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The cost of proactive interference is constant across presentation conditions

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ABSTRACT

Proactive interference (PI) severely constrains how many items people can remember. For example, Endress and Potter (2014a) presented participants with sequences of everyday objects at 250 ms/picture, followed by a yes/no recognition test. They manipulated PI by either using new images on every trial in the *unique* condition (thus minimizing PI among items), or by re-using images from a limited pool for all trials in the *repeated* condition (thus maximizing PI among items). In the low-PI unique condition, the probability of remembering an item was essentially independent of the number of memory items, showing no clear memory limitations; more traditional working memory-like memory limitations appeared only in the high-PI repeated condition. Here, we ask whether the effects of PI are modulated by the availability of long-term memory (LTM) and verbal resources. Participants viewed sequences of 21 images, followed by a yes/no recognition test. Items were presented either quickly (250 ms/image) or sufficiently slowly (1500 ms/image) to produce LTM representations, either with or without verbal suppression. Across conditions, participants performed better in the unique than in the repeated condition, and better for slow than for fast presentations. In contrast, verbal suppression impaired performance only with slow presentations. The relative cost of PI was remarkably constant across conditions: relative to the unique condition, performance in the repeated condition was about 15% lower in all conditions. The cost of PI thus seems to be a function of the relative strength or recency of target items and interfering items, but relatively insensitive to other experimental manipulations.

1. Introduction

Proactive interference (PI) occurs when the retrieval of a stimulus is impaired due to previously experiencing similar stimuli. It has long been known to limit how many items we can remember over the short term (see, among many others, e.g., Baddeley & Scott, 1971; Berman, Jonides, & Lewis, 2009; Cowan, Johnson, & Saults, 2005; Endress & Potter, 2014a; Keppel & Underwood, 1962; Kincaid & Wickens, 1970; Lewandowsky, Oberauer, & Brown, 2009; Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999; Makovski & Jiang, 2008; Wickens, Born, & Allen, 1963) and over the long term (e.g., Baddeley, 1966; da Costa Pinto & Baddeley, 1991; Ericsson & Kintsch, 1995). It might also contribute to one of the classic memory limitations, namely those of Working Memory (WM). WM is a temporary memory store where we can store items for on-going cognitive operations. It has a limited capacity (e.g., Awh, Barton, & Vogel, 2007; Luck & Vogel, 1997; Miller, 1956; Cowan, 2005; Rouder et al., 2008; Zhang & Luck, 2008) or a limited precision (e.g., Alvarez & Cavanagh, 2004; Bays & Husain, 2008; Bays, Catalao, & Husain, 2009; van den Berg, Shin, Chou, George, & Ma, 2012). Some authors have suggested that its function is to counteract the effects of PI (e.g., Engle, 2002). Accordingly, there are interference-based computational models of even the most complex WM tasks — complex span tasks (Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012). Indeed, WM capacity as measured by complex span tasks correlates with susceptibility to interference (e.g., Conway & Engle, 1994; Conway, Kane, & Engle, 2003; Kane & Engle, 2000, 2003; May et al., 1999; Rosen & Engle, 1998), and both WM capacity and susceptibility to interference correlate with IQ (e.g., Braver, Gray, & Burgess, 2008; Burgess, Gray, Conway, & Braver, 2011; Conway et al., 2003; Engle, Tuholski, Laughlin, & Conway, 1999; Fukuda, Vogel, Mayr, & Awh, 2010; Gray, Chabris, & Braver, 2003; Kane et al., 2004). Further, brain imaging studies have shown that the prefrontal regions that are generally linked to control functions in WM tasks are also activated by PI, and, in fact, memory tasks that minimize PI do not seem to recruit these regions (e.g., Hasselmo & Stern, 2006; Ranganath & D'Esposito, 2001; Ranganath & Rainer, 2003; Stern, Sherman, Kirchhoff, & Hasselmo, 2001).

Here, we investigate the cost of PI under different presentation conditions. This question is important because the types of mechanisms we use to remember items over the short-term are not unitary, and show

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contributions from visual, conceptual, linguistic, and attentional processes, among others (e.g., Baddeley & Hitch, 1974; Baddeley, 1996, 2003; Cowan, 1995; Cowan, 2001, 2005; Endress & Potter, 2012; Feigenson & Halberda, 2008; Kibbe & Feigenson, 2014; Olsson & Poom, 2005; Potter, 1976; Potter, 1993; Potter, Kroll, Yachzel, Carpenter, & Sherman, 1986; Rosenberg & Feigenson, 2013; Wong, Peterson, & Thompson, 2008; Wood, 2008). Further, at least according to some prominent theories of WM (Cowan, 2001), the storage function of WM is fulfilled by long-term memory (LTM; though recent research casts doubt on whether LTM is really distinct from more short-lasting forms of memory; see Ranganath & Blumenfeld, 2005, for a review).

Given that PI emerges in a variety of situations, and that it acts on many different processes and memory stores, the effects of PI might well be different in different situations. Here, we start investigating this issue by testing two components of memory: the availability of verbal memory, and the availability of LTM. We take advantage of a recent paradigm that showed virtually no memory limitations over the short-term when PI was minimized, but that revealed more traditional capacity limitations in the presence of strong PI among items (Endress & Potter, 2014a). Specifically, these authors presented adult participants with sequences of everyday pictures (taken from Brady, Konkle, Alvarez, & Oliva, 2008) in rapid sequential visual presentation (RSVP) at a presentation rate of 4 Hz, followed by a yes/no recognition test. Results showed that, as long as memory items were never repeated across trials (hereafter the *unique* condition), the proportion of remembered items, while well below ceiling, was essentially independent of the number of sequence items: the longer the sequence, the more items participants remembered (see Banta Lavenex, Boujon, Ndarugendamwo, & Lavenex, 2015, for similar results). In terms of memory capacities, participants thus did not show any clear capacity limitations. In contrast, when a limited set of items was reused across trials (hereafter the *repeated* condition), more traditional capacity limitations were observed. As repeating items across trials likely creates PI among items, PI limited the number of retrievable items. In fact, such PI is present in most WM experiments, as memory items are typically sampled from a limited set of items that are, therefore, repeated across trials. For example, in Luck and Vogel's (1997) change detection experiment, just 7 colors were re-used in hundreds of trials, which, in turn, might have led to substantial PI across trials. Hence, PI might have limited WM capacity estimates also in previous studies of visual WM (but see Hartshorne (2008); Lin and Luck (2012); Makovski and Jiang (2008), for opposing views, and Endress and Potter (2014a), for discussion).

In the experiment below, we keep "Temporary Memory" as a label for the short-lived memory investigated here. While WM capacity estimates might have been limited by PI in many WM experiments, we believe that the relationship between Temporary Memory and WM is an open issue, especially for the varieties of WM investigated in complex span tasks.

We build on Endress and Potter's (2014a) work, and ask how the cost of PI depends on the availability of verbal processes and of LTM. To manipulate the availability of verbal resources, participants did or did not complete a verbal suppression task simultaneously with the memory task. The manipulation of the availability of LTM relies on Endress and Potter's (2014a, 2014b) experiments. In some of Endress and Potter's (2014a) experiments, participants completed a surprise LTM test at the end of the experiment; the retention delay was about half an hour. Results showed virtually no retention of the unique items, suggesting that a single 250 ms presentation of a memory item is not sufficient to create stable memory traces. In contrast, subsequent experiments showed that four separate 250 ms presentations of an image are sufficient to yield memory traces roughly half an hour later (Endress & Potter, 2014b). To manipulate the availability of LTM, we thus presented memory items either for durations too fast to yield stable LTM traces (250 ms/picture), or for durations that have yielded relatively stable LTM traces in earlier research (1.5 s/picture).

2. Materials and method

2.1. Design

The experiment had a 2 (PI: unique vs. repeated condition)×2 (presentation speed: slow vs. fast)×2 (verbal suppression: present vs. absent) mixed design. The strength of proactive interference (unique vs. repeated) was a within-subject factor; the two PI conditions were administered by blocks, with the order of the blocks counterbalanced across participants. The presentation speed and verbal suppression were between-participant factors.

This design does not separate the contributions of encoding and retrieval operations; rather, our goal was to test whether the availability of verbal resources and of LTM affect memory performance *at all*.

2.2. Participants

Fifty-six individuals (14 per condition; 44 females; mean age = 22 years and 12 males; mean age = 29 years) from City University London participated in the experiments below. The sample size was determined by participant availability, subject to the constraint that the effect sizes in Endress and Potter's (2014a) suggest that we should find reliable PI with this sample size. An additional two individuals took part in the experiment, but were excluded from analysis due to computer malfunction (N = 1) and excessive breaks and unusual behavior (N = 1).

Participants were sequentially assigned to the conditions without verbal suppression and with verbal suppression, respectively. Each participant chose which presentation speed (fast or slow) they wished to take part in, based on the duration of the session they signed up for. The order of the unique and repeated conditions were counterbalanced across participants.

2.3. Apparatus

Stimuli were presented on a Dell P2213 22″ (55.88 cm) LCD (resolution: 1024 × 640 pixels at 60 Hz), using the Matlab psychophysics toolbox (Brainard, 1997; Pelli, 1997) on a Mac mini computer (Apple Inc., Cupertino, CA). Responses were collected from pre-marked "Yes" and "No" keys on the keyboard.

For the verbal suppression condition, participants were provided with a regular rhythm at which they were to repeat the syllables. We used the Metronomo app (downloaded from the Apple Appstore), set to a tempo of 90 beats per minute and a rhythm of 1 beat per measure (i.e., the sequence of sounds did not comprise any accents). The participants' vocalizations were recorded through a USB webcam (Logitech, Lausanne, Switzerland), using Audacity (Version 2.1.0; http://audacity.sourceforge.net/) and exported to the mp3 format using the LAME MP3 encoder (version 3.98.2, http://lame1.buanzo.com.ar/).

2.4. Materials

Stimuli were color pictures of everyday objects taken from Brady et al. (2008). These were randomly selected for each participant from a set of 2400. In the unique condition, the stimuli thus came from a randomly selected set of 1290 pictures; in the repeated condition, a randomly selected set of 22 pictures was used in all trials. There was no overlap between these picture sets.

The pictures were presented at a resolution such that they subtended approximately the same visual angle (approximately 12.7 × 12.7°) as in Endress-WM-Capacity. The syllables participants had to repeat during the verbal suppression task were "vlim," "toff," "plof." These syllables were chosen to have a low phonotactic probability to make it relatively hard to automatize the verbal suppression task.

In the verbal suppression condition, participants were tested individually in a sound attenuated testing room. In the no suppression