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Recall and recognition in mild hypoxia: using covariance structural modeling to test competing theories of explicit memory

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Abstract

To test theories of explicit memory in amnesia, we examined the effect of hypoxia on memory performance in a group of 56 survivors of sudden cardiac arrest. Structural equation modeling revealed that a single-factor explanation of recall and recognition was insufficient to account for performance, thus contradicting single-process models of explicit memory. A dual-process model of recall in which two processes (e.g., declarative memory and controlled search) contribute to recall performance, whereas only one process (e.g., declarative memory) underlies recognition performance, also failed to explain the results adequately. In contrast, a dual-process model of recognition provided an acceptable account of the data. In this model, two processes—recollection and familiarity—underlie recognition memory, whereas only the recollection process contributes to free recall. The best-fitting model was one in which hypoxia and aging led to deficits in recollection, but left familiarity unaffected. Moreover, a controlled search process was correlated with recollection, but was not associated with familiarity or the severity of hypoxia. The results support models of explicit memory in which recollection depends on the hippocampus and frontal lobes, whereas familiarity-based recognition relies on other brain regions.

Keywords: Memory; Amnesia; Modeling; Recollection; Familiarity

1. Introduction

Examinations of memory-impaired patients have played a critical role in shaping theories of explicit memory. Extensive empirical and theoretical work has been done to characterize the relationship between recall and recognition. Early theories assumed that a single underlying form of memory was responsible for both recall and recognition. More recently, neuropsychological dissociations between recall and recognition resulting from different types of brain injury have contributed to the rise of two competing classes of theory proposing at least two processes underlie recall and recognition. One class assumes that *declarative memory*, a general form of memory, contributes to recall and recognition whereas additional processes related to executive control contribute to recall but not recognition. The other class assumes that two memory processes, *recollection* and *familiarity*, contribute to recognition, whereas only recollection contributes to recall. A large body of empirical evidence has contradicted single-process models, but differentiating between the latter two classes of models has proven difficult. In the current study, structural equation modeling was used to directly test the ability of these competing theories to explain observed relationships among recall performance, recognition performance and amnesic severity. The models of interest are first described in more detail, and previous attempts to contrast the models are briefly reviewed. Then, structural modeling methods are described and applied to a study that examined the amnesic effects of mild hypoxia on recall and recognition memory.

1.1. Single-process theories of explicit memory

Single-process theories assume that performance on tests of explicit memory, such as recall and recognition, rely on a single memory process or system (e.g., memory *strength*). Early single-process theorists noted that individuals performed consistently better on recognition than on recall and proposed that greater memory strength was

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required for recall than for recognition (e.g. Postman, 1963). Single-process strength theories remain attractive because of their simplicity. However, a large body of empirical literature now exists that is problematic for those theories. For example, simple strength-based accounts of recall and recognition do not explain behavioral dissociations between recall and recognition observed with manipulations such as word-frequency and list length (for a review of problems associated with simple single-process theories, see Gillund & Shiffrin, 1984). Moreover, neuropsychological studies have indicated that brain damage to frontal regions including prefrontal cortex can severely disrupt recall performance while leaving recognition relatively intact. Such results indicate that frontal lobe regions play a critical role in recall but are less important for recognition. These latter studies are described in more detail below.

1.2. Dual-process theories of recall

A number of multi-stage and multi-process models were designed in part to overcome the difficulties associated with the single-process models. One general class of theories assumes that a common form of memory underlies both recall and recognition, but that one or more additional processes or systems contribute to recall. These theories assume that additional controlled memory search and response monitoring processes contribute to recall. A classic example of this view is the generate-recognize model of recall (Kintsch, 1970). In this model, recall tests first require a generation process to produce items that may have been studied. The initial generation process is followed by a recognition decision process that is used to separate studied from non-studied items. In contrast, recognition tests require only the recognition process because the test items are provided to the subject and a generation process is therefore unnecessary. More recent models, however, do not limit the recall-specific process to generation of potential response items, but include a number of strategic control functions such as organizing a memory search (Squire & Zola, 1998), monitoring of retrieval contents (Moscovitch, 1994) and inhibition of irrelevant or inappropriate responses (Shimamura, 1995). For example, Squire and colleagues have advocated a dual-process view of recall in which *declarative memory*, a unified system involving the hippocampus and the surrounding medial temporal lobe, is required for both recall and recognition, whereas a frontal lobe system supports controlled memory search processes involved in free recall, but not recognition (e.g. Haist & Squire, 1992; Squire & Knowlton, 1995; Squire & Zola, 1998). Moscovitch has proposed a component-process model (Moscovitch, 1990, 1994) that is similar in some ways to that of Squire and colleagues. In this model, both recognition and recall rely on information computed by 'associative memory,' a modular, reflexive retrieval process localized in the hippocampus and surrounding neocortical structures. Additionally, depending on the processing requirements by the specific task, either recognition or recall may reflect the contribution of control processes in the prefrontal cortex involved in directing and monitoring the products of associative memory.

Dual-process recall models have received support from studies showing the importance of the frontal lobes for tests of recall and tests of executive control. For example, lesions to prefrontal cortex can lead to disproportionately large deficits in recall compared to recognition (Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Jetter, Poser, Freeman, & Markowitsch, 1986), suggesting that the frontal lobes contribute to recall to a greater extent than to recognition. Moreover, the recall deficits in patients with frontal lobe damage are often accompanied by impairments in measures of executive function that are thought to tap similar controlled search and monitoring processes, such as verbal fluency (Baldo, Shimamura, Delis, Kramer, & Kaplan, 2001; Bentler & Bonnett, 1980; Janowsky, Shimamura, & Squire, 1989a) and Wisconsin Card Sorting (Milner, Petrides, & Smith, 1985; Parkin, Walter, & Hunkin, 1995). Similarly, healthy aging also leads to reductions in recall and performance on some tests of executive function, but leaves recognition relatively unaffected (Parkin & Lawrence, 1994). Histological and neuroimaging examinations have shown that normal aging is associated with cell loss and reduced blood flow in the frontal lobes (Woodruff-Pak, 1997), providing further evidence for the role of the frontal lobes in supporting the control processes involved in recall but not recognition.

1.3. Dual-process theories of recognition

A separate class of dual-process theories assumes that two memory processes contribute to recognition judgments and that one of these also supports recall performance. That is, recognition can be based on the assessment of stimulus *familiarity* or on a *recollection* process whereby qualitative information about the study event is retrieved, such as when or where the event occurred (e.g. Atkinson & Juola, 1974; Jacoby, 1991; Mandler, 1980; Tulving, 1985). Performance on tests of free recall is expected to rely on recollection because the retrieval cues are not complete enough for a familiarity assessment. Evidence for the contribution of two processes to recognition comes from behavioral studies employing numerous behavioral measurement techniques, studies of patient populations, as well as event related potential and neuroimaging studies (for a review see Yonelinas, 2002).

In general, recollection is thought to be more severely disrupted in medial temporal lobe amnesia than is familiarity (Aggleton & Shaw, 1996; Yonelinas, Kroll, Dobbins, Lazzara, & Knight, 1998; Yonelinas et al., 2002). Moreover, several models further propose that different medial temporal lobe regions are involved in recollection and familiarity (Aggleton & Brown, 1999; Eichenbaum, Otto, & Cohen, 1994). According to these models, the hippocampus supports recollection, whereas the temporal lobe regions surrounding the hippocampus, such as the parahippocampal