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Unitary or non-unitary nature of working memory? Evidence from its relation to general fluid and crystallized intelligence

Cai-Ping Dang [a], Johan Braeken [b], Emilio Ferrer [c], Chang Liu [d,*]

[a] Department of Psychology, Guangzhou Medical University, China
[b] Department of Methodology and Statistics, Tilburg University, The Netherlands
[c] Department of Psychology, University of California Davis, USA
[d] Department of Psychology, Nanjing Normal University, China

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ABSTRACT

This study explored the controversy surrounding working memory: whether it is a unitary system providing general purpose resources or a more differentiated system with domain-specific sub-components. A total of 348 participants completed a set of 6 working memory tasks that systematically varied in storage target contents and type of information processing, as well as a set of 6 tests measuring general fluid intelligence and general crystallized intelligence. A structural equation modeling approach formalized and tested the theoretical expectations of the differentiation perspective on working memory. Visuo-spatial working memory was found to be more strongly correlated with general fluid intelligence than with general crystallized intelligence, and vice versa for verbal–numerical working memory. Additionally, general fluid intelligence was more strongly correlated with visuo-spatial working memory than with verbal–numerical working memory, and vice versa for general crystallized intelligence. These patterns of relationships supported the argument that working memory is not a simple unitary system, but can be differentiated in domain-specific components which are visuo-spatial working memory and verbal–numerical working memory.

1. Introduction

The term *working memory* (WM) refers to the ability to store and manipulate information simultaneously (e.g., Baddeley, 1986). This is a crucial part of our cognitive ability to think and solve problems in daily life. It is therefore no surprise that WM or working memory capacity (WMC) proved to be a good predictor of the performance on various complex tasks and had even been assumed to serve as a "bottleneck" that limits higher cognitive abilities such as intelligence (Süβ, 2001).

The exact nature of this WM system is still a long-lasting controversial topic (Miyake & Shah, 2003, pp5–6). The main controversy is whether WM consists of a unitary system with a single pool of general purpose resources that can be used for a variety of cognitive processes across different domains or whether WM is a more differentiated system with separate domain-specific resource pools. In search for supporting evidence, both theoretical perspectives explored the link between WM and intelligence (for a review on individual differences research on WM see e.g., Jarrold & Towse, 2006; g: Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; RAPM: Wiley, Jarosz, Cushen, & Colflesh, 2011; fluid intelligence: Engle, de Abreu, Conway, & Gathercole, 2010; reasoning: Buehner, Krumm, & Pick, 2005; IQ: Allowaya & Passolunghib, 2011; intelligence: Ackerman, Beier, & Boyle, 2005).

Research within the unitary perspective relates all kind of WM measures to general intelligence (g) or general fluid intelligence (Gf) to support their claim of a single pool of general purpose WM resources. These studies show that both constructs, WM and Gf (or closely related higher cognition constructs), share a considerable percentage of common variance (35%: Engle, Tuholski, Laughlin, & Conway, 1999; 36%:

* Corresponding author. Tel./fax: +86 25 86212351.
E-mail addresses: liuchang@njnu.edu.cn, cglew@163.com (C. Liu).

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Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; 48% and 50%, Colom, Flores-Mendoza, & Rebollo, 2003; 64%: Kyllonen & Christal, 1990; Colom et al., 2003; 72%: Oberauer, Schulze, Wilhelm, & Süß, 2005). Moreover, Engle (2002) goes so far as to claim that WM tasks measure a construct fundamentally important to higher-order cognition, and that it might even be isomorphic to Gf and executive attention. In sum, several investigators have claimed over the past decade that WM and g were identical, or nearly identical, constructs, from an individual-differences perspective (Ackerman et al., 2005). Obviously, these findings indirectly supported the unitary resource position of WM.

In contrast, the differentiation perspective builds on Baddeley's (1986) influential model of WM. The model postulates that distinct and separable spatial and verbal systems serve as "slaves" for a central control structure called "central executive." The visuo-spatial sketchpad is the slave system responsible for generating and maintaining visuo-spatial information and mental imagery. The second slave system is the phonological or articulatory loop which is specialized in the maintenance of speech based verbal information. Clearly, WM differentiation in visuo-spatial and verbal aspects is a tenet of Baddeley's model. Research within the differentiation perspective concentrates on relating specific working memory measures to specific intelligence measures. For example, Jurden (1995) found that verbal WM had no relationship with nonverbal intelligence, whereas nonverbal WM was unrelated to verbal intelligence and academic achievement. Shah and Miyake (1996) indicated that spatial WM span correlated with spatial visualization ability (but not with verbal ability) and a reading span test correlated with verbal ability (but not with spatial ability). Furthermore, a two faceted structure of WM in terms of processing and storage contents was shown to parallel the structure of abilities in the Berlin Intelligence Structure model (Süβ, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Haavisto and Lehto (2004) indicated also that verbal WM relates to verbal ability and learning at school, while visuo-spatial WM was related to nonverbal reasoning and spatial visualization.

Hence, there is some contrast in those results across the reported studies in the literature, and the issue whether or not WM is supported by different pools of resources is certainly not a closed one. See for instance a recent discussion, where Mackintosh and Bennett (2003) stressed the importance of the domain specificity of WM and showed that WM is at least in part domain-specific with three domains: the verbal, the spatial, and the numerical (mental counters), corresponding to Gc (vocabulary test), Gv (mental rotation test), and Gf (abstract reasoning) respectively. With a re-examination of Mackintosh and Bennet's data, Colom and Shih (2004) rebutted against them with an opposite conclusion, stressing the general aspect of WM through a very high correlation which is observed among these second-order latent factors.

In order to analyze the unitary or not-unitary nature of WM, it is necessary to systematically examine individual differences in WM, from different types of information processing and target memory contents, and their relationship to performance on a variety of cognitive tasks that place high demands on WM.

A prototypical example of such highly demanding cognitive tasks are intelligence tests. Although that there is still similar controversy between domain-specificity and unitarity conceptualizations of intelligence, there is a tendency for a consensus towards established psychometric-based models such as the Cattell–Horn Gf–Gc and the Carroll Three-Stratum (see e.g., a recent editorial of McGrew, 2009). Even a more recent contender in terms of a verbal, perceptual, and visual rotation domain (VPR; Johnson & Bouchard, 2005) can be considered to be member of this larger family.

In this study we consider the two-divisions in general fluid intelligence (Gf) and general crystallized intelligence (Gc) given its utility in practice in academia or on the work floor. Gc represents culturally relevant knowledge and skills, such as reading or arithmetic, and verbal abilities which are the result of cultural influence. Gf is involved in working out a novel solution, particularly mentally effortful reasoning processes are required (such as inference, induction, abstraction, or synthesis), but not in simply remembering a previous solution. To measure Gf, more abstract visual problems tend to be used to avoid the culture-verbal aspect of Gc. Hence, this two-divisions in Gf and Gc, allow us to look at highly demanding cognitive tests that are either somewhat more abstract visual or that tend to be more concrete verbalized.

If the different types of WM tasks predict equally well the performance on these established intelligence domains, it may suggest the existence of a single pool of general purpose resources that can be used for a variety of cognitive processes across different domains. Hence, a unitary system perspective would implicate that WM is related to both intelligence types, regardless of the type of WM task.

In contrast, the differentiation perspective would imply that Gf more strongly relates to WM tasks that call upon abstract visuo-spatial resources and processes, and that Gc more strongly relates to WM tasks that call upon concrete verbal–numerical resources and processes. In other words, both Gf and Gc are supported either by domain-specific pools of WM resources or by a single pool of general purpose WM resources.

In short, the current study looks at a broad variety of WM tasks that systematically call on different types of resources and at their relationship to two established intelligence constructs, Gf and Gc. Tests for both types of intelligence place high demands on WM, but at least theoretically would require a different pool of WM resources.

The main strength of the current study is that exactly these two rival theories, the unitary vs. the differentiation perspective, will be formally tested on the latent factor level and this based upon a set of WM tasks that systematically vary in storage target contents and in type of information processing.

2. Method

2.1. Participants

A total of 348 college students (180 males, 168 females) from three Chinese universities participated in the study. The sample consisted of native Chinese speakers, aged between 18 and 22. Some of them received payment for their participation and some volunteered to participate. Written informed consent was obtained prior to the study. Twelve additional cases that took part in the study were removed as