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Individual differences in the fan effect and working memory capacity☆

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Abstract

In opposition to conceptualizing working memory (WM) in terms of a general capacity, we present four experiments that favor the view that individual differences in WM depend on attentional control. High- and low-WM participants, as assessed by the operation span task, learned unrelated sentences for which the subject and predicate of the sentences shared concepts (fan). Sentences were learned in sets organized by subjects (Experiments 1A and 1B) or predicates (Experiments 2A and 2B). WM predicted accuracy and reaction times on a subsequent speeded verification task, but not learning. In Experiments 1A and 2A, low-WM participants had a steeper, positively sloped fan effect for reaction times to studied items than high-WM participants. In Experiments 1B and 2B, fan was eliminated across but not within memory sets, which eliminated individual differences but not slope to the fan effect. These effects suggest the crux of WM is attentional control, and competition across sets causes individual differences.

Keywords: Attentional control; Fan effect; General capacity; Individual differences; Inhibition; Working memory

Introduction

Rapidly and accurately retrieving familiar information from semantic memory sometimes requires working memory capacity. Cantor and Engle (1993, see Experiment 1 of their report) demonstrated as much when they observed that the magnitude (or slope) of fan effects for retrieval from long-term semantic memory varied as a function of individual differences in working memory capacity. Fan effects occur when the time required to verify a proposition encoded in long-term memory increases concomitantly with the number of propositions collectively committed to memory (Anderson, 1983). Fan effects are the product of interference among shared concepts. The critical result in Cantor and Engle (1993)

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was that participants with less working memory capacity revealed more dramatic fan effects than those with more working memory capacity, and the slopes of individual fan effects statistically accounted for the relationship between working memory capacity and reading comprehension, as measured by the Verbal Scholastic Aptitude Test (VSAT). This result has been used to promote the idea of working memory capacity as amount of activation. According to Cantor and Engle's (1993) theoretical framework, working memory is the activated portion of long-term memory, and working memory capacity is the total amount of activation available for cognition (a similar position was taken in Anderson & Lebiere, 1998; Engle, Cantor, & Carullo, 1992; Lovett, Reder, & Lebiere, 1999). Four experiments are reported here; the results of which are inconsistent with the notion of working memory capacity as amount of activation and inconsistent with Cantor and Engle's (1993) interpretation of individual differences in the fan effect. The current experiments suggest that individual differences in working memory capacity and the fan effect are better explained by a model in which working memory capacity refers to the ability to resist interference rather than a limited amount of activation.

Working memory as capacity

There is some consensus among cognitive psychologists that working memory is a system, or set of processes, that allows for the active maintenance of information in the face of concurrent processing and/or distraction (Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Engle, Kane, & Tuholski, 1999; Miyake & Shah, 1999). Working memory span tasks, including counting span, operation span, and reading span, were developed in accordance with this view of working memory (for examples of each see Case, Kurland, & Goldberg, 1982; Daneman & Carpenter, 1980; Turner & Engle, 1989, respectively). Although different in surface level features, these tasks are structurally similar, for some sort of secondary processing (be it counting shapes, solving mathematical operations, or reading sentences) is imposed during encoding to detract from memory for some memoranda. For example, in the operation span task used in the present set of experiments and described more thoroughly in the Prescreening, participants verify the veracity of simple mathematical equations while attempting to remember strings of unrelated words for later recall. Each trial consists of a mathematical operation followed by a memoranda (e.g., Is $(9 * 2) - 2 = 15$? Road), and recall is cued after sets of 2–5 operation-word strings. Working memory span is the number of words correctly recalled. Assessed as such, working memory capacity reliably and strongly predicts more complex cognitive behaviors such as reasoning, problem solving, and reading comprehension (Engle, 2001).

Working memory span was once commonly described as the capacity to share resources among competing goals (Cantor & Engle, 1993; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Turner & Engle, 1989). Daneman and Carpenter (1980), in the tradition of Baddeley and Hitch's (1974) working memory model, proposed that the processing and storage components of their reading span task made competing demands for a shared resource, and they hypothesized that more efficient processing permits more room for storage. Others, including Turner and Engle (1989), took a similar capacity view of working memory, but they differed from Daneman and Carpenter in the extent to which they conceived of this resource as a domain-specific. Turner and Engle made a convincing argument for the domain-generality of working memory when they demonstrated that operation span, which does not involve reading, accounted for as much variance in multiple measures of reading ability as reading span. Reading span and operation span account for the same variance in reading comprehension, and they load on the same factor in factor-analytic studies (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Kane et al., 1999; Kane et al., 2004). Therefore, the processing component need not be reading in order to predict reading comprehension. According to the "general capacity" model of working memory capacity, working memory is a domain-free memory capacity (Engle et al., 1992). The dual components of operation span, as in other span tasks, require active maintenance (i.e., remembering words for later recall) in the face of concurrent processing (i.e., solving mathematical operations).

Working memory as attentional control

The general capacity model was closely associated with a size metaphor for memory capacity and emphasized the measurement of memory ability, but this model has not held up to empirical investigation (e.g., Conway & Engle, 1994; for a review see Engle, 2001). Engle and colleagues, who were largely responsible for proposing and advancing the general capacity model, have found that pure memorial processes fail to account for the covariation between working memory span and higher-order cognition. They have instead argued that working memory is equivalent to short-term memory plus a general, controlled-attention ability (Engle, 2001; Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2003). It is this attentional control component that is responsible for the predictive utility of working memory span tasks. According to Engle and colleagues' "controlled attention" theory of working memory, working memory capacity refers to the attentional ability to maintain activation for goal-relevant information and ignore goal-irrelevant or distracting information via control mechanisms such as goal maintenance and inhibition.