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Contrasting single and multi-component working-memory systems in dual tasking

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ABSTRACT

Working memory can be a major source of interference in dual tasking. However, there is no consensus on whether this interference is the result of a single working memory bottleneck, or of interactions between different working memory components that together form a complete working-memory system. We report a behavioral and an fMRI dataset in which working memory requirements are manipulated during multitasking. We show that a computational cognitive model that assumes a distributed version of working memory accounts for both behavioral and neuroimaging data better than a model that takes a more centralized approach. The model's working memory consists of an attentional focus, declarative memory, and a subvocalized rehearsal mechanism. Thus, the data and model favor an account where working memory interference in dual tasking is the result of interactions between different resources that together form a working-memory system.

1. Introduction

Empirical work has shown that working memory (WM) conflicts between tasks can severely impact overall performance during multitasking (Altmann & Trafton, 2002; Borst, Taatgen, & Van Rijn, 2010; Gray, Sims, Fu, & Schoelles, 2006; Jiang, 2004; Nijboer, Borst, Van Rijn, & Taatgen, 2014; Strayer,

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Cooper, & Turrill, 2013). However, psychological theories of multitasking do not typically address how working memory is used during concurrent task performance in any detail, and consequently, how working memory conflicts can affect multitasking performance. Existing work on multitasking has either described WM as a monolithic, single-component system (Altmann & Gray, 2000; Altmann & Trafton, 2002; Best & Lebiere, 2003a; Borst et al., 2010; Fu et al., 2004; Marois & Ivanoff, 2005; Meyer & Kieras, 1997; Salvucci, 2001; Salvucci & Taatgen, 2008; Wickens, 2002; Zylberberg, Fernández Slezak, Roelfsema, Dehaene, & Sigman, 2010) or not at all (Aasman, 1995; Pashler, 1994; Salvucci, 2005; Schoppek, 2002). This is inconsistent with an increasing number of studies that propose differentiated WM mechanisms consisting of several subsystems, typically a focus-of-attention, an activation-based short-term memory, and modality-specific systems (Baddeley, 2000; Braver & Cohen, 2001; Cowan, 1988, 1995; Ericsson & Kintsch, 1995; Lewis-Peacock, Drysdale, Oberauer, & Postle, 2011; Oberauer, 2002; Unsworth & Engle, 2007; Vosskuhl, Huster, & Herrmann, 2015).

In the current paper, we investigated the role of WM in concurrent multitasking. In particular, we investigated whether a single-component WM is sufficient to explain observed interference patterns in dual-tasks or whether a multi-component WM system is required. We will discuss two experiments, of which we modeled behavioral and neuroimaging results in the shape of a cognitive computer model. We show that a multi-component view of WM that includes a focus of attention, activated short-term memory, and an active rehearsal loop is able to better capture WM use during multitasking than a monolithic WM. Furthermore, the particular WM components, and consequently the interference patterns, vary depending on the particular tasks.

1.1. Background

1.1.1. Task interference

Classical evidence of multitasking costs comes from the Psychological Refractory Period (PRP; Telford, 1931). The PRP paradigm consists of two choice-reaction tasks, of which the stimuli are presented with a short stimulus onset asynchrony. The goal is to respond to the first stimulus (task A) before the second (task B). As the time between the onset of the first stimulus and the second stimulus becomes shorter, the reaction time (RT) for task B becomes longer. This phenomenon can be explained with the response-selection bottleneck model (RSB; Pashler, 1994). The RSB model distinguishes three phases in the component tasks of a dual-task scenario: perception, response selection, and response. The critical assumption is that perception and response can occur in parallel during a dual-task, but response selection can only be performed sequentially (Hazeltine, Ruthruff, & Remington, 2006; Marti, Sigman, & Dehaene, 2012; Pashler, 1994; Sigman & Dehaene, 2008). The RSB model has greatly influenced multitasking research, but it only addresses one particular type of task interference. It cannot, for example, explain interference effects caused by peripheral sources (Wu, Liu, Hallett, Zheng, & Chan, 2013) or memory (Hazeltine & Wifall, 2011; Strayer et al., 2013) or working memory. Working memory interference in particular can be detrimental for performance, as it does not only cause delays in task execution, but can also lead to the forgetting or misremembering of task critical information (Borst et al., 2010; Nijboer, Taatgen, Brands, Borst, & Van Rijn, 2013; Nijboer et al., 2014; Strayer et al., 2013). For example, Strayer and Johnston (2001) found that a complex phone conversation caused drivers to miss traffic signals more than twice as often.

1.1.2. Single or multi-component working memory

Understanding how WM interference affects concurrent task performance requires a detailed model of the WM mechanisms themselves, as well as a good description of how these mechanisms are used within tasks. Recent WM research argues for a multi-component view of WM: for example, Unsworth and Engle (2007) show evidence for a focus of attention combined with an activated short-term memory to retrieve relevant information. Similarly Lewis-Peacock et al. (2011) distinguish the focus of attention from STM, while Vosskuhl et al. (2015) present evidence for a differentiation between WM and STM. These findings are consistent with modern theories of WM (Baddeley, 2000; Braver & Cohen, 2001; Cowan, 1988, 1995; Ericsson & Kintsch, 1995; Oberauer, 2002). In these theories, WM subsystems include elements such as a focus-of-attention, an activation-based short-term memory, or modality-specific systems.