Adolfson, J. Hearing in hyperbaric air. Aerospace Med 37, 783-785, 1966.

Fowler, B. Some comments on "A behavioral approach to nitrogen narcosis", Psychol Bull 78(3), 234-240, 1972.

Jennings, R. D. A behavior approach to nitrogen narcosis. Psychol Bull 69, 216-224, 1968.

Kiessling, R. J. & Maag, C. H. Performance impairment as a function of nitrogen narcosis. J Appl Psychol 46, 91-95, 1962.

Kinney, J. A. S. & McKay, C. L. The visual evoked response as a measure of nitrogen narcosis in Navy divers. Naval Submarine Medical Center, Groton, Conn., NSMRL Rep. No. 664, 1971.

LeVere, T. E. & Bartus, R. T. APDA: A discontiguous S-R automated primate discrimination apparatus. Behav Res Methods & Instrum 1(7), 259-262, 1969.

Miles, S. Underwater Medicine. London: Staples Press, pp. 100-116, 1965.

Miles, S. & MacKay, D. E. The nitrogen narcosis hazard and the self-contained diver. (Medical Research Council Report. Underwater Physiology Sub-Committee 184 Royal Naval Personnel Research Committee), Alverstoke, Hants, 1959.

Poulton, E. C., Catton, M. J., & Carpenter, A. Efficiency at sorting cards in compressed air. Brit J Ind Med 21, 242-245, 1964.

Shilling, C. W. & Willgrube, W. W. Quantitative study of mental and neuromuscular reactions as influenced by increased air pressure. U.S. Naval Med Bull 35, 373-380, 1937.

Walsh, J. M., Thomas, J. R., Thorne, D. R. & Bachrach, A. J. Differential performance changes under hyperbaric conditions. Aerospace Med 43(6), 623-625, 1972.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D	
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)	
1. ORIGINATING ACTIVITY *(Corporate author)* NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY Naval Submarine Medical Center	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP
3. REPORT TITLE BEHAVIORAL EFFECTS OF NITROGEN NARCOSIS IN THE RHESUS MONKEY	
4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* Interim report	
5. AUTHOR(S) *(First name, middle initial, last name)* Raymond T. BARTUS	

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
12 Sept 1973	9	20

8a. CONTRACT OR GRANT NO. b. PROJECT NO. MF51.524.004-9015DA5G.07 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NSMRL Report Number 755 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Center Box 600, Naval Submarine Base Groton, Connecticut 06340

13. ABSTRACT

Rhesus monkeys performed highly trained visual discrimination problems while breathing air at normal pressure or the sea water equivalent of 200 feet. A significant drop in performance was observed at 200 feet with greatest deficits occurring on the most difficult discrimination problems. This impairment was partially alleviated by allowing the monkeys to view the stimuli longer before making their choice responses. These deficits were interpreted as specific impairments in mechanisms necessary for processing visual information.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0102-014-6600

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nitrogen narcosis						
Animal Information Processing						
Visual processes						
Primate Discrimination Learning						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

UNCLASSIFIED
Security Classification