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DISSOCIATION OF THE BEHAVIORAL AND SUBJECTIVE COMPONENTS OF NITROGEN NARCOSIS AND DIVER ADAPTION

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Dissociation of the behavioral and subjective components of nitrogen narcosis and diver adaptation

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Hamilton K, Laliberté M-F, Fowler B. Dissociation of the behavioral and subjective components of nitrogen narcosis and diver adaptation. Undersea Hyperbaric Med 1995; 22(1): 41–49.—We investigated adaptation to nitrogen narcosis by compressing 11 highly experienced divers in a hyperbaric chamber to the equivalent of 54.6 meters of seawater once a day for 5 consecutive days. The behavioral component of narcosis was assessed with a serial choice–reaction time (RT) task, and the subjective component with a global magnitude estimate. Supplementary magnitude estimates were obtained with adjectives describing work effectiveness and body sensations. The results showed that there was no adaptation on the RT task, although learning was evident. In contrast, the global estimate dissociated from RT and showed clear adaptation by Day 3. The work effectiveness adjectives followed RT and did not show adaptation. Some body sensation adjectives showed clear adaptation, but others did not. These results lead to the conclusion that the anecdotal reports of adaptation by divers can probably be attributed to the subjective rather than the behavioral component of narcosis. Dissociation of these components suggests mediation by different brain mechanisms, and it is speculated that the gamma-aminobutyric acid$_A$/benzodiazepine receptor complex, which has been implicated in both the anesthetic and anxiolytic properties of agents such as nitrous oxide, may be involved.

inert gas narcosis, anesthesia, reaction time, nitrous oxide, anxiolytic, subjective ratings, gamma-aminobutyric acid$_A$

It is well known that inert gas narcosis is expressed by both behavioral (objective test performance) and subjective (body sensation) components. The behavioral component includes amnesia and an increase in reaction time (RT), and the subjective component includes dimensions relating to euphoria, state of consciousness, lowered inhibitions, and work capability (*see* 1 for a review). The diving community believes that frequent deep diving ameliorates nitrogen narcosis (2), but the experimental support for this phenomenon of adaptation is weak. Adaptation is defined as a decrease in the effects of narcosis with

repeated exposures, relative to a surface control. Moeller and Chattin (3) initially reported evidence for adaptation in the tracking performance of divers exposed to nitrogen narcosis for the second time. However, more sophisticated experiments by Moeller and others (4), Rogers and Moeller (5), and Whitaker and Findley (6), in which divers were exposed to nitrogen narcosis over the course of several days, failed to corroborate this observation.

Two features are common to the experiments cited above. First, only the behavioral component of narcosis was measured with tasks involving RT, tracking and body sway. Second, learning during the hyperbaric exposure was evident in all experiments. This led Moeller and co-workers (4) and Rogers and Moeller (5) to suggest that either learning had been mistaken for adaptation, or that adaptation is restricted to the subjective component of narcosis, and hence had gone undetected in the laboratory experiments. The latter hypothesis is of considerable interest, because evidence that the two components dissociate would imply that narcosis is mediated by more than one brain mechanism.

Recently, Hamilton et al. (7) tested the dissociation hypothesis by measuring both RT and the subjective symptoms of non-divers who were exposed to 30% nitrous oxide for 5 successive days. RT showed no sign of adaptation, but there was a trend toward adaptation in the global subjective estimate of narcosis, and some adjectives describing the symptoms of narcosis showed adaptation. These inconclusive results could be due either to inexperienced subjects providing unreliable estimates of narcosis, or to a difference in the mechanisms governing adaptation to nitrous oxide and hyperbaric nitrogen. In the test of the dissociation hypothesis reported here, we obviated these possibilities by inducing nitrogen narcosis in experienced divers over 5 consecutive days. Choice RT was employed as the behavioral measure of narcosis, and a global estimate as the subjective measure.

Another question that arises in connection with the dissociation hypothesis is whether all dimensions of the subjective component show adaptation. It could be argued that, in contrast to the dimensions of euphoria, state of consciousness, and lowered inhibitions, the dimension of work capability would not show adaptation because it reflects the efficiency of performance rather than body sensations. Judgments about performance efficiency are presumably influenced by feedback based on the behavioral component of narcosis, at least in experienced divers. Under these circumstances, work capability should follow the behavioral component of narcosis and fail to adapt. We tested this prediction by comparing adaptation in two groups of adjectives representing work capability and body sensations, respectively.

METHODS

Subjects

Eleven experienced Canadian Forces clearance divers (ages 28–38 yr), assigned to the Experimental Diving Unit at the Defence and Civil Institute of Environmental Medicine (DCIEM), participated in this study. They had all dived to at least 54.6 meters of sea water on a number of occasions, but not for at least 2 mo. before the study. All subjects were medically screened and gave informed consent.

Apparatus

The experiment was conducted in a large hyperbaric chamber located at DCIEM that provided an uncrowded testing environment. RT was measured with a serial choice-reac-

tion time task that has been employed in previous hyperbaric experiments (8). The version used in the present experiment consisted of four microswitch keys mounted in a semicircle and individually adjustable in the horizontal plane to accommodate different hand sizes. Immediately in front of each key was a light-emitting diode (LED). The stimulus for depressing a particular key was the illumination of the corresponding LED. A PC computer controlled a sequence of events in which an LED was illuminated until the corresponding key was depressed. This action simultaneously extinguished the LED and randomly illuminated another one. The computer collected both RT and the number of errors (pressing the wrong key). The subjects rested the middle and index fingers of each hand on the keys, and their task was to extinguish each LED as quickly and accurately as possible over a 90-s period.

Global magnitude estimates of narcosis were obtained with a 9-point scale that employed semantic anchors at 1, 3, 5, 7, and 9 labeled as "no narcosis," "mild narcosis," "moderate narcosis," "strong narcosis," and "extreme narcosis," respectively. In addition, magnitude estimates were obtained for 12 adjectives that have been found to be sensitive to narcosis (7,9). One group of adjectives represented work capability and consisted of "efficient," "able to work hard," "alert," "able to concentrate," and "able to think clearly." The other group represented body sensations and consisted of "elated," "uninhibited," "fuzzy," "dizzy," "dreamy," "light headed," and "intoxicated." These adjectives were also rated on a 9-point scale, but the semantic anchors were "not at all," "a little," "somewhat," "quite a bit," and "extremely." The scales and the adjectives were printed in random order on sheets that were used by the subjects to record their estimates.

Procedure

The subjects were briefly familiarized with the tasks before the experiment. A repeated measures design was employed with an experimental and a control condition on each of 5 consecutive days. Chamber air was breathed in both conditions at pressures equivalent to 54.6 and 3.0 meters of seawater (msw), respectively. Rate of descent was 13.2 m/min, testing commenced 5 min after reaching bottom, and maximum bottom time was 30 min. The control condition was conducted approximately 90 min after the experimental condition during the final stages of decompression. The divers were tested in three groups of four and one group of three, and were accompanied by an experimenter. There were four testing stations, two for the RT task and two for the subjective estimates. Testing was conducted in two phases. In the first phase, two subjects performed the RT task, while the other two (or one) made their subjective estimates. In the second phase, the subjects reversed roles. The subjects were not provided with verbal feedback about their performance during the experiment.

RESULTS

Mean correct RT is illustrated in Fig. 1. An inspection of this figure suggests that learning took place on the task, because RT decreased over days. In addition, RT was slowed in the 54.6-msw condition, but there is no persuasive evidence of adaptation, since there is little or no diminution in the amount of this slowing over days. These observations were confirmed by a 2 depths x 5 days repeated measures analysis of variance (ANOVA) that revealed significant main effects for depth (F 1,10 = 43.94; $P < 0.001$) and days (F 4,40 = 6.24; $P < 0.001$), but the depth × days interaction did not approach signifi-

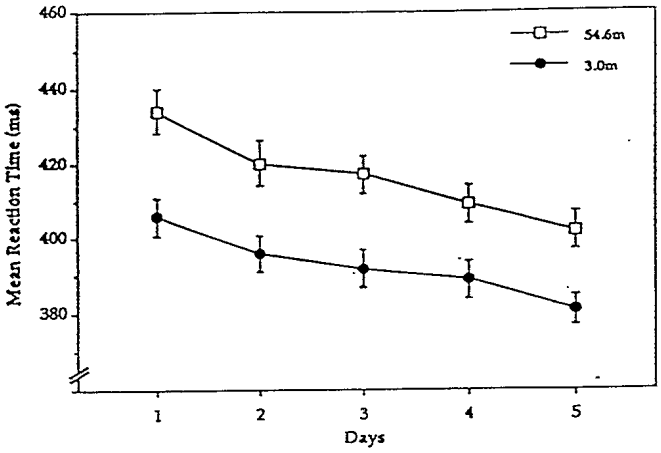

FIG. 1—Mean correct serial choice–reaction time as a function of depth and days. *Bars* represent SEMs.

cance. Number of errors was relatively variable from day to day (Table 1). The analysis of these data revealed a main effect for depth (F 1,10 = 10.50; P <0.009) only, indicating a slight increase in errors at 54.6 msw (2.3 errors at 3.0 msw vs. 2.9 errors at 54.6 msw), but no evidence of either a systematic change over days or adaptation.

The global magnitude estimates of narcosis are illustrated in Fig. 2. In contrast to the RT data, adaptation seems to occur by Day 3, as indicated by the decrease in the estimates at 54.6 msw, relative to the 3.0 msw control. It should be noted that the absence of variability at 3.0 msw is due to consistent estimates of 1 (no narcosis) in this condition. Consequently, the 54.6 msw experimental condition was analyzed with a one-way ANOVA to avoid an increase in the type 1 error rate of the kind experienced by Hamilton et al. (7). A highly significant effect of days (F 4,40 = 17.12; P < 0.0001) was found, confirming the presence of adaptation. This effect was due largely to a decrease in the magnitude of ratings on Day 3 of the experiment (Day 1 vs. 2, ns; 2 vs. 3, P = 0.0002; 3 vs. 4, P = 0.06; Newman-Keuls). These results provide clear evidence that the subjective component of narcosis adapted in this experiment.

With one exception, the adjective magnitude estimates exhibited some variability in the control condition and were therefore analyzed separately with two-way ANOVAs. Any adjective exhibiting an interaction was also analyzed with a one-way ANOVA to confirm the presence of a significant effect. Mean ratings for each adjective, and the P values for the ANOVA associated with it, are illustrated in Figs. 3 (work capability) and 4 (body sensation). Four points should be noted about these results. First, all the adjectives were sensitive to narcosis, as indicated by the significant main effect for depth. Second, in the case of the work capability adjectives there is no reliable evidence of adaptation because none of the interactions approached significance. Third, in contrast to the work capability adjectives, the body sensation adjectives "dreamy," "light-headed," and "intoxicated" show

Table 1: Mean Number of Errors (±SEM) on the Serial Choice–Reaction Time Task

	Days				
Depth, msw	1	2	3	4	5
3.0	2.1 ± 0.5	2.5 ± 0.4	2.4 ± 0.5	2.0 ± 0.5	2.6 ± 0.4
54.6	3.6 ± 0.6	3.2 ± 0.7	2.1 ± 0.4	2.7 ± 0.5	3.0 ± 0.7

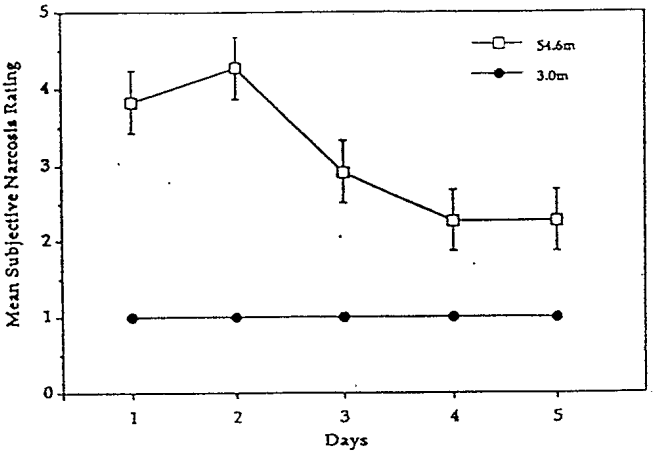

FIG. 2—Mean global magnitude estimates of narcosis as a function of depth and days. *Bars* represent SEMs.

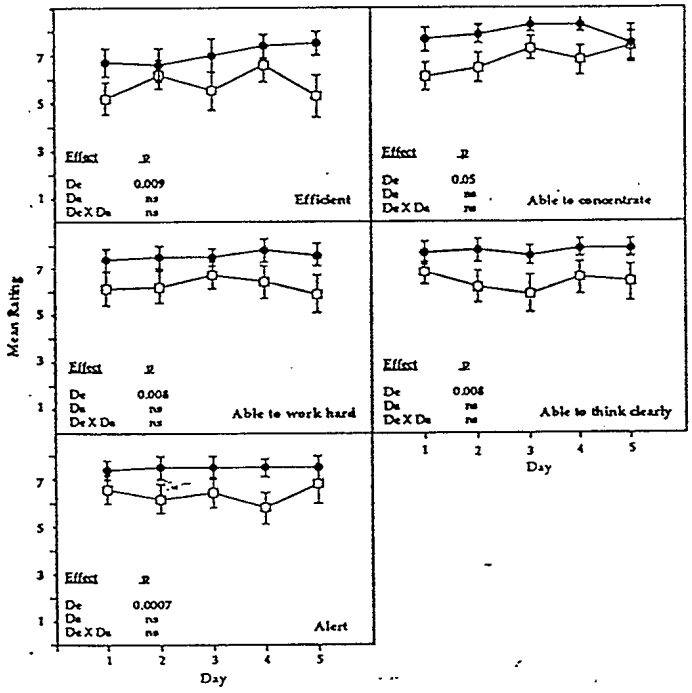

FIG. 3—Mean ratings for each of the adjectives in the work capability group as a function of depth and days. *Open squares* = 54.6 msw; *closed circles* = 3.0 msw. *Bars* represent SEMs. *P* values for the ANOVA performed on each adjective are also shown. *De* = depth, *Da* = days, and *De* × *Da* = interaction.

clear adaptation since a reliable interaction was found in each case. Moreover, a strong trend for an interaction was found for "fuzzy" and "dizzy." This evidence of adaptation is supported by the one-way ANOVAs conducted on these five adjectives in the 54.6-msw condition. Each analysis was significant, with *P* values of < 0.009, 0.0001, 0.0001, 0.03, and 0.03, respectively. "Elated" and "uninhibited" also show signs of adaptation, but it is not possible to draw firm conclusions about these adjectives because statistically reliable interactions were not found. Finally, it is striking that some of the body sensation adjectives follow the pattern of the global estimate and show a trend for adaptation to emerge on Day 3. In summary, the body sensation but not the work capability adjectives provide some evidence for adaptation, as well as a pattern of change over days similar to that found for the global estimate.

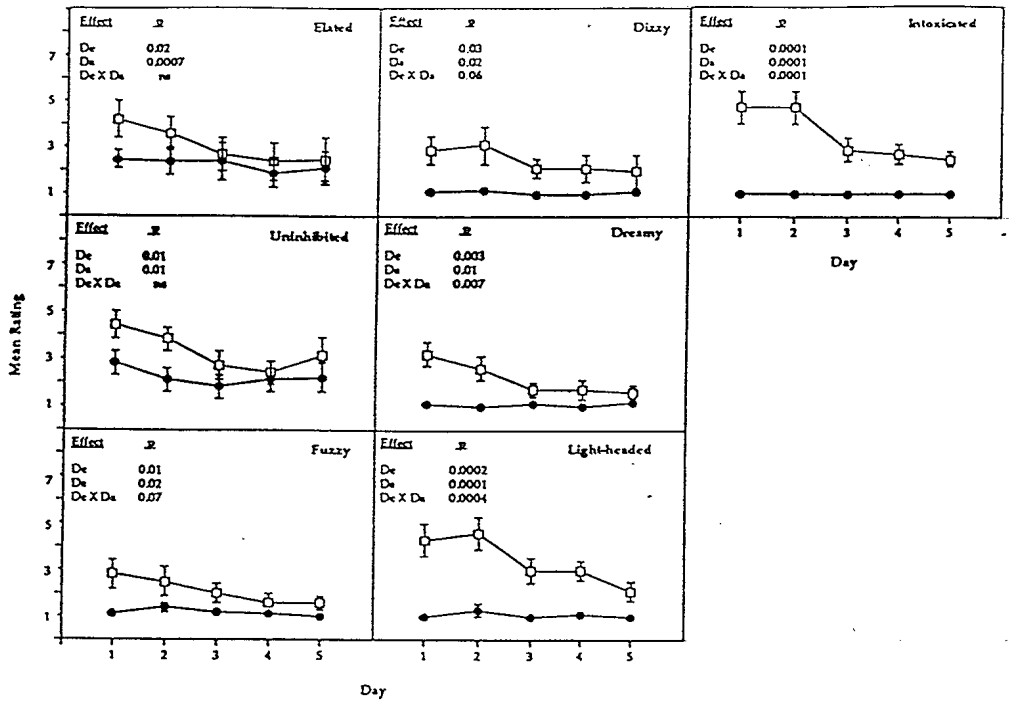

FIG. 4—Mean ratings for each of the adjectives in the body sensation group as a function of depth and days. *Bars* represent SEMs. *P* values for the ANOVA performed on each adjective are also shown. *De* = depth, *Da* = days, and *De* × *Da* = interaction.

DISCUSSION

Although a helium–oxygen control was not employed in this experiment, the behavioral and subjective effects observed at 54.6 msw can be confidently attributed to nitrogen narcosis rather than to other confounding influences in the hyperbaric environment, such as heat or anxiety. This is because previous nitrogen narcosis experiments conducted in our laboratory, employing both a helium control and subjects from the same population at pressures up to 92 msw, have revealed virtually no effect of the hyperbaric environment alone on performance (8).

The major finding from this experiment was that the global estimate of narcosis, but not the RT measure, showed adaptation to narcosis. In the former case, adaptation emerged on Day 3, and there is the suggestion that an asymptotic value may have been reached by Day 5. In the latter case, only learning was evident over the course of the experiment. Learning but not adaptation is typical of hyperbaric laboratory experiments employing behavioral measures (4–7), and the evidence is now fairly convincing that the behavioral component of narcosis does not adapt to any significant degree over at least the first 5 days of exposure. Taken together, these results provide strong support for the dissociation hypothesis of Moeller et al. (4) and Rogers and Moeller (5).

The adjective data suggest that, in experienced divers at least, judgments about work capability can be differentiated from judgments about body sensations. This conclusion is based on the finding that the work capability adjectives showed few signs of adaptation, but three of the body sensation adjectives showed clear-cut adaptation and two others showed a strong trend in the same direction. The fact that work capability judgments

paralleled RT performance suggests that our divers possessed the ability to judge their own performance accurately, although the extent to which past experience and feedback from the RT task played a role in this assessment remains an open question. The mixed results for the body sensation adjectives can be explained as follows. The subjective component of narcosis is a multidimensional state that is presumably captured by a global estimate. Individual adjectives tap limited aspects of this state and may not even be strongly related to it, since only a rough description of each dimension is available at the present time (7,9). Thus variability in the response of individual adjectives to narcosis is not surprising and is apparent in the adjective rating data of Hamilton et al. (7).

The strong adaptation effect observed in the present study contrasts with the unreliable effect observed by Hamilton et al. (7). This difference could be explained either by the substitution of experienced divers for inexperienced non-divers, or hyperbaric nitrogen for nitrous oxide. Neither possibility can be dismissed at present, but we favor the experience hypothesis because the subjective effects of nitrous oxide and hyperbaric nitrogen seem to be identical, although these two agents have not been compared directly (1). Furthermore, the global rating data of Hamilton et al. (7, fig. 1) show in attenuated form what was clearly evident in the present study: adaptation emerging on Day 3 of exposure. This strengthens the argument that adaptation was brought into clear focus by employing subjects who could reliably discriminate the subjective component of narcosis.

This experiment sheds light on the nature of the adaptation process in divers. In all probability, anecdotal reports of adaptation have arisen from an amelioration of the body sensations associated with the subjective component of narcosis, although the possibility that learning has been mistaken for adaptation cannot be ruled out completely. This seems unlikely, however, on the grounds that most underwater tasks are routine and highly overlearned. Moreover, our results suggest that experienced divers can discriminate between the behavioral and subjective components of narcosis, although no doubt this discrimination would be more difficult underwater. It has been proposed that the intensity of narcotic symptoms could be used by divers to gauge the extent of performance loss (10). The present results indicate that this advice is inappropriate for adapted divers because the two components of narcosis uncouple in a direction that could lead to an overestimation of performance capabilities—a potentially dangerous situation. On the other hand, the question arises as to whether adaptation confers any benefits on the diver, since performance efficiency is not directly improved and could be overestimated. In this regard, it could be argued that a reduction in symptom intensity reduces the possibility that attention will be focused on subjective sensations rather than the task at hand.

Finally, the observation that the behavioral and subjective components of narcosis dissociate suggests a difference in the mechanisms mediating each component. Although the nature of this difference can only be a matter of speculation at present, recent advances in molecular and cellular biology offer hopeful avenues for exploration. An agent such as nitrous oxide is said to manifest analgesic, anesthetic, and anxiolytic effects (11). The anesthetic effect can be thought of as the end point of narcosis and is a property shared by many agents. Controversy has surrounded attempts to develop a unitary model of anesthesia (*see* 12 for a review), but the traditional view that anesthetics act by non-specific perturbation of cell membranes is now being challenged by new evidence suggesting that inhalation anesthetics influence transmission in the gamma aminobutyric acid $(GABA)_A$–benzodiazepine receptor chloride channel complex (GBRC) directly (13–16). This enhancement of GABA-mediated activity could depress CNS functioning, either by hyperpolarizing the cell or by increasing transmission through inhibitory synapses (12). According to the slowed processing model, this CNS depression is translated into a non-specific slowing rather than a distortion of information processing (17,18). This slowing is

manifested by the event-related brain potential P300, and at the behavioral level by RT. From this point of view, an RT task such as the one used in the present study can be considered as the purest behavioral expression of the anesthetic cellular mechanism. Anxiolysis is also a property of hyperbaric nitrogen (9), but it has not been studied as a separate feature of the subjective component of narcosis and was not assessed directly in the present study. Nevertheless, it seems reasonable to assume that the anxiolytic effect formed part of the global estimate. Of particular note is that recent work by Quock and co-workers (11,19), Czech and Quock (20), and Emmanouil et al. (21) points to the involvement of the benzodiazepine receptors of the GBRC in the anxiolytic effect produced by nitrous oxide. Thus, it may be that this anxiolytic mechanism mediated the adaptation observed in the present study.

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