The levels of processing effect under nitrogen narcosis

Wendy Kneller, Malcolm Hobbs

Department of Psychology, University of Winchester, Winchester, United Kingdom

CORRESPONDING AUTHOR: Dr. Wendy Kneller – *wendy.kneller@winchester.ac.uk*

ABSTRACT

Previous research has consistently demonstrated that inert gas (nitrogen) narcosis affects free recall but not recognition memory in the depth range of 30 to 50 meters of sea water (msw), possibly as a result of narcosis preventing processing when learned material is encoded. The aim of the current research was to test this hypothesis by applying a levels of processing approach to the measurement of free recall under narcosis. Experiment 1 investigated the effect of depth (0-2msw *vs*. 37-39 msw) and level of processing (shallow *vs*. deep) on free recall memory performance in 67 divers. When age was included as a covariate, recall was significantly worse in deep water (*i.e*., under narcosis), compared to shallow water, and was significantly higher in the deep processing compared to shallow processing conditions in both depth conditions. Experiment 2 demonstrated that this effect was not simply due to the different underwater environments used for the depth conditions in Experiment 1. It was concluded memory performance can be altered by processing under narcosis and supports the contention that narcosis affects the encoding stage of memory as opposed to self-guided search (retrieval).

INTRODUCTION

Exposure to increased ambient pressure while breathing air causes inert gas narcosis, a form of intoxication caused by the action of these gases in the brain [1]. Narcosis is a problem for any individual exposed to increased pressure but is most often experienced by undersea divers, where symptoms become apparent at depths greater than 30 meters of sea water (msw). The diving community commonly uses the term "nitrogen narcosis" after the gas held to be primarily responsible when breathing normal air mixtures. The symptoms of narcosis include a spectrum of cognitive and motor deficits [2,3], which pose a significant problem for safety [4,5] and work performance [6,7] in high-pressure environments.

One symptom of narcosis is memory loss, which previous research [8,9] has indicated primarily results from impairment of long-term memory (LTM), as opposed to short-term/working memory. LTM function is often assessed by measuring the delayed free recall of word lists and on cued-recall recognition tests, where participants identify words previously presented on a list containing additional novel words. Using these measures, multiple studies [9,10,11,12,13,14] have consistently shown that narcosis impairs free recall but not recognition memory in the depth range of 30 to 50 msw. The apparent contradiction of a differential impact of narcosis on these two measures of LTM remains a matter of contention, but two possible explanations [14,15] have been suggested.

The first is that narcosis impairs the self-guided search of memory [14] – that is, the process enacted by an individual to retrieve information in the absence of external memory cues. According to this hypothesis, while narcosis allows information to be stored in LTM as normal, it impairs self-guided search, thus leading to a degraded ability to retrieve information which manifests itself as impaired free recall. Recognition memory is not affected because the provision of memory cues at the retrieval stage circumvents the need for self-guided search.

The second explanation is that narcosis disrupts processing at the encoding stage. In this scenario, material is learned but the quality of encoding and processing is reduced, resulting in a weaker memory trace. In a recognition test the possible responses are provided by the experimenter, requiring a less "sophisticated" level of processing for effective performance, and hence recognition memory is not impaired.

Hobbs and Kneller [14] provided evidence for the second explanation that narcosis disrupts processing when learned material is encoded. Their study examined the impact of narcosis on free recall and recognition memory by comparing memory performance for word lists learned and recalled both in shallow water (no narcosis) and in deep water (with narcosis) at 40 msw. While recognition memory was not impaired, free recall was impaired when words were learned in deep water and recalled in either deep or shallow water. But, significantly, free recall was not impaired when information was learned in shallow water and recalled in deep water, suggesting intact self-guided search and impaired processing at the encoding stage.

The current research aimed to follow up these results and directly test the hypothesis that narcosis disrupts processing at the encoding stage by applying a levels of processing (LoP) approach. The LoP approach states that the durability of a given stimulus in memory depends upon the depth of processing brought to bear on that stimulus during initial exposure to it [16]. A common explanation of the LoP effect is that deep processing activates more relevant knowledge compared to shallow processing, and this activated information becomes associated with the stimulus to form a more elaborate or distinctive memory trace [17,18]. Therefore, this greater trace elaboration results in better recollection because of either greater distinctiveness or greater integration with existing knowledge structures.

In a typical LoP task, participants are presented with words which they are required to process either in a "shallow" or "deep" manner. For example, shallow processing might mean deciding whether the word is written in capital or lower-case letter, or whether the word contains an "e." Deep processing may involve deciding whether a word fits into a particular semantic category: whether the word fits into a particular sentence ("does this word fit into the sentence, 'She put the … in her pocket'), or whether a word is pleasant or unpleasant [18,19]. Using such tasks, evidence from PET and fMRI studies have shown that deeper semantic processing yields a stronger memory trace [20,21].

If narcosis does affect the encoding of information, it would be predicted that deeper processing would extinguish or lessen the impairment of recall seen under narcosis. That is, deeper processing of material learned under narcosis will continue to lead to better recall than shallow processing. In contrast, if the hypothesis that narcosis impairs self-guided search is to be accepted, as the impairment rests in the ability to retrieve information and not how well it was encoded, deep processing under narcosis should not improve free recall.

The current study examined the LoP effect under narcosis in two underwater field experiments. Experiment 1 tested the effect of depth underwater (shallow *vs.* deep) – that is, whether individuals were under the effects of narcosis or not – and level of processing (shallow processing *vs.* deep processing) on the free recall of word lists. Experiment 2 addressed one of the methodological limitations of Experiment 1: that the results could simply have been due to environmental differences between the depth conditions.

EXPERIMENT 1: LEVELS OF PROCESSING UNDER NITROGEN NARCOSIS

Experiment 1 aimed to test the LoP effect in shallow (swimming pool; no narcosis) and deep (ocean; under narcosis) water. It was predicted that at a shallow depth, in the absence of narcosis, deeper processing should lead to improved recall compared to shallow processing as demonstrated in previous levels of processing studies. It was also predicted that at a deep depth free recall would be reduced compared to a shallow depth but, as prior studies suggest that narcosis disrupts the encoding of information, deeper processing would lead to a lessening or extinguishing of this effect.

METHOD

Design

We utilized a 2 x 2 factorial design between participants to investigate the effect of level of processing [shallow processing (SP) *vs.* deep processing (DP)] and depth of water (shallow *vs.* deep) on free recall memory performance (number of correct words recalled). Shallow water represented a depth of 0-2 msw and deep water a depth of 37-39 msw. Participants were randomly assigned to processing conditions, and the depth conditions were assigned on an opportunistic basis.

Participants

Sixty-seven participants (46 male) volunteered for the study, aged between 18 and 67 years (M=36.7; SD=12.1). They had completed between zero and 3,000 dives (M=304.4; SD=637.7) over a period up to 40 years (M=7.1; SD=8.9). There were 36 participants in the shallow depth condition and 31 participants in the deep depth condition. There were 35 participants in the shallow processing (SP) condition and 32 participants in the deep processing (DP) condition. The slightly unequal groups arose because of the financial and practical necessity of collecting data using small groups of participants who all had to complete the same condition, rather than collecting the data on individuals.

Participants in the shallow condition were recruited from Eastleigh BSAC diving club in the United Kingdom, whereas participants in the deep condition were recruited from the recreational dive center Big Blue in Dahab, Egypt. Big Blue carried out an established screening process to determine whether each diver was suitably qualified and medically fit to dive to the depth required for the study, and ethical permission was granted by the University of Winchester.

MATERIALS

The free recall test used 30 target words matched for imagery, familiarity and concreteness using the MRC Psycholinguistic Database: Machine Usable Dictionary (v2.0). The same words were used in each condition and presented in the same order. In the SP condition each target word was preceded by an orientating question: either "Is the word in capital letters?" or "Is the word in lower-case letters?" The target word was printed in either lower-case or capital letters, with an equal number of words in each format and an equal number of true/false answers.

Each word was displayed on a laminated card and presented one at a time for five seconds. In the DP condition each target word was preceded by a sentence with a word missing, *e.g.*, "The____fell off the table". The target word below either made sense as part of the sentence or did not, with an equal number of readily perceived/nonsensical options. Again, each word was presented for five seconds. Participants were required to indicate whether the target word made sense as part of the sentence. Participants indicated the response to each card by writing them on an underwater slate.

Procedure

The deep depth conditions were carried out, from the shore, in Dahab, Egypt. The sites used consisted of a sloping seabed, leveling off to a sandy plateau at 35-40 msw. Conditions were calm with a consistent 20- to 30-meter visibility, no current and a water temperature of 24ºC. These water conditions were comparable to those in the shallow depth conditions which were carried out in a swimming pool in Eastleigh in the UK.

Participants were extensively briefed on the surface, using relevant example cards to aid understanding, so that they were thoroughly familiar with the protocol. Upon entering the water the researcher guided participants to the required depth (maximum descent time = six minutes) where they knelt on the seabed/pool bottom. Once on the bottom each participant was shown the cards, one card at a time. After presentation of all 30 words there was a break of three minutes. After the break they were given another slate with the directive "Write down as many target words as you can remember from those I just showed you" and were given 90 seconds to complete the task. Participants were ignorant of the fact that this question would be asked of them. Testing took place in groups of no more than three, depending on experience. Once testing was finished the researcher led the participants back to the surface.

Data reduction and analysis

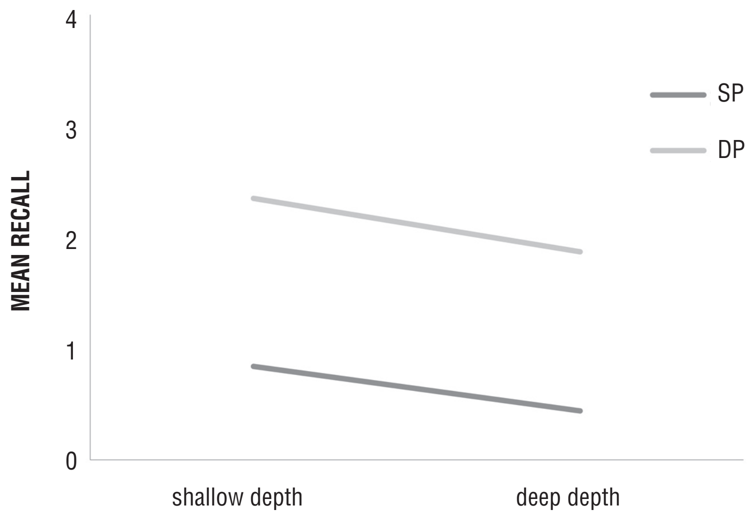
Means were calculated for number of words recalled for each condition. All data was tested for skew and log transformed if the level of skew was considered to be too high. The data were then analyzed using a 2 *x* 2 ANOVA (depth *x* level of processing), with an Alpha value of 0.05 used as the criterion for significance.

RESULTS AND DISCUSSION

Means for the number of words recalled for each condition are illustrated in Figure 1. Recall in the SP conditions was slightly lower at deep depths (M=0.44; SD=1.0) compared to shallow depths (M=0.84; SD=1.2); this pattern was repeated in DP conditions, with recall lower in deep water (M=1.87; SD=1.1) compared to shallow water (M=2.35; SD=2.1). Despite lower actual recall in deep water, this depth effect was not significant, $F(1,63) = 2.12$, and there was no depth *x* level of processing interaction, $F(1,63) = 0.21$. As predicted by LoP, recall was significantly higher in both DP conditions compared to the SP conditions at each depth, $F(1,63) = 15.96$.

The lack of an effect of depth initially appeared to indicate no effect of narcosis on recall. However, it was noted that the mean age of participants in the shallow depth condition (M=39.4; SD=12.4) was older than in the deep depth condition (M=29.4; SD=11.0). Prior research shows that in older adults (~60 years+) ability on free recall tests is significantly lower than that of 20-30 year olds [22] and may even begin to deteriorate at 45 years of age [23]. For this reason, we ran the analysis again with age taken into account as a covariate. The subsequent ANCOVA found a significant effect of depth $F(1,62) = 4.94$, and level of processing $F(1,62) = 14.75$, but no significant depth *x* level of processing interaction $F(1,62) = 0.43$.

FIGURE 1



Mean recall (number of words correctly recalled) for each depth (shallow = 0-2 msw; deep = 37-39 msw) and LoP condition (SP = shallow processing; DP = deep processing) in Experiment 1

These results demonstrated a detrimental effect of narcosis at depth on free recall performance. More importantly, once age was considered, a significant effect of LoP was revealed where, regardless of depth of water, participants in the deep processing conditions recalled more words compared to those in the shallow processing conditions. This is supportive of earlier studies [10,14] showing that free recall performance is impaired by narcosis at depths of 36-40 msw. These results also support previous LoP studies which have found deeper processing leads to significantly greater recall compared to shallow processing [17,18]. That deeper processing led to significantly increased recall in deep water supported the hypothesis that narcosis disrupts the encoding stage of memory, as opposed to self-guided search.

EXPERIMENT 2: FREE RECALL IN THE POOL *vs.* THE OCEAN

Experiment 1 demonstrated that recall was impaired in the ocean at depths of 37-39 msw, compared to recall at 0-2 msw in a swimming pool. Although the warm-water ocean environments chosen for deep-water testing have exceptionally good conditions, a potential criticism is that it may not be valid to compare this data to that collected in a swimming pool. It could be argued that any difference in memory performance may simply be the result of differing environmental conditions, rather than the effects of narcosis, in which case Experiment 1's conclusion that narcosis affects encoding would be void. Prior studies [24,25] have noted that performance decrements from narcosis are sometimes larger in the ocean compared to those conducted in hyperbaric chambers and there is some evidence that performance may differ between "tank" and ocean dives [26]. It has been suggested [25,27] that these disparities are because the different environmental conditions in the ocean (colder water, lower visibility, currents, surge and wildlife), which are not present in a pool or chamber, may distract or stress participants.

The aim of Experiment 2 was to address this concern. Experiment 2 aimed to assess whether free recall differed when measured in the swimming pool compared to in shallow water in the ocean. In the event free recall is lower in the ocean it would have to be conceded that any memory drop in the deep ocean could simply be the result of the differences in the underwater environments. If no difference is found in recall performance between the pool and ocean, it could be concluded that comparing the pool and ocean are valid in this case.

METHOD

Design and measures

A within participants design was utilized comparing the effect of diving environment (pool *vs.* ocean) on the free recall performance using two 15-item wordlists (A & B). The words were matched for concreteness, imageability, and familiarity using the MRC Psycholinguistic database: Machine Usable Dictionary (v2.0). The order of the diving environment conditions was counterbalanced as were the order of the word lists.

Participants & procedure

Twenty-six participants (19 male) aged between 18 and 58 years (*M*=32.7; *SD*=10.4) volunteered to take part in the study. Participants were recruited from the staff and customers at Nautilus Watersports, Port Vila, Vanuatu. They had between 0.3 and 26 years of diving experience (*M*=7.3; *SD*=6.1), and had completed between 14 and 1,500 (*M*=275.3; *SD*=385.9) dives. All pool conditions were conducted in a swimming pool at Nautilus Watersports. The pool was no more than 2 msw deep with a temperature of 26ºC. Participants were fully submerged wearing dive gear and knelt in front of the researcher who presented each word on laminated cards for five seconds each. Once all words had been presented there was a two-minute delay before participants were handed a slate on which they wrote down as many words as they could remember. The protocol in the ocean was exactly the same and conducted at depths between 5 and 11 msw in Mele Bay in Port Vila, Vanuatu. Participants either knelt on the sea floor or hung from a bar suspended beneath a dive boat. The ocean temperature was 27-29ºC, with visibility between 10 and 30 meters.

RESULTS AND DISCUSSION

The mean number of words for each condition was calculated. No significant effects of diving environment order or word list order were found and are not discussed further. Recall was very similar in the ocean and in the pool, with participants recalling between three and 11 words in both environments. Mean recall in the pool was 6.04 words (*SD*=2.1) and 5.85 words (2.0) in the ocean. A paired t-test confirmed that there was no significant difference in recall between the pool and the ocean, $t(25) = 0.54$, $p = .59$. It was concluded that diving environment did not affect memory performance and that, at least as far as tropical conditions are concerned; it is valid to compare performance in a pool with performance in the ocean.

GENERAL DISCUSSION

It has previously been proposed that nitrogen narcosis causes a deficit in free recall performance either by impairing self-guided search or encoding when information is learned. Experiment 1 tested the hypothesis that narcosis reduces effective processing when material is encoded by employing a LoP approach to examine the effect of deeper encoding on the free recall performance in deep water (*i.e.*, under the effects of narcosis) compared to a shallow-water control. Participants recalled fewer correct words in deep water (37-39 msw) compared to shallow water (0-2 msw), indicating a detrimental effect of narcosis on free recall performance.

In addition, a significant effect of LoP was revealed with participants in the deep processing conditions recalling more correct words than those in the shallow processing conditions. This LoP effect was intact under the effects of narcosis, indicating that deeper processing lessened the narcotic deficit and supporting the hypothesis that narcosis causes memory impairment by disrupting the encoding of information.

It is proposed that this study provides the first piece of evidence for the suggestion made by previous studies [14,15] that nitrogen narcosis effects the encoding stage of memory. If narcosis impaired self-guided search, it would be predicted that deeper processing would not improve free recall performance over shallow processing, as the disruption occurs during retrieval when recall takes place: How information was encoded would thus be irrelevant. In the current study, while the recall of words significantly decreased in the deep depth conditions compared to the shallow depth conditions, the LoP effect was not significantly altered in deep water. This suggests that while recall is significantly poorer at a deep depth as a result of nitrogen narcosis, this deficit can be improved by utilizing deeper processing of the materials to be learned in the encoding stage. Therefore, as altering encoding can lead to changes in recall it is likely that narcosis acts to reduce encoding effectiveness.

One potential alternative explanation for these results was that the impairments in the deep water were simply the result of differing environmental conditions between depth conditions (pool *vs.* ocean). Experiment 2 eliminated this explanation by demonstrating that free recall performance was no different when compared in shallow water in the pool and in the ocean.

In Experiment 1, recall was generally poor across all conditions. The number of words recalled ranged from a mean of 0.44 (deep SP) to 2.35 words recalled (shallow

DP), with 34% of participants recalling no words, from a maximum of 30 words in total. Higher recall rates would have been preferable as a potential flooring effect was a concern, but the low recall rates were not considered critical to the conclusions. For example, if a difference in recall between the deep and shallow water had not been found and all scores were close to zero, the concern would have been that a flooring effect may have obscured any effect of depth. As it was, the test used in Experiment 1 remained sensitive enough to measure statistically significant effects of both depth and processing conditions, even though these effects were small in this case.

In our previous study [14] recall was higher using the same number of words and at a comparable depth. The lower recall in this study can be attributed to necessary methodological changes that made the recall task harder and the increased age of several participants. Further research might benefit from replicating Experiment 1 in an easier form (*e.g.*, shorter word lists) to allow more variation in responses to be measured. It is also acknowledged that the amount of time to process the information across LoP may be a confounding factor here. It could be argued that the level of processing is likely to be confounded with processing time, that the deeper tasks require more processing time, and that it is this extra processing time that is the cause of the effect.

The standard presentation used in LoP studies per word ranges from about two to five seconds per word [28]. However, research has shown that the LoP effect persists when the timing confound is removed [17].

That narcosis appears to primarily affect encoding has both positive and negative implications for those operating in pressurized environments. On the one hand, it is good news for divers, as it suggests the knowledge that is most impaired by narcosis is information presented at depth. Thus, prior knowledge, gained in training on the surface or in shallow water, and which is important for safety or an underwater task, may be more resistant to the effects of narcosis. This is supported by previous findings [14] that recall of information learned in shallow water is not impaired at depth.

The bad news is that important information related to safety or the task at hand that comes available to divers in deep water may not be encoded properly and may be lost when important later in the dive or back on the surface. To suggest some examples, divers entering a deep wreck may not recall important markers that lead to the exit, may not recall information they recently viewed on their dive computers and air gauges – all of which may contribute to a dive accident. Alternatively, for divers undertaking tasks or collecting data for military or scientific purposes, they may fail to recall important relevant information. For example, Morrison and Zander (2008) cite the example of mine countermeasures divers who are required to locate mines underwater and memorize fine details about the mine to report back to teams on the surface. The current study suggests that divers engaged in tasks such as these would benefit from employing memory strategies that encourage deeper processing to lessen narcotic memory impairment, or employ additional equipment when possible to negate memory impairment (*e.g.*, underwater cameras).

To conclude, this research supports the assertion that nitrogen narcosis affects the encoding stage of memory and that such deficits can be improved by utilizing a deep level of processing when learning information to be later remembered. As this is the first piece of research directly demonstrating this, it is suggested that further studies be conducted to ascertain the reliability of these findings.

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