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Divided attention during encoding causes separate memory traces to be encoded for repeated events

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ABSTRACT

Strengthening some items on a list adversely affects memory for the remaining items on the list – a phenomenon known as the list-strength effect (LSE; e.g., Tulving & Hastie, 1972). Whether the LSE is observed depends on how memory is tested and how items are strengthened (Malmberg & Shiffrin, 2005; Ratcliff, Clark, & Shiffrin, 1990), with free recall producing robust LSE, whereas recognition test typically producing null LSE. In this report, we examined the LSE in free recall and recognition when items were learned with full attention or under divided attention at encoding. In free recall, the results showed a robust LSE under full attention, but a null LSE in divided attention. In contrast, in recognition a null LSE was observed under full attention, but a positive LSE emerged under divided attention. Within REM theoretical framework, the combination of these findings suggests that DA reduces the tendency to accumulate information across repetitions in a single trace, thereby reducing the influence of differentiation.

Introduction

During the study of a list of items, we encode the meaning and physical properties of the items, form inter-item associations between them, and create associations between the items and the episodic context (Anderson & Bower, 1972; Humphreys, Bain, & Pike, 1989; Lehman & Malmberg, 2013; Murdock, 1983; Raaijmakers & Shiffrin, 1980). What features of the event are encoded, and the extent to which they are encoded is determined by task demands and the goals of the participant (Atkinson & Shiffrin, 1968). For instance, an instruction to attend to semantic content of the words enhances the encoding of a word's meaning (e.g., Craik & Lockhart, 1972). Likewise, instructions to create sentences out of temporally adjacent words increases the tendency to encode inter-item associations and to recall the words in the order in which they were studied (e.g., Lehman & Malmberg, 2013). Hence, different tasks may orient attention to the encoding of item and inter-item content of new memory traces.

Less is known about the attentional demands of contextual encoding. Explicit instructions to integrate items and context during study enhance context-dependent memory (Murnane, Phelps, & Malmberg, 1999). Without explicit instructions to integrate items with their context, item-to-context associations are created and enhanced by distributed or spaced repetitions of the items (Murnane & Phelps, 1995). Taken together, these results suggest that both item and context information may be encoded automatically, but additional attentional resources are beneficial to both when applied.

Although encoding under divided attention (DA) conditions impairs memory (e.g., Mulligan, 2008), the mechanisms underlying the disruption are not well understood. DA could disrupt the encoding of some or all types of information comprising an event. DA could impair the encoding of items, without perhaps affecting the amount of context stored in episodic trace, and/or it could impair the degree of contextual encoding. It is also possible that DA disrupts the ability or tendency to access prior episodic traces, which impedes their ability to be updated and increases the tendency for repetitions to be represented by multiple independent traces as opposed to accumulating in the original trace (Flexser & Bower, 1974; Hintzman, 2010 for a review).

List-strength manipulations

In our approach to these questions, we used a mixed-pure lists paradigm, in which memory is tested for three lists of items, varying in composition. The term *mixed list* refers to a list that contains a mixture of strong and weak items, whereas the term *pure strong* or *pure weak* refer to separate lists, where all items are either strongly or weakly encoded. When the strengthening operation involves distributed or

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spaced repetitions of the items and memory is tested via free recall, strong items are better recalled for mixed lists compared to pure-strong lists, whereas weak items are better recalled for a pure-weak list compared to the mixed list (Malmberg & Shiffrin, 2005; Tulving & Hastie, 1972). In other words, although strong items are better recalled than weak items, the effect is magnified on the mixed list compared to the pure lists. This is known as *a positive list-strength effect or LSE*, which is commonly observed when the strengthening operation involves spaced repetitions. In contrast, when memory is tested with recognition or cued-recall, typically a null or slightly negative LSE is observed, where the strength of other items on the list has little or perhaps a beneficial effect on memory of remaining items – strong items show advantage over weak items, but the magnitude of difference is typically similar for pure and mixed lists, and sometimes it is slightly smaller on the mixed list, known as the negative LSE (Ratcliff et al., 1990; Wilson & Criss, 2017).

A comprehensive account of list-strength effects

Within the framework of the search of associative memory theory (SAM, Shiffrin, Ratcliff, & Clark, 1990) and the retrieving effectively from memory theory (REM, Shiffrin & Steyvers, 1997), there are two primary sources of information – item information, and context information, and each type of information can be used to probe memory. Free recall and recognition memory are probed with different types of information – context information is used in free recall, whereas item (plus context) information is used to probe recognition. Strengthening operations are assumed to increase the amount of information stored in a memory trace representing the occurrence of the item itself and the context in which it occurred. A well-known strengthening operation is spacing or distributing the repetitions of list items, leading to better memory for items repeated in spaced fashion compared to massed fashion (Crowder, 1976; and Hintzman, 1974 for reviews). Spaced repetitions produce traces containing additional information about the item and additional information about the encoding context compared to traces of items that were not repeated or repeated in a massed fashion (Malmberg & Shiffrin, 2005).

Free recall

In the present REM model, the positive LSE for free recall is explained in terms of retrieval competition arising from the strength of contextual information in the memory trace (Malmberg & Shiffrin, 2005). Free recall is assumed to be initiated with context cues, and the match between the context stored in the traces and context used to probe memory determines which traces are sampled. The traces that contain more context features that match context cue are more likely to be sampled compared to traces that contain fewer context features that match the context cue. According to the one-shot hypothesis for context encoding, all traces have about the same amount of context stored in them after a pure list is studied, and thus all other things being equal have the same chance to be sampled (Malmberg & Shiffrin, 2005). The situation is different after a mixed list is studied, because items strengthened via spaced repetitions have more context features stored than weakly encoded items. Hence, the traces of items studied more than once in a spaced fashion dominate the traces of item studied only once (or presented in a massed fashion) in the retrieval competition. This produces the positive LSE in free recall. Thus, the relative magnitude of LSE can be indicative of how a particular manipulation affects the strength of contextual encoding.

Recognition

The same encoding assumptions that predict a positive LSE for free recall, predict a slightly negative or null LSE for item recognition (Shiffrin & Steyvers, 1997, 1998; Criss, 2006). One of the assumptions in REM is that the items are stored in memory probabilistically, which means that the memory traces of items are incomplete. During encoding, each feature is stored with some probability, and if a feature is not stored, that feature value in the trace is zero, and indicates a lack of information. As items are strengthened (via increased study time, depth of encoding, or repetitions), the memory traces of those items become updated (by replacing the zero features), which makes them more complete and informative. As additional item features accumulate in the memory trace, it decreases the similarity between the contents of different traces, known as *differentiation* (Criss, 2006, 2009; Kilic, Criss, Malmberg, & Shiffrin, 2017).

The key predictions concern the effect of differentiation on item recognition. According to REM models, strengthening operations increase the hit rates and lower false-alarm rates for strong items. Retrieval is assumed to involve a global-matching process, which compares the test item to the contents of all the traces stored in memory during the study phase of the experiment. The more similar a trace is to the test item, the more positive evidence it provides. Hence, strengthening operations increase the hit rates. Importantly, increasing the strength with which a trace is encoded decreases its similarity to representations of other items, which lowers false-alarm rates. When strength is manipulated between lists, the increase in hit rates and decrease in false-alarm rates is referred to as the *strength-based mirror effect* (Wixted & Stretch, 2004).

Spaced repetitions produce an increase in the number of item features stored compared to massed repetitions (Malmberg & Shiffrin, 2005). An important finding is that when strength is manipulated via spaced repetitions, recognition accuracy is unaffected by the composition of the study lists, unlike free recall where a positive LSE is observed. In fact, slightly negative LSEs for item recognition have often been reported (Ratcliff et al., 1990). This is predicted by the REM differentiation model because adding strong item representations to memory reduces the noise associated with the global-matching process, on the assumption that at least half of the repetitions result in the accumulation of features in a trace representing a previous event (Shiffrin & Steyvers, 1997; Malmberg, Holden, & Shiffrin, 2004). If trace accumulation does not occur or rarely occurs, then a positive LSE is predicted (e.g., Murnane & Shiffrin, 1991a, 1991b).

The interaction between list-strength and divided attention

The literature suggests that concurrent tasks performed at encoding not only impair item memory, but they also impair the ability to identify the source or the context in which those items were presented (e.g., Naveh-Benjamin, Guez, & Marom, 2003; Naveh-Benjamin, Guez, & Shulman, 2004; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Smyth & Naveh-Benjamin, 2016). Thus, DA at encoding impairs explicit retrieval of context. If encoding of context is impaired by concurrent tasks, it would lead to difficulty retrieving the context during the test phase. Although deficits in source identification due to DA can be viewed as consistent with the hypothesis that encoding of context demands attention, such findings do not provide direct evidence for it. Source identification involves a complex attributional process that can be influenced by many factors, including guessing biases (Chalfonte & Johnson, 1996). Also, source identification requires retrieval of context given the item, whereas the current investigation examines the opposite problem – retrieval of items given a context cue, allowing us to examine how context *encoding* is affected by DA.

Specifically with respect to the LSE, Malmberg and Shiffrin (2005) speculated that attentional factors may negatively affect updating of existing memory traces when items are repeated in a spaced fashion. For instance, it is likely that attentional demands limit the ability to encode item features representing an event. Moreover, it is possible that under taxing loads, retrieval of a trace stored previously is impaired, making it difficult to update it with item and/or context features representing the second (or subsequent) encoding attempts. If so, overall free recall and recognition performance should be harmed, the positive LSE for free recall should be severely diminished, and the slightly