



Effects of divided attention on episodic memory in chronic traumatic brain injury: a function of severity and strategy

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Abstract

Eleven patients with mild traumatic brain injury (MTBI) and 13 patients with moderate-to-severe TBI (STBI) were compared to 10 matched controls on episodic memory for pictorial scene–object associations (e.g. kitchen–bread) and a range of standardized neuropsychological tests of memory and frontal-lobe functions. We tested the hypothesis that deficits in episodic memory result from impaired attentional resources and/or strategic control by manipulating attentional load at encoding (focused versus divided attention) and environmental support at retrieval (free recall and recalled cued by scene versus recognition of object and scene). Patients with TBI were disproportionately affected by the divided attention manipulation, but this effect was modulated by injury severity and encoding strategy. Overall, MTBI patients were impaired only when items were encoded under divided attention, indicating memory deficits that were secondary to deficits in the executive control. STBI patients could be differentiated into two distinct functional subgroups based on whether they favored a strategy of attending to the encoding or digit-monitoring task. The subgroup favoring the digit-monitoring task demonstrated deficits in the focused attention condition, and disproportionate memory deficits in the divided attention condition. In contrast, the subgroup favoring the encoding task demonstrated intact performance across all memory measures, regardless of attentional load, and despite remarkable similarity to the other STBI subgroup on demographic, neuropsychological, and acute injury severity measures. We discuss these outcome differences in terms of the relationship between strategy and executive control and highlight the need for more sensitive anatomical and behavioral measurement at both acute and chronic stages of injury.

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1. Introduction

Patients with traumatic brain injury (TBI) commonly report residual deficits in memory and attention that interfere with their everyday lives, often preventing them from returning to work or school at their pre-injury level [16,39,40,43,63]. Indeed, a recent report found that both patients and their close relatives find poor memory to be the most troubling problem associated with the long-term (>6 years) outcome of TBI [45]. Yet, it is not uncommon for these subjective reports to contrast with intact performance on objective clinical measures of cognitive functions, partic-

ularly when acute injury is mild or moderate and/or medial temporal lobe structures are intact [6,41,59]. The goal of the present study is to test one hypothesis that has emerged to account for this apparent paradox: that memory deficits are largely due to deficits in attention and/or executive control, and thus, may only be apparent when task demands on attention and its strategic allocation are sufficiently high [34,49,60].

Dual-task conditions provide an experimental environment in which to test both attentional capacity and the ability to exert control over the allocation of attentional resources. Numerous behavioral and neuroimaging studies have demonstrated that divided attention limits the likelihood that information will be processed to a deep, semantic level in temporal and inferior prefrontal cortices,

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and interferes with strategic organization of the material, a process putatively subserved by dorsolateral prefrontal regions [3,12,19,32]. Thus, we would expect that divided attention would interfere with episodic memory formation not only in TBI patients, but also in control subjects. However, encoding under divided attention is not only a function of the quantity of available resources, but also the ability to allocate these resources in an efficient, goal-directed manner [4,50,51]. The finding that dual-task performance can faithfully reflect instructed trade-offs (i.e. primary-task emphasis, secondary-task emphasis, or equal emphasis) demonstrates that attention is a resource whose distribution is under control of a supervisory or executive control process [2,8]. Thus, performance on the primary (memory) task can only be properly evaluated when performance on the secondary task, and any potential strategic trade-offs that may occur between tasks, are taken into account.

If executive control processes were impaired by TBI, we would expect the degree of impairment when information is encoded under divided attention to be disproportionate to that of control subjects, and to be unaccounted for by performance on either task alone [5]. Deficits in executive control have been associated with damage to the prefrontal cortex, but may also occur as the result of damaged connections between the prefrontal cortex and posterior regions [11,38]. Fronto-temporal damage and diffuse axonal shearing, particularly of longitudinal connections, are common sequelae of the typical deceleration/acceleration injury associated with TBI [25]. In particular, orbitofrontal and anterior temporal regions are vulnerable to TBI because of the jagged internal geometry of the skull around the orbits and cranial nerve processes, although lesions occasionally occur more superiorly [34]. Thus, the hypothesis that executive control deficits form a core feature of TBI appears to fit with the neurophysiological profile of the typical TBI patient.

It is therefore surprising that many behavioral studies have failed to provide unambiguous support for a specific deficit in executive control (for review see [49]). For example, when required to simultaneously perform a dot-counting task while engaged in a driving simulator, no disproportionate deficits were found in subacute patients (<30 days post-injury) when slowing on the single-tasks was taken into account [40,64]. Vilkkki et al. [65] also failed to find dual-task deficits in either subacute patients or patients with focal frontal lesions. Deficits were found, however, in acute patients, suggesting that time-since-injury influenced performance. Age at the time of injury may also be a factor. Stablum et al. [54] did not find dual-task deficits in MTBI patients under 30 years old, but did find deficits in older patients. Finally, the nature of the secondary task and the degree to which it taxes both attentional resources and executive control is likely to influence performance. Hartman et al. [18] found that conversation with the experimenter caused disproportionate impairment in STBI patients on a visual-motor tracking task, but a digit-span task did not. In contrast, McDowell et al. [36] found that concurrent perfor-

mance of a digit-span task was sufficient to disrupt simple reaction time in patients with either subacute or acute severe TBI.

Data on the specific effects of dual-tasks on long-term memory in TBI patients is sparser and even less supportive of a clear deficit in attention and/or executive function. To our knowledge, the only studies that have investigated the effects of divided attention on episodic memory performance in chronic patients have used severe TBI patients. In these studies, patients were equally impaired in both focused and divided attention conditions, rather than disproportionately impaired in the divided attention condition, as would be predicted by a specific deficit in executive control [48,66]. The effects of divided attention on the memory performance of patients with mild and moderate-to-severe TBI also have not been compared directly. Whereas patients with severe TBI may sustain chronic deficits in their ability to encode new information into episodic memory regardless of attentional load, mild TBI may result in a memory deficit that is only revealed under the greater attentional demands of dual-task processing. In addition, these previous studies only assessed performance on retrieval tasks that provided some type of environmental support (i.e. cued recall, recognition). Thus, far, the effects of divided attention in TBI have not been evaluated on retrieval tasks that are specifically associated with effortful processing and frontal-lobe function, such as tests of free recall and source memory [67]. Even in normal adults, divided attention at encoding affects source memory to a greater extent than item memory [62].

In the present study we investigate the extent to which attention and/or executive control resulting from TBI influence episodic memory performance. Specifically, we hypothesize that in the case of mild TBI, deficits in the executive control of attention interfere with the ability of intact memory processes to function optimally, whereas in moderate-to-severe TBI, deficits in executive control only further exacerbate primary memory deficits. Indeed, for patients with more severe TBI, a basic impairment in episodic encoding, rather than executive control of attentional resources, may constitute the core deficit.

To address these hypotheses, we measured episodic memory in a paradigm where we carefully controlled and/or manipulated the patient, stimulus, and test factors over which attention and executive control processes would likely vary. Specifically, patients with mild or moderate-to-severe TBI were compared to age, education, and SES matched controls on memory for item (object) and context (scene) associations under conditions of focused or divided attention at encoding. We explored the extent to which factors in the acute stage of TBI predicted cognitive outcome by subdividing patients for analysis in two ways. First, patients were divided a priori according to differences in injury severity (i.e. Glasgow Coma Score (GCS), loss of consciousness (LOC), and post-traumatic amnesia (PTA)) and evaluated in terms of behavioral differences. Then patients were subdivided a posteriori according to differences in behavioral performance in

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