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A combined neuropsychological and neuroimaging study of topographical and non-verbal memory in semantic dementia

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Abstract

A combined neuropsychological and neuroimaging investigation was carried out on a patient (O.I.) with semantic dementia who had asymmetrical temporal lobe atrophy, greater on the left. His performance on tests of verbal memory was gravely impaired. Similarly, his visual memory as indexed by recognition of unfamiliar faces was impaired. By contrast, his recognition memory for topographical memoranda (e.g. buildings, landscapes) and ability to find his way around was preserved. In order to identify the neural substrates supporting the preserved recognition of static topographical memoranda, O.I. was scanned using positron emission tomography (PET) during the encoding and recognition of building and landscape stimuli. In common with control subjects, during encoding O.I. activated parahippocampal cortex bilaterally, along with bilateral temporo-parietal, retrosplenial and left frontal cortices. During recognition, both patient and controls activated right parahippocampal, right superior parietal and right frontal cortices. Notably, control subjects, but not O.I., also activated at encoding the precuneus and at recognition the retrosplenial cortex. This allows the conclusion that these two areas while involved may not be necessary for topographical memory. Interestingly, the patient also activated regions that were not evident in control subjects both during encoding and recognition. These additional areas of activation may be necessary in a compensatory role. Overall, these data represent the first reported assessment of the functional integrity of degenerating brain tissue and its contribution to preserved topographical memory. The combination of the neuropsychological and neuroimaging approaches may provide insights into the functional-anatomy of memory while having clinical utility for the assessment of residual brain tissue.

Keywords: Semantic dementia; Topographical memory; Functional neuroimaging; Visual memory

1. Introduction

Studies of patients with acquired neurological lesions have informed us about the degree to which neurocognitive systems fractionate in the adult brain. For example, with reference to visual memory, patients have been reported to show selective difficulties in recognising unfamiliar buildings and landmarks (e.g. [5,46,47,59]; for a review see [1]). Despite this severe impairment, some of these patients have preserved memory for unknown faces (e.g. [26]). For example, Carlesimo et al. [10] described a patient presenting with a severe memory impairment for topographical scenes despite being able to learn unfamiliar faces with the same accuracy as control subjects.

The opposite pattern of dissociation has also been documented. Maguire and Cipolotti [33] described a patient with the clinical diagnosis of fronto-temporal dementia [42]. In particular, this patient showed features of one of the three main syndromic variants of this type of dementia, namely semantic dementia. Her MRI scan showed asymmetrical temporal lobe atrophy with greater left-sided damage. Cognitively she presented with a progressive and severe nominal dysphasia, and gravely impaired verbal and non-verbal memory [12]. However, her topographical recognition memory for unknown buildings, landscapes and outdoor scenes was selectively preserved. Her ability to recall familiar routes and learn new ones through a complex virtual reality town was also entirely normal. These findings suggest that the adult visual memory system is fractionable into at least two functionally independent cognitive subsystems, topographical memory on one hand and other aspects of non-verbal memory on the other. These functional independent subsystems seem to be selectively susceptible to brain damage.

Two recent studies have suggested that these neurocognitive subsystems can also fractionate developmentally. Cipolotti et al. [13] studied a patient (P.E.) with multiple

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developmental disorders including Gilles de la Tourette syndrome and autism. This individual showed significantly impaired recognition memory for unfamiliar faces in the context of appropriately developed recognition memory for unknown buildings, landscapes and outdoor scenes. Interestingly, P.E. also showed recognition memory impairment for animals. These findings have been replicated and extended in a group study of individuals with autism [7]. A significant impairment in the recognition memory for potential agents whether they were living (human faces, cat faces and horses) or non-living (motorbikes) was described. In contrast, normal recognition memory for objects such as topographical stimuli (buildings) and leaves, items that do not have agency was reported. It was speculated that these findings may indicate the possible existence of dissociable systems for particular forms of visual recognition memory, perhaps movement versus non-movement based.

As well as providing insights into the cognitive architecture of visual memory, neuropsychological studies have provided functional–anatomical evidence that right medial temporal lobe lesions in particular are often associated with visual memory deficits (e.g. [38,48]). Given the lack of selectivity of the lesions involved, however, neuropsychological studies have been less successful in identifying specific neuronal structures supporting different types of visual memory. Functional neuroimaging studies of healthy subjects have provided additional information regarding the functional neuroanatomy of visual recognition memory systems. The recognition of previously unfamiliar human faces has been linked with activation of the fusiform gyri (e.g. [6,24,27–29]). Memory for complex visual scenes (e.g. [54,41]) and memory for famous buildings (e.g. [34]) have been linked with activations in the parahippocampal gyrus, typically on the right.

In a recent neuroimaging experiment, Maguire et al. [35] systematically examined the pattern of brain activation associated with explicit encoding and recognition of four different types of unfamiliar visual stimuli. Two of the stimulus types were face stimuli (human and animal faces) and two of the stimulus types were static topographical stimuli (buildings and landscapes). In terms of the temporal lobes, encoding of both human and animal faces activated the fusiform gyrus bilaterally, while recognition was associated with activation in the fusiform gyrus on the right. In contrast, encoding of both buildings and landscapes activated the parahippocampal cortex bilaterally, while the right parahippocampal cortex was active during recognition. In addition, left frontal cortex was associated with encoding of stimuli in general, while right frontal cortex and right inferior parietal areas were active during recognition for all stimulus types. Overall, these data indicated that both human and animal faces share an underlying neuronal network based on lateral temporal structures. Similarly, topographical memoranda such as buildings and landscapes also share an underlying neuronal network but involving medial temporal structures.

While neuroimaging reveals brain regions normally active in the performance of a task, in healthy subjects it offers no insight into whether these brain regions are necessary or indeed sufficient for successful performance. However, the functional neuroimaging of patients may allow the identification of brain systems that are necessary and sufficient for task performance (for full discussion see [36,49]). In other words, combining the two approaches by performing a neuroimaging experiment with a neuropsychological patient who has a selective preservation for one type of memory may permit the identification of the brain area(s) necessary and/or sufficient for that particular type of memory.

In this paper, we report a patient (O.I.) with semantic dementia who, as with the previously reported patient [12,33], showed a preservation of topographical memory. O.I. had normal performance on recognition memory tasks employing topographical memoranda (buildings, landscapes and outdoor scenes). In contrast, he presented with a severe verbal and visual memory impairment, the latter including a recognition memory deficit for unfamiliar faces. Additionally, the patient was able to undergo a positron emission tomography (PET) scan following the protocol employed by Maguire et al. [35]. In particular, during scanning the patient was tested using landscape and building memoranda similar to those for which he had shown an intact recognition memory performance. The aims of the PET study were three-fold:

(1) to reveal if any structurally compromised tissue in the patient remained functionally active;
(2) to identify the brain regions sufficient to support the preserved memory for static topographical memoranda;
(3) to identify regions, that while active in control subjects, were not necessary for successful performance.

2. Case report

The patient was a 72-year-old left-handed retired bank manager who was first referred to Prof. Rossor in 1997 for evaluation of progressive memory and word finding difficulties. Neurological examination was normal except for the cognitive deficits described below. A brain MRI contemporaneous with his second neuropsychological assessment and the experimental investigation showed asymmetrical temporal lobe atrophy with greater left-sided damage. The left temporal lobe atrophy was more marked anteriorally (for details see Fig. 1).

His general neuropsychological profile is first described, followed by a specific description of his memory performance.

3. Neuropsychological assessment

The patient was first referred to the Neuropsychology Department of the National Hospital for Neurology and