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Selective Performance Effects of Nitrous Oxide

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Twenty-one U.S. Navy divers were given several standard visual tests, the Purdue Pegboard, the Bennett Hand Tool Dexterity Test, and the Wechsler Memory Scale while breathing air or 30% nitrous oxide. The results showed that visual function, fine and gross motor performance, and long-term memory were normal under nitrous oxide, while learning and short-term memory were significantly impaired. The subjective effects of breathing nitrous oxide were similar to those experienced during compressed air narcosis. The selective impairment of short-term memory suggests that divers might be able to perform useful work at depths deeper than those currently authorized, provided the tasks were well learned and practiced.

INTRODUCTION

The effects of inert gas narcosis are an important concern for both military and sport divers, because narcosis not only impairs job performance but sometimes results in fatal diving accidents. It has been shown that inert gas narcosis inhibits central nervous system activity, sometimes producing motor disturbances, defective vision, and auditory hallucinations (Bennett, 1966). Kiessling and Maag (1962) demonstrated that manual dexterity, reaction time, and conceptual reasoning were consistently impaired at simulated depths as shallow as 100 ft. while divers breathed air, and that the amount of impairment increased with the complexity of the task. Baddeley, De Figueredo, Curtis, and Williams (1968) have shown that cognitive tasks were more impaired than motor performance during mild narcosis, while Bennett (1966) found that arithmetic reasoning was readily disrupted at shallow depths.

Relatively little attention has been directed, however, toward further specifying which basic performance factors are susceptible to narcosis, or toward determining whether learning or memory is most readily impaired. Results of several studies indicate that practice and experience may result in improved performance under narcosis (Kiessling and Maag, 1962; Poulton, Catton, and Carpenter, 1964), while another study has shown that long-term memory may be less impaired than short-term memory (Steinberg and Summerfield, 1957). Maintenance of performance during narcosis would suggest that properly trained and conditioned divers could work at depths deeper than those presently considered safe. For example, the United States Navy currently limits air dives to 190 ft. except for emergencies.

This study is concerned with some of the specific performance effects of inert gas narcosis using 30% nitrous oxide to simulate the anesthetic properties of air at a depth of 210 ft. of seawater (Cherkin, 1968). The performance factors studied included motor coordination, orientation, learning, long- and short-term memory, and visual recall. Several measures of visual function were also taken.

METHOD

Subjects

The subjects were 21 divers assigned to the U.S. Navy Experimental Diving Unit, Washington, D.C. Divers ranged in age from 24 to 41 years. Median age for the group was 28 years.

Procedure

All tests were administered under standardized conditions. Subjects were tested in counterbalanced order; 10 were tested first on air followed by nitrous oxide, and 11 received the reverse order. The subjects breathed through a conventional face mask equipped with a transducer for voice communication. The mask was attached by rubber tubing to a meteorological balloon which was fed gas from a pressurized cylinder. The control valve was opened to the room atmosphere during tests on air. The narcotic gas used during the tests consisted of 30% nitrous oxide, 20% oxygen, and 50% nitrogen.

Subjects were given 10 min. on the mask prior to testing, and were periodically asked to comment on their sensations. The divers were also asked whether these sensations had been previously experienced. Visual tests were administered after this initial breathing period, followed by tests of learning and memory. Motor performance was then tested using simple psychomotor tasks.

TASK DESCRIPTIONS

Visual Tests

Visual acuity at 20 ft. was estimated using a standard Snellen Chart, while near visual acuity was measured with an American Optical reading card held 14 in. from the eyes. Extraocular muscle function was tested by observing the eyes in three places, with and without a red glass cover. Subjects were asked to describe any diplopia. Phorias were estimated using the Maddox Wing. Proximal accommodation was determined with both eyes simultaneously, measuring the distance at which the smallest characters on the vision card became indistinguishable. Intraocular pressure was tested with a Schiotz Tonometer; stereopsis was evaluated using standard Titmus rings. Each subject was examined for spontaneous nystagmus. Assymmetrical optokinetic nystagmus was tested using a standard optokinetic drum. Corrective lenses were not used during any of the tests.

Bennett Hand-Tool Dexterity Test

The task used on the Bennett Hand-Tool Dexterity Test consisted of removing nuts, washers, and bolts from one side of a steel frame and reassembling them on the other side of the frame, using a standard set of wrenches and screwdrivers. Subjects were given three practice trials prior to testing in order to minimize practice effects. The performance score was the total time required to complete the task. This task measures mechanical aptitude and gross motor skill.

Purdue Pegboard

The task used on the Purdue Pegboard required that a set of pins, collars, and washers be assembled in a prescribed order on a pegboard. Three practice trials were also given before testing. The performance score was the number of parts assembled correctly in 30 sec. This task is a measure of manipulative skill and fine motor performance.

Wechsler Memory Scale

The Wechsler Memory Scale consists of seven subtests which test for knowledge of personal and current information, orientation to time and place, mental control, recall of logical material, digit span (forward and back

ward), reproduction of simple geometric figures from memory, and associative learning. The two forms of the test were administered in a counterbalanced order.

RESULTS

Visual Functions

Results of the visual tests are shown in Table 1. The data indicated that vision was not significantly impaired while subjects were breathing 30% nitrous oxide. Those differences which did exist were small, inconsistent, and always within normal limits.

All subjects were able to read the smallest characters on the near vision card while breathing nitrous oxide. Results using the nine Titmus stereopsis patterns were normal, as were tests of interocular pressure and accommodation. Spontaneous nystagmus was not detected, while tests of optokinetic nystagmus found normal, symmetrical movements under both test conditions. Tests of extraocular muscle function showed conjugate reflexes to be normal. Subjective diplopia was not reported. Evidence of slight insignificant exophoria was found in ten subjects using the Maddox Wing; vertical phorias, however, were not detected. Some subjects also showed slight, insignificant impairment in distance vision.

TABLE 1
Modal Scores on Visual Tests

Test	*Air*	*Nitrous Oxide*
Visual Acuity		
Near	0.5D line	0.5D line
Distant	20/20	20/20
Titmus Stereopsis	All correct	All correct
Intraocular Pressure (Scale Units)	5.75	5.50
Optokinetic Nystagmus	Normal	Normal
Versions	Normal	Normal
Accommodation (Inches)	7.0	6.5
Maddox Wing (Scale Units)		
Horizontal	0	0
Vertical	0	0

Motor Performance

Table 2 shows the results for performance on the Bennett Hand-Tool Dexterity Test and the Purdue Pegboard. There were no statistically significant differences revealed between performance on air versus performance on nitrous oxide, indicating that neither gross nor fine motor performance was significantly impaired during narcosis. Performance on the two motor tasks was highly variable, however, and represented a wide range of mechanical skill and dexterity. It is clear that motor performance remained unimpaired during moderate narcosis.

Wechsler Memory Scale

Results of the Wechsler Memory Scale are presented in Table 3, which shows that orientation to time and place, mental control, digit span, and visual recall remained essentially normal under nitrous oxide, while short-term memory for logical material and associative learning were significantly impaired.

Figure 1 shows that substantial improvements in performance occurred, however, in the associative learning task over three trials on nitrous oxide. These data suggest that some learning is possible even during moderate

TABLE 2
Mean Scores and Standard Deviations on Psychomotor Performance Tests

	Air		*Nitrous Oxide*		
Test	*Mean*	*S.D*	*Mean*	*S.D.*	t
Bennett Hand Tool (Sec.)	346.48	43.66	342.38	30.72	0.69
Purdue Pegboard (Parts/30 sec.)	38.24	5.39	38.33	3.87	0.10

TABLE 3
Mean Scores and Standard Deviations for Correct Items on the Wechsler Memory Scale

Test	Air		Nitrous Oxide		
	Mean	S.D.	Mean	S.D.	
Orientation	10.57	0.74	10.09	1.11	[illegible]
Mental Control	7.04	1.73	6.04	1.78	[illegible]
Digit Span					
Forward	7.09	1.05	6.57	1.30	[illegible]
Backward	5.04	1.51	4.61	1.39	[illegible]
Visual Recall	11.80	2.30	12.00	1.92	0.34
Short-Term Memory	14.90	3.12	8.28	2.07	[illegible]*
Associative Learning[a]					
Simple	5.51	0.75	4.39	1.18	[illegible].37*
Complex	2.13	1.24	1.21	1.06	[illegible]47*

[a] Mean for all three trials.
*$p < 0.01$.

narcosis. Results from the Wechsler Memory Scale subtests are discussed below.

Personal History, Current Information, and Orientation

This test asks for age, date of birth, names of public officials, and other information, such as current date and location. Memory for this information remained normal while breathing nitrous oxide. Approximately 90% of these answers were correct under both test conditions. It should be emphasized that this kind of information is relatively permanent, and that this may have enhanced recall under nitrous oxide.

Mental Control

These tasks require counting backwards from 20 to 1, repeating the alphabet, and counting forwards by threes or fours. The performance score was the number correct. The results showed that performance on nitrous oxide was not significantly different from that on air. The results suggest that long-term memory and simple cognitive performance were essentially normal at this level of narcosis.

Digit Span

In this subtest, digit sequences of increasing length are recited from memory until two consecutive sequences are missed. Digit span is the length of the longest series correctly recalled. Performance on this subtest was normal under both conditions. This finding suggests that rote memory remains largely intact under nitrous oxide.

Visual Recall

This test requires that simple geometric figures be reproduced from memory. The figures are printed on three test cards and presented in order of increasing complexity. The designs are viewed for 10 sec., and must then be drawn from memory. A standardized format is used to score the drawings. Performance on this task was essentially normal while breathing nitrous oxide. These results are noteworthy, however, because the material to be remembered is visual, while that on the other subtests of the Wechsler Memory Scale is largely verbal. Moreover, this information was new and had to be learned under nitrous oxide, while much of the information on previous subtests had been learned prior to narcosis.

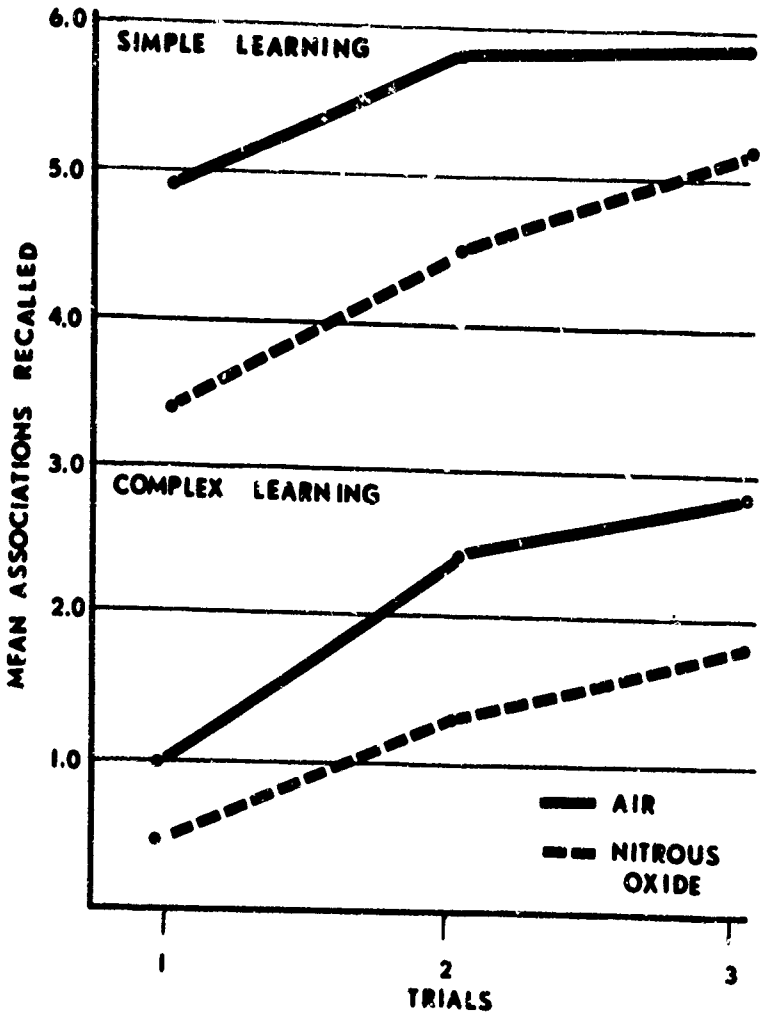

Figure 1. Mean number of simple and complex verbal associations correctly recalled over three trials.

Short-Term Memory

This task consists of recalling from memory the contents of two brief stories which are read aloud. The performance score was the average number of ideas correctly remembered. The results (Table 3) indicated that short-term memory of verbal material was significantly impaired during narcosis. Subjects remembered 71% of the ideas under normal conditions, while only 39% were recalled during narcosis. It is uncertain whether this performance resulted from lack of attention or impaired recall. Performance on previous subtests suggest that recall, rather than attention, was probably impaired. If attention had decreased under nitrous oxide, performance on previously administered subtests, such as visual memory and digit span, should also have been disrupted.

Associative Learning

This test consists of ten word associations; six associations are logical and easy to learn, and four are difficult. The ten paired associates were presented three times, and retention was tested after each presentation. During testing the first word of the pair was read aloud and had to be answered correctly within 5 sec. or the correct association was supplied. Figure 1 shows that performance on this subtest was impaired on nitrous oxide. The results, however, suggest that substantial learning is possible during narcosis. Recall of both the easy and difficult associations increased over the three trials, with recall of the easy items being normal on the third trial. It is apparent that ease of association was helpful in recalling the paired words. These data appear to substantiate the above findings that memory for previously learned material remained largely intact under moderate narcosis. Material which was new and which could not readily be integrated with past experience was most readily impaired during narcosis.

Subjective Reports

Fourteen divers stated that sensations experienced during narcosis were similar to those encountered while breathing compressed air at depths of 200 to 250 ft., which corresponds closely to the predicted anesthetic equivalence of air and nitrous oxide (Cherkin, 1968). Five of the remaining divers indicated that they found the effects similar to alcohol intoxication, while the other two subjects did not relate the sensations to any previous experience. None of the divers reported noticing any unusual sensations while breathing air through the face mask.

DISCUSSION

The results of this study indicated that while breathing 30% nitrous oxide (1) visual function remained normal, (2) fine and gross motor performance were not disrupted, (3) long-term memory remained intact, (4) visual learning and memory were normal, (5) verbal learning and short-term memory were significantly impaired, and (6) subjective effects similar to those experienced during compressed air narcosis were reported.

Results of the visual tests suggested that sensory function was essentially normal under 30% nitrous oxide. The results from the test for nystagmus were particularly significant, because it has been demonstrated that other depressant drugs, such as barbiturates and anticonvulsants, often produce spontaneous vestibular nystagmus (Bender, 1946). The results of the present study suggest that nitrous oxide can be useful in visual tests or examinations in which light anesthetic is required.

Fine and gross motor performance were also normal. These data are consistent with results from other studies which show that tasks having a large motor component are least susceptible to the effects of inert gas narcosis (Baddeley, 1966; Kiessling and Maag, 1962). It is difficult, however, to determine whether it is simplicity alone or past experience with similar tasks which resulted in normal performance. Results from the cognitive tasks suggest that past experience and practice are important factors in maintaining performance during moderate narcosis.

Results of the Wechsler Memory Scale showed that cognitive tasks involving long-term memory were less impaired than tasks requiring learning and short-term memory. This suggests that many of the performance effects of nitrous oxide could possibly be eliminated if the material has been sufficiently learned prior to narcosis. These results were similar to those of previous studies which found that practice can minimize the performance effects of inert gas narcosis (Kiessling and Maag, 1962; Poulton, Catton, and Carpenter, 1964). This also confirms the results of other studies which how that cognitive performance on tasks requiring short-term memory is significantly disrupted

while breathing 30% nitrous oxide (Frankenhaeuser and Beckman, 1961; Steinberg and Summerfield, 1957). Although this study found that learning of new information was impaired under nitrous oxide, significant improvement in performance did occur and may have approached control levels with more practice.

It is noteworthy that short-term visual recall remained intact despite the significant impairments in short-term verbal memory. Although these two tasks have never been formally equated, a comparison of scores under control conditions showed that the percentage of error on the visual task was about the same (16%) as that which occurred on the first trial of the simple association task (18%), indicating that the two tests may have been approximately equal in difficulty. Performance during narcosis would, therefore, suggest that nitrous oxide selectively impaired memory for verbal information, while leaving visual recall intact. These results are similar to those of another study (Parkhouse, Henric, Duncan, and Rome, 1960) in which memory for paired designs on 30% nitrous oxide was significantly better than memory for nonsense syllables. The basis for this difference, however, is unknown. Although nitrous oxide had probably reached those mechanisms involved in visual recall long before testing occurred (Kety and Schmidt, 1948), it is possible that this dosage was not sufficient to disrupt normal activity in these mechanisms (Brazier, 1954). Differences between the two tasks could also account for the results.

CONCLUSIONS

The results of this study indicated that inert gas narcosis selectively disrupted performance. Vision, motor performance, long-term memory, and visual recall remained largely intact under nitrous oxide while learning and short-term memory were significantly impaired. Some learning and short-term memory were possible during moderate narcosis, suggesting that performance may have approached normal levels with adequate practice. These results differ from those of other studies of narcosis, especially those which have tested performance during actual chamber dives (Baddeley, De Figueredo, Curtis, and Williams, 1968; Kiessling and Maag, 1962). Both motor performance and simple cognitive tasks were generally less impaired in this study, perhaps because these divers had more experience with narcosis and the testing conditions were less stressful. The divers used in this study had all performed underwater tasks during nitrogen narcosis, and may have learned to adjust partially to its effects. Moreover, other studies have suggested that the psychological stress of diving may worsen the performance effects of nitrogen narcosis (Baddeley, 1966). Nitrous oxide could prove useful in studying interactions between psychological stress and nitrogen narcosis.

Although these results indicate that the performance effects of inert gas narcosis can be minimized in certain situations, further study will be necessary before these conclusions can be substantiated and applied to actual diving conditions.

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