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Asymmetric frontal activation during episodic memory: the effects of stimulus type on encoding and retrieval

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Abstract

Recent functional neuroimaging studies have suggested that the left prefrontal cortex is preferentially involved in the encoding of episodic memory whilst the right prefrontal cortex is preferentially involved in the retrieval of episodic memory, irrespective of the type (e.g. modality) of information being remembered. In the present PET activation study, a 2×2 design was employed to investigate the relationship between encoding and retrieval of verbal and non-verbal material in episodic memory. Accordingly, seven healthy volunteers were scanned whilst encoding and then recalling stimuli which either emphasised visual or verbal processes. When encoding and retrieval tasks were compared directly, significantly greater prefrontal activation was observed in the encoding conditions, regardless of modality, although these changes were bilaterally distributed. In contrast when the verbal and visual memory tasks were compared directly, the former was associated with rCBF changes that were predominantly located in the left lateral frontal cortex whilst the latter was associated with rCBF changes that were predominantly located in the right lateral frontal cortex. These results suggest that encoding and retrieval may actually involve similar regions of the lateral prefrontal cortex when all factors relating to the type of stimulus material (i.e. modality), are appropriately controlled.

Keywords: PET; Episodic memory; Frontal lobes; Hemispheric asymmetry

1. Introduction

A common distinction made in the cognitive neuropsychology of memory [56,57] is that between semantic memory, which refers to people's general knowledge of the world [22] and episodic memory, which refers to the conscious recollection of personal experiences [57]. Although autobiographical memories (personally experienced episodes from one's past life) are most clearly synonymous with Tulving's original conception of episodic memory, most studies have used recall and recognition of recently studied material or 'new learning' as a vehicle for investigating episodic memory.

Over the past ten years, there has been a steady accumulation of experimental data to suggest that in humans there is an asymmetrical involvement of the left and right prefrontal cortices in the encoding and retrieval of episodic memory, respectively. For example, Kapur et al. [17] used positron emission tomography (PET) to examine 'deep' and 'shallow' episodic memory encoding by presenting healthy subjects with single nouns and instructing them to either decide whether they contained the letter 'a' (e.g. shallow processing) or decide whether the noun was 'living' (e.g. deep, semantic processing). On subtracting the blood flow associated with the shallow episodic memory encoding condition from that associated with the deep episodic memory encoding condition it was found that there was a significant activation of the left inferior prefrontal cortex. Since there was no significant differ-

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ence in activity in the right prefrontal cortex between the two encoding conditions, the data was taken to suggest that the left prefrontal cortex may be specialised for the encoding of episodic memory.

In a second PET study, Tulving et al. [58] examined episodic memory retrieval by instructing healthy subjects to learn auditory sentences in a pre-scan session and presenting them with new and old sentences mixed in varying proportions during subsequent PET scans. The subjects were required to keep track of new sentences, although, during the critical period of data acquisition in each scan, the sentences were either all new or all old. Subtraction of the activation associated with the *detection* of the new sentences from the activation associated with the *recognition* of old sentences showed significant right dorsolateral prefrontal cortex activation. On this basis, it was suggested that the right prefrontal cortex is more active than the left during episodic memory retrieval, or in this case, recognition.

A separate investigation by Shallice et al. [50] into episodic memory encoding and retrieval converged upon the same findings as Kapur et al. [17] and Tulving et al. [58]. For the encoding of episodic memory, subjects were PET scanned whilst being presented with rare word categories each paired with an exemplar from that category. For the retrieval of episodic memory, subjects were prompted with a category at a regular rate during scanning and had to recall the associated exemplar. It was found that, in comparison to a passive listening control condition, the episodic encoding condition activated the left anterior cingulate cortex extending to the left medial frontal gyrus (BA 9/10). In contrast, in comparison to a verbal repetition control task, the episodic memory retrieval task activated the right middle prefrontal cortex (BA 46/10) and the left anterior cingulate cortex (BA 32).

Since these initial investigations, many neuroimaging studies have provided evidence to support the asymmetrical involvement of the left and right prefrontal cortices in the encoding and retrieval of episodic memory, respectively. The majority of these studies have investigated episodic memory directly [e.g. 1,2,4,6,9–15,17,18,19,29,31–32,34,40,44–45,50,53,58], whilst others have investigated specific cognitive functions such as speech and language, which provide indirect information about the neural basis of episodic memory [e.g. 8,38,43]. In addition, most of these studies have used verbal material as stimuli [e.g. 2,4,6,7–12,17,19,31,32,38,40,43,45,50,53,58], although, non-verbal stimuli such as spatial patterns and faces have occasionally been used [e.g. 1,13–15,18,29,34,44]. A recent review of the literature has led Nyberg et al. [33] to conclude that there is convincing evidence to support an asymmetrical involvement of the left and right prefrontal cortices in the encoding and retrieval of episodic memory, irrespective of whether verbal or non-verbal material is employed.

In spite of this evidence, there are a number of reasons to suggest that the hemispheric asymmetry model needs to be assessed further. First, a number of PET studies have provided data that are inconsistent with the predictions of the asymmetry model. For example, several studies have found that both the right and left prefrontal cortices are involved in both the encoding and retrieval of episodic memory [e.g. 2,5,18,40,49,59–60], while others have observed a complete absence of left or right prefrontal cortex activation during episodic memory retrieval [e.g. 16,21,48]. Second, according to the asymmetry model, patients with left sided prefrontal lesions should be disproportionately impaired at episodic memory encoding while patients with right sided prefrontal lesions should be disproportionately impaired at episodic memory retrieval. Although encoding has always proved difficult to assess in patients (since retrieval is invariably required to test the efficacy of encoding), there have been a number of neuropsychological studies to suggest that this is not the case. [e.g. 25,51,52,54]. Finally, the majority of studies supporting the asymmetry model have not systematically controlled for the possible disproportionate involvement of verbal processes in encoding or retrieval tasks, an important consideration given the known dominance of left hemisphere regions in language processes [26,27]. Recently, it has been suggested that subjects may preferentially use verbal strategies during the encoding of episodic information (whether that information is ostensibly verbal or not) and that these strategies may be less critical for efficient retrieval [34]. For example, memorisation of visual information is frequently accompanied by a sub-vocal verbal repetition of the material to be remembered. In contrast, if subjects are required to choose between two stimuli, one of which they have seen previously, verbalisation is not necessarily required for visual recognition to occur. Similarly, in studies where verbal material is employed, encoding often requires the subjects to repeat and/or learn a series of words, thereby emphasising sub-vocal or vocal articulation and rehearsal. In contrast, retrieval of those same words, particularly when tested through free recall, may be mediated by a combination of verbal, semantic or visual retrieval strategies.

To date, only two studies to our knowledge have investigated the significance of verbal strategies during memory encoding and retrieval. Using PET, Klingberg and Roland [21] found that stimuli which were difficult to encode using verbal processes (e.g. uncommon sounds) activated the right middle prefrontal cortex during memory encoding, whilst no prefrontal cortex activation was observed during memory retrieval. Similarly, Kelley et al. [20] used functional magnetic reson-