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Research Report

fMRI evidence of word frequency and strength effects in recognition memory

Greig I. de Zubicaray[a,*], Katie L. McMahon[a], Matthew M. Eastburn[a], Simon Finnigan[a], Michael S. Humphreys[b]

[a]Centre for Magnetic Resonance, The University of Queensland, QLD, 4072, Australia
[b]Centre for Human Factors and Applied Cognitive Psychology, The University of Queensland, QLD, Australia

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Abstract

We used event-related fMRI to investigate the neural correlates of encoding strength and word frequency effects in recognition memory. At test, participants made Old/New decisions to intermixed low (LF) and high frequency (HF) words that had been presented once or twice at study and to new, unstudied words. The Old/New effect for all hits vs. correctly rejected unstudied words was associated with differential activity in multiple cortical regions, including the anterior medial temporal lobe (MTL), hippocampus, left lateral parietal cortex and anterior left inferior prefrontal cortex (LIPC). Items repeated at study had superior hit rates (HR) compared to items presented once and were associated with reduced activity in the right anterior MTL. By contrast, other regions that had shown conventional Old/New effects did not demonstrate modulation according to memory strength. A mirror effect for word frequency was demonstrated, with the LF word HR advantage associated with increased activity in the left lateral temporal cortex. However, none of the regions that had demonstrated Old/New item retrieval effects showed modulation according to word frequency. These findings are interpreted as supporting single-process memory models proposing a unitary strength-like memory signal and models attributing the LF word HR advantage to the greater lexico-semantic context-noise associated with HF words due to their being experienced in many pre-experimental contexts.

Theme: Neural basis of behaviour
Topic: Cognition

Keywords: Word frequency; Recognition; Episodic memory; Encoding strength; fMRI; Recollection; Familiarity

1. Introduction

Recognition memory experiments typically involve participants studying a list of words and, following a delay, being tested with a series of words that were included in the study list and some that were not. The participants decide which of these words they have seen before and which are unstudied words. These experiments have revealed two important phenomena: Repeating words presented in a study list increases their hit rate (HR; correct responses to studied words) at test, and HRs are superior for low frequency (LF) than high frequency (HF) words. In addition, unstudied LF words are less likely than unstudied HF words to be judged incorrectly as belonging to the study list (a "false alarm"; FA)—an example of a mirror effect [22]. When between-list experimental designs are employed, a mirror effect is also observed for repeated items [5,58].

Many memory theories hypothesise that item repetition strengthens episodic memory representations by either adding features to an existing trace or storing a novel one [34,47,54]). The single-process models proposed by Shiffrin and Steyvers ("retrieving effectively from memory" or REM) [54] and McClelland and Chappell [43] are examples of this approach. Single-process models of memory assume the existence of a unitary, continuous multi-component

* Corresponding author. Fax: (+617) 3365 3833.
E-mail address: greig.dezubicaray@cmr.uq.edu.au (G.I. de Zubicaray).

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memory trace or signal. Conversely, dual-process theories consider episodic memory strength to involve contributions from putatively separate strength-like (familiarity) and recall-like (recollection) processes [5,29,31,49,67]. For example, in Malmberg et al.'s [41] dual-process extension of the REM model, recollection serves the purpose of assessing the content of an episodic trace. As content becomes stronger with increasing storage of item features (familiarity), a better assessment of the features can be provided (recollection), assisting correct rejection of unstudied items at test. Item repetition is also considered to strengthen both familiarity and recollection in the dual-process models proposed by Reder et al. ("source of activation confusion" or SAC [5,49]) and Yonelinas [67], with recollection accounting for a relatively greater proportion of hits to repeated words than familiarity.

Accounts of the LF word hit rate advantage vary between theories. Some propose it to be a result of relatively greater attentional allocation to the features of LF words at encoding (e.g., Attention Likelihood Theory or ALT [22]; see also [16,39,40]), while others attribute it to processes occurring solely at test (e.g., "bind-cue-decide in memory" or BCDMEM [9]) or a combination of both [5,41]. For example, the original single-process REM model attributed the effect to familiarity due to the relatively more diagnostic or distinctive features of LF words [54]. In the dual-process extension of REM, this explanation is maintained: the recall or recollection mechanism does not favour LF words [41]. However, this view contrasts with several other dual-process models that consider LF words to be more recollectable than HF words [5,31].

An alternative class of memory model – the *context noise model* – makes different assumptions about the mechanisms responsible for word frequency and repetition effects in recognition memory [9]. Both item and context information are incorporated in a number of memory models [5,41], although most emphasise the role of the former type of information, and are hereafter referred to as *item-noise* models. Item information pertains to the features (e.g., orthographic, graphemic) describing each word, whereas context information might be best considered a *lexical-semantic* construct referring to the manner in which a word is used, related to word frequency [57]. For example, the word *spanner* is used in a relatively specialised way in conversations or text concerning tool use or engineering, whereas the word *morning* is likely to be used in many different scenarios. Item-noise models assume the majority of interference or noise in memory is caused by other items presented in the study list, whereas context-noise models [e.g., BCDMEM [9]) assume this sort of interference is negligible (see also Sikström [55]). To explain the LF word hit rate advantage, BCDMEM assumes that HF words are subject to greater interference due to the number of pre-experimental contexts in which they have been encountered [9]. In this account, a cue consisting of context information is used to search memory in order to retrieve an episodic trace at test, the traces similar to the information in the cue become activated, and this information contributes to the recognition decision. As LF words tend to have been encountered in fewer pre-experimental contexts, they are more strongly associated with the study context and the context that the participant reinstates at test. Thus, their traces receive relatively greater activation compared to those of HF words. However, strengthening the association between a word and the experimental context by repeating it at study is not considered to interfere with the memory retrieved to a different word in the list [9].

Information about the neurophysiological mechanisms contributing to recognition memory is being used increasingly to constrain and support theoretical perspectives [45,52]. Functional magnetic resonance imaging (fMRI) experiments have contrasted cerebral activity associated with studied and unstudied items, revealing consistent involvement of discrete anterior, superior and inferior regions of the prefrontal cortex, the left lateral and medial (cuneus/precuneus) parietal cortex and, less consistently, the medial temporal lobe (MTL) [11,15,25]. The respective roles of the prefrontal regions have been the subject of debate concerned with differentiating initial-retrieval- from post-retrieval-related processes. For example, the right superior region might be involved in monitoring and evaluating the products of a retrieval attempt [52], while activity in the left inferior prefrontal cortex (LIPC) might represent retrieval success or the outcome of the retrieval attempt [12,52]. A more tonic "episodic retrieval mode", a mental set or state deemed necessary for remembering studied items, is proposed to be mediated by a right anterior region (frontal polar cortex) [38]. Cortical correlates of the dual-process theoretical constructs of recollection and familiarity have also been proposed based upon results from these experiments. Responses in the left lateral *inferior* parietal cortex and, less frequently, in the hippocampal formation in the MTL (when observed) have been attributed to recollection, while activity in adjacent MTL structures such as the amygdala, rhinal and parahippocampal cortices is proposed to represent a familiarity-based signal [15,26,45,52]. A potential dissociation of these responses in terms of their direction has also been proposed: whereas recollection is reflected in positive activity for studied vs. unstudied items, the familiarity response shows the opposite relationship [26,52]. This is viewed as being consistent with the assumption that familiarity and implicit priming represent similar memory processes [42], as implicit priming effects are usually associated with reductions in cerebral activity in fMRI experiments [24,48]. Although Rugg and Yonelinas [52] have explicitly attributed retrieval-related activity in the left parietal cortex to recollection, it is worth noting that contradictory evidence exists. For example, several recent studies have failed to observe retrieval success effects in this region (e.g., [11,32,64,65]), and Wheeler and Buckner [64] recently proposed an alternative interpretation based upon the