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Encoding time and the mirror effect in recognition memory: Evidence from eyetracking

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ABSTRACT

Low-frequency (LF) words have higher hit rates and lower false alarm rates than high-frequency (HF) words in recognition memory, a phenomenon termed the *mirror effect*. Visual word recognition latencies are longer for LF words. We examined the relationship between eye fixation durations during study and later recognition memory for individual words to test whether (1) increased fixation time on a word is associated with better memory, and (2) increased fixation times on LF words can account for their hit rate advantage. In Experiments 1 and 2, words of various frequencies were presented in lists in an intentional study design. In Experiment 3, HF and LF critical words were presented in matched sentence frames in an incidental study design. In all cases, the standard frequency effect on eye movements emerged, with longer reading times for lower frequency words. At test, studied words and new words from each frequency class were presented. The hit rate portion of the mirror effect was evident in all experiments. The time spent fixating a word did predict memory performance in the intentional encoding experiments, but critically, the frequency effect on hit rates was independent of this effect. Time spent fixating a word during incidental encoding did not predict later memory performance. These results suggest that the hit rate advantage for LF words is not due to the additional time spent on these words at encoding, which is consistent with retrieval-stage models of the mirror effect.

Introduction

The *mirror effect* is a classic finding in the recognition memory literature, in which one type of stimulus is both better recognized as old when old (higher hit rate; HR) and better rejected as new when new (lower false alarm rate; FAR) compared to another type of stimulus (Glanzer & Adams, 1985, 1990). The frequency-based mirror effect is one example, as low frequency (LF) words have both higher HRs and lower FARs compared to high frequency (HF) words. In a meta-analysis of recognition experiments assessing the frequency-based mirror effect, Glanzer and Adams (1985) found that the mirror pattern held in 23 of 24 cases.

Despite the apparent ubiquity of this effect, the mechanism by which frequency affects memory performance remains unclear. The primary mechanism for producing the mirror effect varies substantially across models of recognition memory, with some models localizing the mechanism in the encoding stage and others during retrieval. Encoding-stage models include principle roles for attention (DeCarlo, 2007; Glanzer & Adams, 1990; Glanzer, Adams, & Iverson, 1991; Malmberg & Nelson, 2003) and unequal strengthening of items with study (DeCarlo, 2002). Retrieval-stage models, on the other hand, point to mechanisms such as differential familiarity and recollection (Reder et al., 2000), criterion shifts (Brown, Lewis, & Monk, 1977; DeCarlo, 2002), diagnosticity of feature values

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(Shiffrin & Steyvers, 1997), variability of feature values (McClelland & Chappell, 1998), and context noise (Dennis & Humphreys, 2001).

Each of these models makes assumptions about the processing of HF and LF words that are not easily measured in the typical recognition paradigm. Frequency effects also emerge in visual word recognition tasks, suggesting that our understanding of the mirror effect in memory could benefit from what is already known about processing of HF and LF words in other domains. In contrast to the memory advantage for LF words, however, visual word recognition studies reveal advantages in the processing of HF words. HF processing benefits emerge in a wide range of visual word recognition paradigms, including naming (Monsell, Doyle, & Haggard, 1989; Norris, 2006; Raman, Baluch, & Besner, 2004), lexical decision (Murray & Forster, 2004), semantic categorization (Monsell et al., 1989; Norris, 2006), and eye fixations in reading (Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Staub, White, Drieghe, Hollway, & Rayner, 2010; White, 2008). Across this diverse group of tasks, HF words consistently lead to faster and more accurate responses than LF words.

Models of visual word recognition generally appeal to the structure of the lexicon, or the nature of the search process through the lexicon, to account for frequency effects. Specific implementations of frequency effects include higher resting activation levels or lower selection thresholds for HF words (McClelland & Rumelhart, 1981; Morton, 1969; Rumelhart & McClelland, 1982), additional traces of HF words in memory (Logan, 1988), stronger weights in the connections for HF words (Seidenberg & McClelland, 1989), frequency-ordered search of the lexicon (Murray & Forster, 2004; Paap, Newsome, McDonald, & Schvaneveldt, 1982), the privileged use of a faster, whole-word route in processing HF words (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), or Bayesian calculations with frequency-based prior probabilities of words (McDonald & Shillcock, 2003; Norris, 2006). Regardless of the specific mechanism for producing frequency effects, each of these models assumes that LF words require more evidence or a more thorough search of the lexicon to complete lexical access.

The present work considers the possibilities that the processing difficulty, increased time, or increased attention associated with initial visual identification of LF words can explain the eventual benefit for LF words in recognition memory. There is evidence to support the claim that more difficult initial processing leads to stronger or more complete representations in memory. Miller and Kintsch (1980) and Keenan and Kintsch (1974) have shown that optimal memory for text results when processing is moderately difficult, with a decrease in accuracy for text that is either too difficult or too easy. This inverted U-shaped relationship between processing difficulty and memory is also reflected in recognition paradigms that manipulate frequency, as LF words are better remembered than both HF words and extremely LF words or nonwords (Estes & Maddox, 2002; Schulman, 1976).

It is also possible that increased encoding time on LF words, observed in many experimental paradigms, directly contributes to improved memory for these words. It is a well-known finding in the recognition memory literature that presenting words for a longer duration during study improves memory accuracy at test (Criss & Shiffrin, 2004; Hirshman & Hostetter, 2000; Ratcliff, Clark, & Shiffrin, 1990; Ratcliff, McKoon, & Tindall, 1994; Ratcliff, Sheu, & Gronlund, 1992; Schulman & Lovelace, 1970; Yonelinas, 1994). Schulman and Lovelace (1970) demonstrated an increase in accuracy for both HF and LF words when presented at a slower rate during study, providing further support for the hypothesis that longer encoding times during initial processing will lead to stronger memory representations and higher accuracy at test across all levels of word frequency.

While longer encoding times for LF words could be a direct result of the difficulty of initial word recognition, it is also possible that more time is spent processing LF words simply because they attract more attention at encoding, perhaps by virtue of being more surprising or distinctive than HF words. de Zubicaray, McMahon, Eastburn, Finnigan, and Humphreys (2005) reported increased activation in the left inferior prefrontal cortex during encoding of LF words compared to HF words, which they indicated as a sign of an increased allocation of attention to LF words. Increased activation in this region at encoding was also associated with better recognition at test, providing some support for the role of attention in the mirror effect.

In sum, it is possible that LF words are better remembered at test because they are more difficult to recognize at encoding, because recognition of LF words takes longer at encoding, or because they attract more attention at encoding. We note that while in principle these are distinct hypotheses, in practice they all predict that some or all of the LF advantage in memory is due to the longer time spent attending to and/or recognizing LF words.

To test this general prediction, it is necessary to accurately measure processing time during encoding. The time the eyes spend on a word in normal reading is usually interpreted as reflecting the difficulty of lexical access, with shorter reading times on HF words suggesting faster lexical access compared to LF words (Rayner, Liversedge, White, & Vergilino-Perez, 2003; Staub et al., 2010). Though there is some evidence that lexical processing may not be complete by the time the eyes leave a word, in the form of 'spillover' effects whereby variables such as lexical frequency influence fixation durations on the next word (e.g., Rayner & Duffy, 1986), these effects tend to be both small and unreliable compared to the effect of a word's frequency on reading times on the word itself (e.g., Staub, 2011). For this reason, models of eye movements in reading such as E-Z Reader (Reichle, Rayner, & Pollatsek, 2003) and SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005) propose that the decision to saccade to the next word is triggered by the completion of a stage of lexical processing. Furthermore, because eye gaze is closely related to visual attention and cognitive processing (Deubel & Schneider, 1996; Irwin, 2004), fixation durations also allow a test of models that posit increased attention to LF words during encoding as the mechanism for their advantage at test.