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A test of interference versus decay in working memory: Varying distraction within lists in a complex span task ☆

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ABSTRACT

We tested two competing explanations of the effect of processing on working memory. According to decay models, memory representations decay during processing and can be rehearsed or refreshed in the free time between processing steps. Alternatively, one interference-based model assumes that processing involves encoding of distractor representations in working memory, and free time is used to remove distractors. In several experiments the demand from distractor processing was varied within lists, such that one burst of processing following an item on the list was either particularly demanding or particularly undemanding. The exceptional distractor burst had its greatest effect on the list item that immediately preceded it (a local effect), and it affected items that had not yet been presented as well as preceding items. Both findings are predicted by a computational interference model of working memory, and together are problematic for the viewpoint that refreshing offsets decay.

Introduction

Memory researchers recognise that avoiding distraction is key to maintaining efficient cognitive processing (Farrell & Lewandowsky, 2012; Kuhl, Dudukovic, Kahn, & Wagner, 2007; Levy & Anderson, 2002): People need to hold in mind relevant information while ignoring irrelevant information, and need to forget no-longer relevant information to avoid being distracted by it. Researchers—particularly those examining working memory—have thus been very interested in our ability to keep in mind important or goal-relevant information whilst dealing with distraction (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Vogel, McCollough, & Machizawa, 2005). Apart from the obvious applied interest (e.g., Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013) focus has been on two questions. First, by what mechanism does distractor information impair our ability to keep in mind relevant information? On this question the recent literature has seen the re-emergence of a debate on the fundamental issue of whether forgetting occurs through decay (e.g., Barrouillet, Bernardin, & Camos, 2004; Barrouillet, Portrat, & Camos, 2011; Page & Norris, 1998; Towse, Hitch, & Hutton, 2000) or interference (e.g., Lewandowsky & Farrell, 2008; Oberauer & Lewandowsky,

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[1] Data and code for performing analyses and computational modelling are available at https://github.com/psy-farrell/global-local-wm.

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2008; Oberauer, Farrell, Jarrold, Pasiecznik, & Greaves, 2012; Oberauer, Lewandowsky, Farrell, Jarrold, & Greaves, 2012; Saito & Miyake, 2004), and these two accounts entail entirely different explanations for the effect of distracting information. The second question is, how does the working-memory system keep the distracting effects of irrelevant information under control? The ability to focus attention on relevant information and keep irrelevant information from influencing thought and behaviour is regarded as a key function of working memory (e.g., Fawcett & Taylor, 2008; Kane, Bleckley, Conway, & Engle, 2001; Oberauer, Farrell, et al., 2012, Oberauer, Lewandowsky, et al., 2012; Unsworth, Schrock, & Engle, 2004).

A task commonly used to study distraction in working memory is the complex span paradigm, in which memoranda that are to be later recalled in serial order are interleaved with brief bursts of distracting processing activity, such as reading a small set of digits or words (Lewandowsky, Geiger, Morrell, & Oberauer, 2010); reading a sentence (Daneman & Carpenter, 1980); making perceptual judgements (Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007; Jarrold, Tam, Baddeley, & Harvey, 2010); or counting (Case, Kurland, & Goldberg, 1982; for a review, see Conway et al., 2005). Performance is typically impaired by the distracting activity when compared to so-called simple span in which no distracting activity occurs (Lewandowsky et al., 2010; Unsworth & Engle, 2007a). A central question in contemporary working memory research is how exactly this distracting activity has its effects.

One family of models holds that information is forgotten from working memory by a process of passive decay, and that this decay is counteracted by rehearsal in periods not taken up by the processing of distractors. One specific version of this account, the task-switching model (Hitch, Towse, & Hutton, 2001; Towse et al., 2000), was developed to account for performance in the reading span task, in which the distractor activity is reading sentences, and the memoranda are the final words of the sentences read. It is assumed that when reading the sentences, people switch from encoding and rehearsing the memoranda to reading the sentence, and during sentence reading stored memory traces to decay over time. An alternative decay-plus-rehearsal model is the time-based resource-sharing (TBRS) model of Barrouillet, Camos and colleagues (Barrouillet & Camos, 2001; Barrouillet et al., 2004, 2011; Camos, Lagner, & Barrouillet, 2009; Oberauer & Lewandowsky, 2011). This model updates earlier resource-based models (e.g., Daneman & Carpenter, 1980) by assuming that the resource shared between storage of memoranda and processing of distractors is time: Attention can be paid either to encoding and refreshing list items, or to performing required operations on distractors. Although superficially similar to the task-switching model, TBRS makes the important additional assumption that attention can be rapidly switched between refreshing and distractor processing. Accordingly, whereas the task-switching model assumes that attention is entirely dedicated to distractor processing for the full duration of a processing episode, TBRS assumes that attention is rapidly switched between refreshing and distractor processing during the processing episode. Evidence favouring the more fine-grained allocation of attention in TBRS comes from the finding that increasing the pace of a distractor task leads to worse memory performance when controlling for the overall duration of the task (Barrouillet & Camos, 2001; Barrouillet et al., 2004). Conversely, holding constant the amount of processing required whilst allowing more time for the distractor task enhances memory performance (Barrouillet & Camos, 2001; Barrouillet et al., 2004), a situation in which the task-switching account predicts a decrement because overall retention time is increased.

An alternative perspective is offered by interference-based accounts, which assume that the detrimental effect of distractor processing arises because this activity introduces irrelevant information into memory that interferes with memoranda (Oberauer & Kliegl, 2006; Oberauer, Lewandowsky, et al., 2012; Saito & Miyake, 2004). For example, an extension of the C-SOB model of serial recall (Farrell, 2006; Lewandowsky & Farrell, 2008) accounts for complex-span performance by assuming that distracting information is encoded in exactly the same manner as list items, by associating the distracting material to a representation of the current context (Lewandowsky et al., 2010; Oberauer & Lewandowsky, 2008). Specifically, the information generated during a processing burst is associated to the positional marker representing the position of the immediately preceding list item. Accordingly, when that positional marker is used to cue for the associated list item, it will also retrieve information from the associated distractor(s), thus leading to interference. This model accounts for the finding that processing a larger number of different distractors in a fixed time window leads to worse performance with varying distractors (Barrouillet & Camos, 2001; Barrouillet et al., 2004; Saito & Miyake, 2004). In addition, interference-based accounts also explain similarity-related effects in complex span. For example, the extent of interference from processing in complex span at least partly depends on whether it comes from the same domain (e.g., verbal versus visuo-spatial) as list items (e.g., Bayliss, Jarrold, Gunn, & Baddeley, 2003; Chein, Moore, & Conway, 2011; Jarrold et al., 2010; Shah & Miyake, 1996).

One limitation of a basic interference approach is that it cannot easily account for data showing that free time during complex span can be used to ameliorate the effects of distraction. In particular, the advantageous effect of a slower pace of distracting material when the total amount of interference is controlled (Barrouillet & Camos, 2001; Barrouillet et al., 2004) suggests that people use the free time between distractors to enhance memory, and this has typically been taken to imply refreshing of decaying memory traces (Barrouillet & Camos, 2001; Barrouillet et al., 2004, 2011; Hudjetz & Oberauer, 2007). However, Oberauer, Lewandowsky, et al. (2012) have shown that the beneficial effect of free time is equally compatible with an elaborated interference account. In their SOB-CS model (Serial-Order-in-a-Box model of Complex Span), the time following a distractor is used to remove that distractor from memory by "unlearning" the association of the distractor to the current positional marker. This same mecha-