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The unique contributions of the facilitation of procedural memory and working memory to individual differences in intelligence

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ABSTRACT

Individual differences in working memory account for a substantial portion of individual differences in complex cognitive processes (e.g., comprehension) and fluid intelligence. However, a large portion of the variance in fluid intelligence and comprehension is unexplained. The current investigation was conducted to evaluate whether individual differences in the facilitation of procedural memory accounts for unique variance in intelligence not accounted for by working memory. To measure variability in the facilitation of procedural memory, we used a task that required participants to first classify exemplars of two categories; facilitation was then operationalized by subsequent improvements in the speed of classifying new exemplars from those categories (i.e., an operation-specific memory procedure). Three measures of each focal construct (facilitation in procedural memory, working memory, comprehension and fluid intelligence) were administered to 256 participants. We used structural equation modeling to examine the relationships among these latent variables. Working memory did account for variance in fluid intelligence and comprehension, but most important, individual differences in facilitation of procedural memory accounted for unique variance in fluid intelligence and comprehension.

1. Introduction

Working memory (WM) has been touted as a major source of individual differences in learning and problem solving since Baddeley and Hitch (1974) proposed the multiple components model of WM. Measures of WM are related to comprehension, reasoning ability, crystallized intelligence (*gC*) and fluid intelligence (*gF*). Nevertheless, as we discuss below, WM is not identical to higher-order cognition, and in particular, *gF*. That is, WM accounts for only a portion of *gF*, with a large portion of variance left unexplained. Accounting for this unexplained variance is the focus of our investigation, so we will briefly discuss previous research on the relations between WM and *gF* that motivate it.

A great deal of the research on intelligence and reasoning ability has focused on the relationship between WM and *gF* (e.g., Kyllonen & Christal, 1990), which continues to demonstrate that these two constructs are highly related. Based on these consistent results, several researchers have argued that WM and *gF* (or perhaps general intelligence) are unitary concepts (for reviews, see Ackerman, Beier, & Boyle, 2005; Kane, Hambrick, & Conway, 2005; Oberauer, Schulze, Wilhelm, & Süß, 2005), but this view is no longer well received. For instance, Heitz et al. (2006) explained that although WM and *gF* are indisputably related ($r = .70$), approximately 50% of the variance between the two constructs is not shared. Ackerman et al. (2005) completed a meta-analysis and found the average correlation (r) between WM and g to be .48. Given that the majority of variance between the two constructs is unexplained, the question remains: If WM and *gF* are not unitary concepts, what other cognitive processes contribute to *gF*?

Another potential contributor to variance in gF was described by Was and Woltz (2007), who investigated the relationship between WM, discourse comprehension, and a new task referred to as *the availability of long-term memory* (ALTM) task (see also Woltz & Was, 2006). This task in part measures the facilitation of procedural memory, and in particular the facilitation of the procedures involved in classifying exemplars from a specific category. They proposed that individual differences in this facilitation accounted for unique variance in discourse comprehension. To better understand their rationale, we describe the ALTM task in detail next, and then we more fully explore how the construct that it taps (i.e., facilitation of procedural memory) differs functionally from WM. The procedure for measuring the facilitation of procedural memory (Woltz & Was, 2006, 2007) is illustrated in Fig. 1, which presents an example trial of the original ALTM task (Woltz & Was, 2006). Each trial in the task includes four components. All four trial components were completed before moving on to the next trial.

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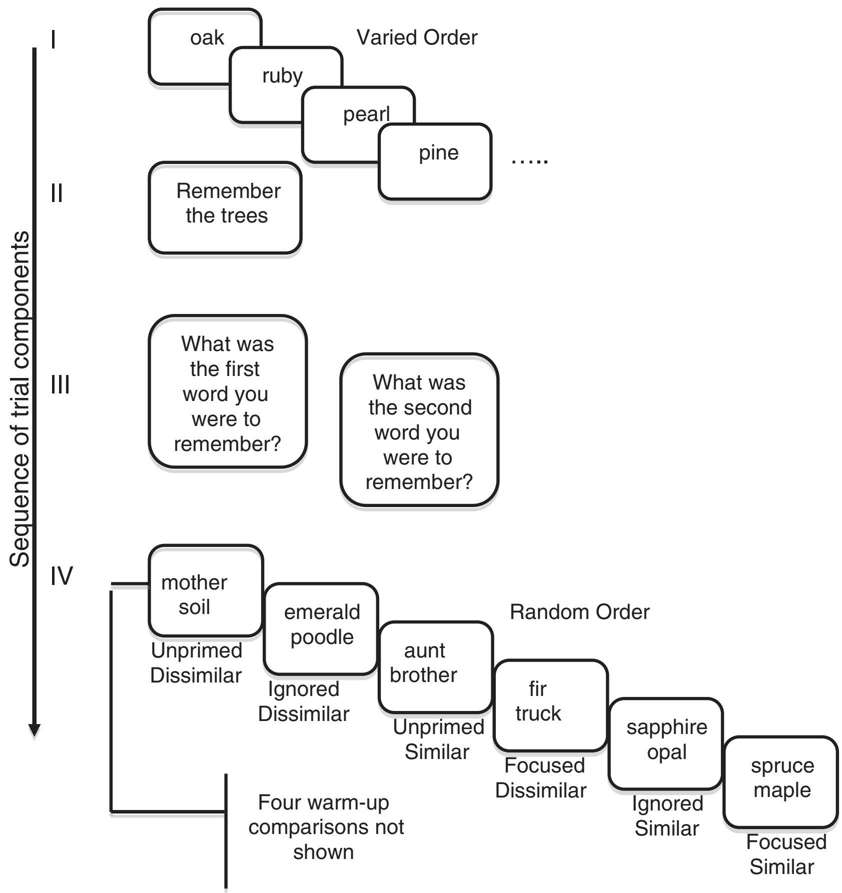

Fig. 1. Example trial from Woltz and Was (2006).

The first component was a memory load of four words (typically 2 syllables each) that were presented one at a time for later recall. The words came from two semantic categories; in Fig. 1, the categories are *trees* and *precious stones*. The second component was a concurrent demand that increased the amount of processing allocated to one of the semantic categories. This focused allocation was accomplished by instructing the participant to identify and remember the words from one of the two presented categories (e.g., *trees*). This *selection instruction* could take one of several forms, such as "remember the trees." This component was designed to engage procedures involved in identifying exemplars from one category, while concurrently requiring participants to maintain the memory load. The third component was recall of the words that participants were instructed to remember (e.g., *oak*, *elm*). The fourth component consisted of a series of *same-different* category verification frames in which two exemplars were presented and the participant determined whether the stimuli were exemplars of the same category (e.g., *oak elm*) or different categories (e.g., *diamond uncle*). Importantly, stimuli presented in the memory load (component 1) were not later presented in the category verification frames; instead, stimuli presented in the verification frames were exemplars from the memory load categories that were not previously presented (e.g., *maple*). Therefore, each new category verification frame contained exemplars from one of three categories: the *focused* category from the memory load (i.e., the category that participants had been instructed to remember — *trees*), the *ignored* category from the memory load (e.g., *precious stones*), and an *unprimed* category that was not presented in the memory load (e.g., *family members*). Increased facilitation of procedural memory was measured by the difference in response speed to previously processed categories as compared to the unprimed category that was not previously processed. Most important, on average, response times for the category verification were faster for focused than unprimed categories, and substantial individual differences arose in the amount of this facilitation. This facilitation is not due to repetition priming, because exemplars in the memory-load component did not appear in the category verification frames.

Originally, Woltz and Was (2006) were attempting to evaluate models of WM that propose cognitive processing requires efficient access to elements in long-term memory elements (e.g., Anderson, Reder, & Lebiere, 1996; Cowan, 1995; Oberauer, 2002) and hence the task was referred to as the availability long-term memory task. For example, Cowan's embedded processes model of WM assumes that WM consists of a hierarchical structure of long-term memory, a subset of activated long-term memory elements, and a subset of activated long-term memory elements currently in the focus of attention. Woltz and Was attempted to demonstrate that simple processing in the focus of attention would lead to temporally limited residual activation of related but unattended memory elements as described by Cowan. However, across multiple experiments, Woltz and Was (2006, 2007; Was, 2010) ruled out several alternative explanations for individual differences on the ALTM task that relate to the construct of activated long-term memory, such as explanations based on spreading activation, episodic priming, and perceptual priming. Put differently, the ALTM (despite its name) does not appear to measure long-term memory retrieval.

Based on this and other evidence, Woltz and Was (2006, 2007; see also Was, 2010) have proposed this enhanced response speed was in part due to the facilitation of a specific memory procedure (called *procedural memory*). Procedural memory here is akin to a condition-action rule or production as conceptualized in ACT-R (Anderson, 1995). Anderson's (1993) model of memory differentiates between the semantic components of declarative memory and procedural