Journal of Memory and Language 62 (2010) 392–406

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Working memory capacity: Attention control, secondary memory, or both? A direct test of the dual-component model

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ARTICLE INFO

Article history:
Received 27 March 2009
revision received 28 January 2010
Available online 24 February 2010

Keywords:
Working memory capacity
Attention control
Secondary memory
Fluid intelligence

ABSTRACT

The current study examined the extent to which attention control abilities, secondary memory abilities, or both accounted for variation in working memory capacity (WMC) and its relation to fluid intelligence. Participants performed various attention control, secondary memory, WMC, and fluid intelligence measures. Confirmatory factor analyses suggested that attention control, secondary memory, and WMC were best represented as three separate, yet correlated factors, each of which was correlated with fluid intelligence. Structural equation modeling suggested that both attention control and secondary memory accounted for unique variance in WMC. Furthermore, structural equation modeling and variance partitioning analyses suggested that a substantial part of the shared variance between WMC and fluid intelligence was due to both attention control and secondary memory abilities. Working memory capacity also accounted for variance in fluid intelligence independently of what was accounted for by the other two factors. The results are interpreted within a dual-component model of WMC which suggests that both attention control and secondary memory abilities (as well as other abilities) are important components of WMC.

Introduction

Measures of working memory capacity (WMC) such as operation and reading span have consistently been shown to be one of the best predictors of higher-order cognition. In particular, several studies have demonstrated moderate to strong correlations between WMC and higher-order cognitive abilities such as fluid intelligence (Ackerman, Beier, & Boyle, 2002; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Kyllonen & Christal, 1990), reading comprehension (e.g., Daneman & Carpenter, 1980; Daneman & Merikle, 1996), and scholastic aptitude performance (Engle et al., 1999; Turner & Engle, 1989). It is clear from these large scale latent variable studies as well meta-analytic reviews (Ackerman, Beier, & Boyle, 2005; Daneman & Merikle, 1996) that WMC has substantial predictive power in terms of predicting performance on a number of measures. However, the reason for this predictive power remains elusive. Recently, two main types of theories have been put forth to explain the predictive power of WMC. One type of theory suggests that attentional abilities are at the heart of WMC predictive power, while another type of theory suggests that WMC predictive power derives from basic memory abilities. The current study examines the extent to which attention abilities, memory abilities, or both account for WMC's predictive power.

Attention and memory based theories of working memory capacity

The notion that attention and working memory are intimately related has long been a core component of a

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0749-596X/$ - see front matter
doi:10.1016/j.jml.2010.02.001

number of working memory models. These include the notion that both attention control (e.g., Engle & Kane, 2004) and the scope or size of the focus of attention (e.g., Cowan, Fristoe, Elliot, Brunner, & Saults, 2006; Cowan et al., 2005) are important components of working memory and WMC. That is, Engle, Kane, Conway and colleagues (e.g., Engle & Kane, 2004; Kane, Conway, Hambrick, & Engle, 2007) argue that the ability to control attention is an important component of working memory, whereas Cowan and colleagues (e.g., Cowan et al., 2005, 2006) argue that the scope of attention is also an important component of working memory. In particular, Cowan and colleagues argue that the scope of attention is an important determinant of the number of items that can be held in the focus and thus act as a storage component. In the current study we primarily focus on attention control abilities, but will we discuss the importance of Cowan and colleagues' scope of attention view again in the Discussion.

According to attention control based theories of WMC, the primary determinant of individual differences in WMC and the reason why WMC predicts performance on so many tasks is attention control abilities (e.g., Engle & Kane, 2004; Hasher, Lustig, & Zack, 2007; Kane & conway et al., 2007). This corresponds to Baddeley's (1986) concept of the central executive and suggests that the primary underlying construct of interest is attention control capabilities. Indeed, Baddeley (1993) noted that "the central executive component of working memory does not itself involve storage, which produces the apparently paradoxical conclusion that not all working memory studies need involve memory" (p. 167). Thus, attention control, and not memory per se, is the primary component of WMC in these attention based theories. Specifically, Engle, Kane, Conway and colleagues (Engle & Kane, 2004; Kane & conway et al., 2007) have suggested that domain-general attention control abilities are needed to actively maintain task relevant information in the presence of potent internal and external distraction. Attention control is needed to ensure that task goals are maintained in an active state and to prevent attentional capture from other distracting stimuli. According to this attention control theory of WMC, high WMC individuals have greater attention control capabilities than low WMC individuals, and thus are better at actively maintaining information in the presence of distraction. Specifically, Engle and Kane (2004) noted that "when we refer to individual differences in WMC, we really mean the capability of just one element of the system: executive attention. Thus, we assume that individual differences in WMC are not really about memory storage per se, but about executive control in maintaining goal-relevant information in a highly active accessible state under conditions of interference or competition" (p. 149). Thus, these views suggest that although WMC is a multifaceted construct, the primary component in terms of the predictive power of WMC is attention control.

Important evidence for the attention control view comes from numerous studies demonstrating differences between high and low WMC individuals on low-level attention tasks that make little demands on memory. For instance, recent work has demonstrated WMC differences in selective and divided focus in dichotic listening (Colflesh & Conway, 2007; Conway, Cowan, & Bunting, 2001), Stroop interference (Kane & Engle, 2003; Long & Prat, 2002), flanker interference (Heitz & Engle, 2007; Redick & Engle, 2006), voluntary saccade control in antisaccade paradigms (Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Schrock, & Engle, 2004), as well as differences in flexible visual attention allocation (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2004; Poole & Kane, 2009; Sobel, Gerrie, Poole, & Kane, 2007). In each case, high WMC individuals were better at controlling aspects of their attention than low WMC individuals even though demands on memory were low. As such, these studies provide important evidence for attention control theories of WMC and suggest that one major difference between high and low WMC individuals is the ability to control attention.

Additionally, it should be noted that the attention control view of WMC also predicts differences in memory tasks when interference and competition is high (Conway & Engle, 1994; Kane & Engle, 2000; Rosen & Engle, 1997, 1998). According to the attention control view, WMC differences that arise in memory tasks do so because of basic differences in attention control. That is, attention control (or executive attention) is needed to combat interference and engage in a strategic search of memory in these memory tasks. Thus, in this view of WMC, memory differences arise because of differences in attention control. This suggests that a unitary domain-general factor accounts for differences found in both low-level attention tasks and in basic memory tasks (e.g., Engle & Kane, 2004).

Furthermore, attention control theories of WMC suggest that the main reason that WMC correlates with aspects of higher-order cognition (such as fluid reasoning) is because of this variation in attention control. That is, as noted by Engle et al. (1999), "the primary factor contributing to the relationship between measures of WM and gF is controlled attention" (p. 326). Engle et al. (1999) went onto note that in that particular study there were no measures of attention control and thus, the conclusion that attention control was the common factor between WMC and gF was "at best, an educated conjecture" (p. 326). Additionally, Kane, Hambrick, and Conway (2005) noted that "What the field needs now, then, is a latent variable approach to the problem, in which many subjects complete many marker tests of WMC, gF, and attention control. These studies should report the magnitude of the WMC-attention correlation and examine whether the shared variance between WMC and attention accounts for substantial gF variance (and more gF variance than is accounted for by residual variance from WMC or attention constructs" (p. 70). One aim of the current study was to examine this "educated conjecture" and to provide a test of the attention control view as suggested by Engle et al. (1999) and Kane et al. (2005).

In contrast to attention control views of WMC, recent work has suggested that individual differences in WMC and the reason that WMC is related to higher-order cognition is because of basic memory abilities (e.g., Mogle, Lovett, Stawski, & Sliwinski, 2008; see also Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008 for an account based on short-term memory abilities). That is, these theories suggest that attention control and active mainte-