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Removal of information from working memory: A specific updating process

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ABSTRACT

Previous research has claimed that working memory (WM) updating is one of three primary central executive processes, and the only one to reliably predict fluid intelligence. However, standard WM updating tasks confound updating requirements with generic WM functions. This article introduces a method for isolating a process unique to WM updating, namely the removal of no-longer relevant information. In a modified version of an established updating paradigm, to-be-updated items were cued before the new memoranda were presented. Overall, longer cue-target intervals—that is, longer time available for removal of outdated information—led to faster updating, suggesting that people can actively remove information from WM. Experiments 1 and 2 demonstrated that well-established effects of item repetition and similarity on updating RTs were diminished with longer cue-target interval, arguably because representational overlap between outdated and new information becomes less influential when outdated information can be removed prior to new encoding. Experiment 3 looked at individual differences, using the reduction of updating RTs to measure removal speed. Removal speed was measured reliably but was uncorrelated to WM capacity. We conclude that (1) removal of outdated information can be experimentally isolated and measured reliably, (2) removal speed is a unique, active WM updating ability, and (3) the view of WM updating as a core executive process that uniquely predicts fluid abilities is overstated.

Introduction

Imagine you ask a colleague for his phone extension and he replies: "It's 3266. No, hang on, in my new office it's actually 3257". Ideally, one should easily discard the last two digits of the outdated information given (i.e., "66") and replace them in working memory with the correct digits (i.e., "57"). However, this updating of working memory content is no trivial task, and outdated information often continues to affect memory (De Beni & Palladino, 2004; Oberauer, 2001).

Working memory updating has been identified as one of three primary central executive processes Miyake, Friedman, Emerson, Witzki, Howerter, & Wager (2000). Updating has been claimed to be the only executive process to predict fluid intelligence (Chen & Li, 2007; Friedman et al., 2006). However, most updating tasks used in previous research (e.g., Miyake et al., 2000) not only require memory updating but arguably also measure general working memory (WM) abilities. This has led some researchers to conclude that updating tasks constitute reliable assays of general WM capacity (Schmiedek, Hildebrandt, Lovdén, Wilhelm, & Lindenberger, 2009; see also Chuderski, Taraday, Nęcka, & Smoleń, 2012; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Martínez et al., 2011).

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This creates an unsatisfactory situation. If WM updating tasks measure just the same as other WM tasks such as complex span tasks, then there is no empirical basis for identifying 'updating' as a separate executive-function factor. Yet, both conceptually and theoretically, updating can be distinguished from maintenance and processing in WM. If updating is to be established as a non-redundant construct, it must be isolated and measured separately from other WM processes.

In a recent individual-differences study, we identified a processing component that was independent of general WM capacity and unique to situations that demanded memory updating (Ecker, Lewandowsky, Oberauer, & Chee, 2010). In that study we analyzed the processing components involved in widely used WM updating tasks, and we identified three separable components: retrieval, transformation, and substitution. The only component process that was unique to WM updating tasks was the substitution of information in memory. To illustrate those components, consider the scenario of a restaurant manager advising a chef early in the evening that they were expecting 20 patrons. If the manager later advised the chef that twice as many guests were expected as before, the chef will need to retrieve the initial expectation (i.e., 20), transform it (i.e., 2 × 20 = 40), and substitute the outdated information with the updated information (i.e., 40). Ecker et al. designed an updating task with eight conditions, fully crossing all possible combinations of retrieval, transformation, and substitution. Applying structural equation modeling to their data, they found that retrieval and transformation operations co-varied with general WM capacity, but that the substitution component did not. This is illustrated by the structural equation model for their updating accuracy data, shown in Fig. 1. This finding was interpreted as showing that substitution is the only process that uniquely represents WM updating, without being "contaminated" by any association with general working memory abilities.

One implication of this analysis is that previous studies measuring WM updating did not separate variance unique to updating from the variance of generic WM processes. As a consequence, the conclusions concerning the predictive relation between WM updating and fluid intelligence (Chen & Li, 2007; Friedman et al., 2006) were arguably not based on a proper measure of WM updating, but may instead reflect the well-known association between higher cognitive functions and general WM capacity (Engle, Tuholski, Laughlin, & Conway, 1999; Oberauer, Schulze, Wilhelm, & Süß, 2005).

In this article, we further decompose the components of WM updating. In Ecker et al. (2010), we suggested that information substitution can be further subdivided into the removal of outdated information and the encoding of new information. For example, the chef would need to

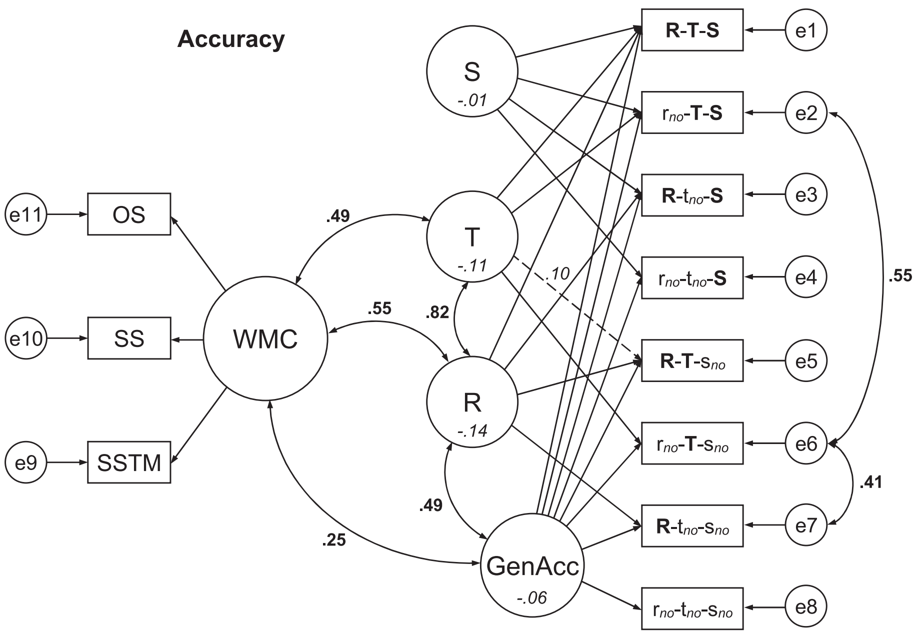

Fig. 1. Graphical representation of the structural equation model of updating accuracy data from Ecker et al. (2010), showing the prediction of latent updating factors GenAcc (general accuracy), R (retrieval), T (transformation), and S (substitution) by a latent working memory capacity (WMC) factor. Manifest accuracy variables reflect log-transformed accuracy data referring to Ecker et al.'s eight experimental conditions, with bold, capital letters implying the process was involved in the condition, and small letters with a 'no' subscript indicating the process was not involved in the condition (e.g., the experimental condition involving all three processes is labeled **R**-**T**-**S**; the condition featuring only a substitution is labeled r_{no}-t_{no}-**S**, etc.). The WMC-related manifest variables reflect mean performance in WM capacity tasks OS (operation span), SS (sentence span), and SSTM (spatial short-term memory). Estimated standardized weights (correlations, in boldface) are presented adjacent to latent connections. Estimated unstandardized means (in log-accuracy units, italicized) are shown inside the latent factors. Means of latent factors that are not given in the figure (error variables and WMC factor) were fixed at 0. Regression weights in the working memory updating (WMU) measurement model were fixed at 1, with the exception of the link between T and the **R**-**T**-s_{no} variable, which was freely estimated (dashed arrow with unstandardized estimate in italics). All estimated covariances provided in the figure are (marginally) significant, $p < .051$; all estimated means are significantly different from 0, $p < .001$. e1–e11 = error variables.