Available online at www.sciencedirect.com

SCIENCE DIRECT

Cognitive Brain Research 22 (2005) 439–450

COGNITIVE BRAIN RESEARCH

www.elsevier.com/locate/cogbrainres

Research report

fMRI evidence of word frequency and strength effects during episodic memory encoding

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*

Accepted 7 October 2004
Available online 28 October 2004

Abstract

Word frequency (WF) and strength effects are two important phenomena associated with episodic memory. The former refers to the superior hit-rate (HR) for low (LF) compared to high frequency (HF) words in recognition memory, while the latter describes the incremental effect(s) upon HRs associated with repeating an item at study. Using the "subsequent memory" method with event-related fMRI, we tested the attention-at-encoding (AE) [M. Glanzer, J.K. Adams, The mirror effect in recognition memory: data and theory, J. Exp. Psychol.: Learn Mem. Cogn. 16 (1990) 5–16] explanation of the WF effect. In addition to investigating encoding strength, we addressed if study involves accessing prior representations of repeated items via the same mechanism as that at test [J.L. McClelland, M. Chappell, Familiarity breeds differentiation: a subjective-likelihood approach to the effects of experience in recognition memory, Psychol. Rev. 105 (1998) 724–760], entailing recollection [K.J. Malmberg, J.E. Holden, R.M. Shiffrin, Modeling the effects of repetitions, similarity, and normative word frequency on judgments of frequency and recognition memory, J. Exp. Psychol.: Learn Mem. Cogn. 30 (2004) 319–331] and whether less processing effort is entailed for encoding each repetition [M. Cary, L.M. Reder, A dual-process account of the list-length and strength-based mirror effects in recognition, J. Mem. Lang. 49 (2003) 231–248]. The increased BOLD responses observed in the left inferior prefrontal cortex (LIPC) for the WF effect provide support for an AE account. Less effort does appear to be required for encoding each repetition of an item, as reduced BOLD responses were observed in the LIPC and left lateral temporal cortex; both regions demonstrated increased responses in the conventional subsequent memory analysis. At test, a left lateral parietal BOLD response was observed for studied versus unstudied items, while only medial parietal activity was observed for repeated items at study, indicating that accessing prior representations at encoding does not necessarily occur via the same mechanism as that at test, and is unlikely to involve a conscious recall-like process such as recollection. This information may prove useful for constraining cognitive theories of episodic memory.

Theme: Neural basis of behaviour
Topic: Cognition

Keywords: Word frequency; Episodic memory; Learning; fMRI; Repetition priming

1. Introduction

Pure single item recognition memory experiments typically involve participants making "old" versus "new" judgements for single words presented at test after they have studied a word list. Two phenomena identified by these experiments are termed the word frequency (WF) and strength effects, respectively. The WF effect refers to the superior hit-rates (HR; correct "old" responses to studied words) for low frequency (LF) compared to high frequency (HF) words. In addition, for unstudied new words, LF words are less likely than HF words to be judged as old (a "false alarm")—an example of a mirror effect [28]. The strength

* Corresponding author. Fax: +61 7 3365 3833.
E-mail address: greig.dezubicaray@cmr.uq.edu.au (G.I. de Zubicaray).

0926-6410/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.cogbrainres.2004.10.002

effect describes the incremental effect(s) upon HRs associated with repeating an item at encoding [42,65]. Both effects are important phenomena for theories of episodic memory to explain.

Normative word frequencies are utilised in memory experiments as they are assumed to be related to an individual's actual experience of words in everyday life [8]. If this assumption is correct, the WF effect may be related to repetition priming, as Estes and Maddox [19] have suggested. Repetition priming is a well-established effect in which prior exposure to a word facilitates its processing (e.g., the speed with which it can be named or the probability that a degraded version can be identified) at a later presentation [53,59]. According to one encoding-based explanation of the WF effect, HF words attract little attention or processing time when presented in a study list due to their having been already extensively primed, whereas LF words attract more attention due to the relative novelty of their features [28,37,39,41,62]. A corollary to this hypothesis is that the amount of attention allocated to a word at study influences the strength of its episodic memory trace at test. It is known that dividing attention at encoding significantly reduces subsequent memory performance [12]. Alternate explanations of the WF effect place little emphasis on allocation of attention at encoding per se and/or variations in processing during the study phase. For instance, explanations emphasising processes occurring solely at test attribute the LF word HR advantage to the increased noise from the multiple contexts in which HF words have been previously encountered [15], and LF words being recollected more often because of less interference from prior contexts [55].

The attention-at-encoding (AE) account has had limited empirical evidence to directly support it. Behavioural investigations have examined either the amount of self-paced study time allocated to LF and HF words at encoding, or manipulated the presentation duration of study trials (for a review, see Ref. [39]). The former studies have assumed that longer study times are associated with increased allocation of attentional resources; LF words should therefore be studied longer than HF words at encoding. However, this does not provide a direct test of the hypothesis. The latter studies have assumed that limiting the study time permitted during encoding limits the amount of attentional resources that can be allocated; the advantage for LF words should therefore be directly related to study time. Although LF words are typically studied longer than HF words in self-paced experiments, the empirical evidence from the investigations involving experimenter-manipulated study time is mixed [38]. While experiments that confounded study time with study-test lag typically failed to find an effect, experiments using a mixed list design to control for study-test lag have confirmed the AE hypothesis [10,39]. Using the latter design, Malmberg and Nelson [39] showed that the LF word HR advantage was attributable to processing occurring solely between the first 250–1000 ms of study.

It is generally accepted that, as an item is presented repeatedly at study, the stronger its memory trace or signal is at test. Single process models of memory tend to assume the existence of a single, continuous multicomponent memory trace or signal, while dual-process theories consider encoding strength to involve contributions from putatively separate familiarity and recollection-based processes. Although the proposed mechanisms for strengthening a memory trace vary between theories, most assume an incrementing process of sorts. For example, in Shiffrin and Steyvers' [63] "retrieving effectively from memory" (REM) single-process model, this is attributed to the increased processing and storage of item features with each additional presentation. In Malmberg et al.'s [40] dual-process extension of REM, recollection (a recall-like process) serves the purpose of assessing the content of an episodic trace. As content becomes stronger with increasing storage of item features, a better assessment of the features can be provided, assisting correct rejection of unstudied items at test. Repetition is also considered to strengthen both familiarity and recollection in other dual-process theories [55,72].

Some issues associated with encoding strength also warrant mention here: First, study may involve accessing prior representations of repeated items, or assessing their content [40], and where this issue has been explicitly addressed in theory, it has been assumed to involve the same mechanism involved in recognition at test [42]. However, each presentation of an item might also be stored separately [35,51]. Second, a repetition priming effect of sorts occurs with multiple presentations at study as well as at test [53,59].[1] This might indicate that less attentional or processing effort is entailed for encoding each repeated presentation of an item compared to the first, as Cary and Reder [7] have speculated recently. Without this assumption, repeated presentations of items produced identical amounts of memory strengthening in their dual-process model, resulting in a poor fit to experimental data [7].

Cognitive neuroscience investigations of episodic encoding have exploited the "subsequent memory" method. This procedure involves contrasting neural activity measured during study of a series of items according to whether an item is recognised or not at test. Any differences found are assumed to represent successful encoding-related processes (for reviews, see Refs. [57,69]).[2] Cerebral regions found to

[1] Repetition priming is typically considered an index of implicit or unconscious memory processes. However, with item repetition during encoding, there is the potential for participants to make explicit connections between the separate study events, particularly when several study/test blocks are employed, as is the case here.

[2] This assumption neglects the fact that several theories assume forgetting processes that would not be revealed by a simple comparison between subsequently remembered and unrecognised items. For example, Murdock and Lamon [44] attributed forgetting to the characteristics of the other items in a study list, while Dennis and Humphreys [15] assume a major role for contextual reinstatement and preexisting associates with context.