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Inert gas narcosis disrupts encoding but not retrieval of long term memory

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HIGHLIGHTS

- Free-recall memory significantly impaired only when words were initially learned at high pressure.
- Free recall not impaired when words learnt at low pressure and then recalled at low or high pressure.
- Deeper processing failed to significantly improve free-recall ability across each condition.
- Pattern of results support hypothesis that narcosis disrupts encoding of information, not retrieval.

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ABSTRACT

Exposure to increased ambient pressure causes inert gas narcosis of which one symptom is long-term memory (LTM) impairment. Narcosis is posited to impair LTM by disrupting information encoding, retrieval (self-guided search), or both. The effect of narcosis on the encoding and retrieval of LTM was investigated by testing the effect of learning–recall pressure and levels of processing (LoP) on the free-recall of word lists in divers underwater. All participants (n = 60) took part in four conditions in which words were learnt and then recalled at either low pressure (1.4–1.9 atm/4–9 msw) or high pressure (4.4–5.0 atm/34–40 msw), as manipulated by changes in depth underwater: low–low (LL), low–high(LH), high–high (HH), and high–low (HL). In addition, participants were assigned to either a deep or shallow processing condition, using LoP methodology. Free-recall memory ability was significantly impaired only when words were initially learned at high pressure (HH & HL conditions). When words were learned at low pressure and then recalled at low pressure (LL condition) or high pressure (LH condition) free-recall was not impaired. Although numerically superior in several conditions, deeper processing failed to significantly improve free-recall ability in any of the learning–recall conditions. This pattern of results support the hypothesis that narcosis disrupts encoding of information into LTM, while retrieval appears to be unaffected. These findings are discussed in relation to similar effects reported by some memory impairing drugs and the practical implications for workers in pressurised environments.

1. Introduction

Human memory is composed of a hypothetical set of cognitive structures and processes proposed to have direct neural correlates in the brain [1]. Pharmacological interference with these neural correlates will directly impact memory performance selectively, according to which brain regions or systems are affected [2]. One such pharmacological phenomenon is inert gas narcosis which causes memory loss when individuals are exposed to increased ambient pressure [3]. At pressures greater than 4 atmospheres (atm)/30 metres of sea water (msw) inert gas molecules absorbed into the body via breathing mixtures interfere with neural transmission [4] to an extent that performance impairments on a number of tasks are measurable. Numerous studies have demonstrated that at pressures of 4–6 atm (30–50 msw) both the delayed free- and cued-recall of wordlists are impaired compared to surface or low pressure controls [5–14]. It was initially suggested that this indicated narcosis prevents the input of information into long-term memory (LTM) [10]. However, when delayed recognition tests are employed, also a measure of LTM, this impairment does not occur [7,10,15]. This contradictory effect of narcosis on different measures of LTM suggest a more nuanced effect of narcosis on memory which is potentially explained in one of three ways: 1) narcosis disrupts retrieval of LTM; 2) narcosis disrupts encoding into LTM; and 3) narcosis affects both retrieval and encoding of LTM.

In the first (retrieval) explanation, information is stored in LTM but impairment of self-guided search by narcosis means the information is harder to retrieve. The discrepancy between the free-recall and recognition measures is explained as resulting from the cues provided during the recognition test reducing the need for self-guided search [10].

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However, data from two studies [8,10] places doubt on the self-guided search theory. These studies reported an impairment of free-recall only when information was learned at high ambient pressure (i.e. under narcosis) and either recalled at high or low pressure (no narcosis). When information was learned at low pressure and recalled under narcosis no impairment was found and retrieval appeared to be unaffected [10]. This suggested that narcosis interfered with the input of new information into LTM when it was initially encoded, rather than in retrieval. Thus, according to the second, encoding explanation material can still be learned but the quality of the encoding process is reduced, leading to a weaker memory trace. In a recognition test the cues provided make retrieval less demanding than self-guided search [16] and hence a weaker memory trace is sufficient for successful recognition. The encoding explanation has also been investigated using the levels of processing (LoP) approach [17] which claims the durability of memory is dependent on the depth of processing the stimulus undergoes when it is initially encoded. In two studies, Kneller and Hobbs [11,12] compared the LoP effect underwater at narcotic pressures with a shallow water control but the results were inconclusive. In one study [11] deeper processing improved recall under narcosis lending support for the encoding hypothesis but in the second study [12] recall was not improved by deeper processing under narcosis indicating support that narcosis affects self-guided search.

The third explanation is based on the slowed processing model of narcosis [18,19]. In this model task performance is impaired because narcosis acts as a depressant on the central nervous system, reducing efficiency, rather than acting in a more targeted way by disrupting particular cognitive structures. The depressant effects of narcosis slow down the cognitive system as a whole, predicting that both self-guided search and encoding will both be affected by narcosis. At present there is little data to support this contention, except that by Fowler et al [20,21] who reported that during a memory task the rate of rehearsal during the encoding process and response time was slowed by narcosis.

The existing studies of narcosis and memory provide an inconclusive set of data with some support found for all three of the above explanations. These studies might be reconciled by combining the learning–recall and LoP methodologies into one experiment, providing data comparing the LoP effect while concurrently manipulating the presence or absence of narcosis at either encoding or during self-guided search. This can disentangle the effects of narcosis on both self-guided search and encoding. The current study did this by testing free-recall memory ability when words were learned and recalled at either high (H) or low (L) ambient pressure. Participants learned and recalled words in four combinations: low pressure to low pressure (LL); low pressure to high pressure (LH); high pressure to high pressure (HH); and high pressure to low pressure (HL). In addition, half the participants encoded the words using shallow processing and half using deep processing. The explanations outlined above predict three potential outcomes: 1) Encoding affected: impairment from narcosis will only be present when words are learned at high pressure (HH & HL conditions), not when learned at low pressure (LL & LH). Deep processing will improve recall over shallow processing in all conditions, but some impairment from narcosis will remain. 2) Retrieval affected: impairment from narcosis will only be present when words are recalled at high pressure (LH & HH), not when recalled at low pressure (HL & LL). Deeper processing will improve recall only when recall takes place at low pressure (HL & LL) and not at high pressure (LH & HH). 3) Encoding and retrieval affected: recall will be the lowest when both learning and recall takes place at high pressure (HH) under narcosis. Recall will be the highest when learning and recalled takes place at low pressure in the absence of narcosis (LL), with the LH and HL conditions falling somewhere in between. Improved recall from deeper processing will be extinguished, or severely diminished, in the HH condition and reduced in the LH and HL conditions. At present prior evidence seems to favour the first prediction. Thus, in the current study it was hypothesised that free-recall performance would be affected by narcosis in a pattern that reflected an impairment during the encoding of memory.

2. Method

2.1. Design

The study employed a 4×2 mixed design comparing the effects of a within participants variable of learning and recall pressure [low–low (LL) vs. low–high (LH) vs. high–low (HL) vs. high–high (HH)] and a between participants variable of LoP (shallow vs. deep) on free recall performance. Narcosis was manipulated by testing in shallow water where narcosis is not considered to be present in the low pressure conditions (1.4 atm to 1.9 atm/4–9 msw) and in deep water at depths considered narcotic in the high pressure conditions (4.4 atm–5.0 atm/34–40 msw). The degree of narcosis in the high pressure conditions was maintained by only testing at ocean depths in the narrow range between 34 and 40 msw. At low pressure participants were tested at 1.4 atm to 1.9 atm (4–9 msw) and at high pressure at 4.4 atm–5.0 atm (34–40 msw). The order of the pressure conditions was counterbalanced across four combinations so that order effects could be tested for: 1) HH–LL–LH–HL; 2) HL–LL–LH–HH; 3) LL–HH–LH–HL; and 4) LL–LH–HH–HL.

2.2. Participants

The protocol was approved by the ethics committee of the University of Winchester. Sixty divers volunteered for the study, with 30 assigned to each processing condition. All participants were customers and staff of the recreational dive operation West Bay Divers on Roatan Island, Honduras. West Bay Divers screened participants to ensure they were medically fit and suitably qualified to dive to the depths required for the study. Participants who were not qualified to PADI Deep Diver Specialty (or equivalent) or unwilling to do this course before taking part in the study were not admitted. Participants over the age of 52 years were not admitted to the study because of the detrimental effects of older age on memory ability [22]. In order to allow sufficient numbers of divers to be recruited, volunteers with a range of experience levels were recruited. The experience level of the divers ranged from PADI Deep Diver (or equivalent) certification up to Instructor level certifications. Participants self-reported to the researchers how many dives they had completed and how many years it was since they had started diving as a measure of general diving experience.

2.3. Measures and materials

Five word lists of 10 target words each were formulated for the free recall task. The target words were chosen using the MRC Linguistic Database v2.0. Target words were between four and six letters long, with a maximum number of 2 syllables (e.g. mash; rebel; empire). All target words were matched for familiarity, concreteness, and imageability. All wordlists consisted of different target words. One wordlist was only used when participants were tested on the surface during the practice session. The other four lists (labelled A to D) were used underwater and counterbalanced across the conditions to control for order effects. Each target word was printed on paper and laminated into a card (font size 19, Times New Roman). Above each target word was printed a sentence which varied according to the processing condition. In the shallow processing condition the sentence was either: "Is the word in lower case letters?" or "Is the word in upper case letters?". The target word below was printed in either lower case or uppercase letters. The participant was required to answer the question with a yes/no response. There were an equal number of lower and upper case questions, and an equal number of target words in upper and lower with an equal number of yes/no correct responses, in each list. In the deep processing condition varying sentences were printed with a word missing (e.g. "The