Intelligence 53 (2015) 166–180

Contents lists available at ScienceDirect

Intelligence

The relation between a multicomponent working memory and intelligence: The roles of central executive and short-term storage functions

Peera Wongupparaj [a,*], Veena Kumari [a,b], Robin G. Morris [a]

[a] Department of Psychology, Institute of Psychiatry, Psychology, and Neuroscience, King's College London, UK
[b] NIHR Biomedical Research Center for Mental Health, South London and Maudsley NHS Foundation Trust, London, UK

ARTICLE INFO

Article history:
Received 14 April 2015
Received in revised form 18 September 2015
Accepted 20 October 2015
Available online xxxx

Keywords:
The central executive
Short-term storage
Fluid intelligence
Crystallized intelligence
Latent variable analysis

ABSTRACT

This study examined the relationship among multifaceted functions of working memory, namely central executive functions (shifting, inhibition and updating) and short-term storage components (phonological loop and visuo-spatial sketchpad), and general intelligence in 110 healthy participants using structural equation modelling. The key findings support a multidimensional model of the central executive in showing that updating, inhibition and short-term storage differentially correlate with general intelligence, including both fluid and crystallized intelligence. These results suggest that both processing and storage components of working memory contribute to the relation with general intelligence.

1. Introduction

Working memory (WM) as a concept has proven remarkably fruitful in stimulating experimental studies of cognition (Baddeley & Hitch, 1974, 2007; Cowan, 2005). Pertinent to the research considered here, this includes the relationship between WM and higher cognitive abilities, in particular fluid intelligence (*gF*) or reasoning ability, both in non-clinical and clinical populations (e.g. Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Fukuda, Vogel, Mayr, & Awh, 2010; Mogle, Lovett, Stawski, & Sliwinski, 2008; Shelton, Elliott, Matthews, Hill, & Gouvier, 2010; Unsworth, Fukuda, Awh, & Vogel, 2014; Wongupparaj, Kumari, & Morris, 2015). Some researchers have concluded that WM and general intelligence (*g*) or *gF* are almost isomorphic constructs, found to be closely correlated when considering data from samples investigated using different test batteries (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Oberauer, Schulze, Wilhelm, & Süß, 2005; Shelton, Elliott, Hill, Calamia, & Gouvier, 2009). Others, however, have reported that associations between WM and performance on tests of overall cognitive ability are more variable, with the correlation coefficients ranging approximately from 0.60 to 0.90, and thus suggesting that WM is possibly not tantamount to *g*, *gF*, or any other group factor for intelligence (Ackerman, Beier, & Boyle, 2005; Beier & Ackerman, 2005; Kane, Hambrick, & Conway, 2005), the two aspects being conceptually distinct (Alloway, Gathercole, Willis, & Adams, 2004; Engel de Abreu, Conway, & Gathercole, 2010; Mackintosh & Bennett, 2003).

Consequently, there has been debate concerning the precise contribution of WM specific-components or mechanisms to higher cognition (Conway & Getz, 2010; Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Nisbett et al., 2012), especially which WM model or framework that might be applied to understanding associated complex cognitive processes. As Baddeley (2012) has indicated recently, the overall concept of WM requires further investigation and elucidation since, despite considerable process, it is still in part understood only within a loose theoretical framework rather than through precise modelling that leads to specific predictions.

1.1. The central executive of WM and related concepts

One of the most prominent models of WM includes, as a main feature, the Central Executive System (CES) (Baddeley, 2007; Baddeley, Eysenck, & Anderson, 2009). In essence, it functions to direct attentional focus during task performance, dividing and switching between concurrent tasks or important target information if required, and additionally integrating WM and long-term memory (LTM). Originally, the CES concept was deliberately homunculus like and underspecified (Baddeley & Hitch, 1974), but a more fine-grained concept was later developed to fractionate individual functions, including using an individual difference

* Corresponding author at: Department of Psychology, P078, Institute of Psychiatry, Psychology and Neuroscience, King's College London, De Crespigny Park, London SE5 8AF, UK.
E-mail address: Peera.wongupparaj@kcl.ac.uk (P. Wongupparaj).

http://dx.doi.org/10.1016/j.intell.2015.10.007
0160-2896/

perspective and functional neuroimaging (Bledowski, Kaiser, & Rahm, 2010; Cowan, 1999, 2005; Oberauer, 2010; O'Reilly, Braver, & Cohen, 1999; Smith & Jonides, 1999). An example of the individual differences approach, used here, is the framework developed by Miyake et al. (2000) who proposes a general set of executive functions (EFs) relating to WM that mirror those attributed to the CES, and are described as correlated but separable components, namely: (1) Inhibition of prepotent responses – "inhibition" – the ability to deliberately suppress dominant, automatic/prepotent responses, (2) updating WM representations – "updating" – the ability to monitor and code task relevant incoming information and then update as appropriate by replacing old, no longer relevant information with newer, more relevant information, and (3) shifting between tasks or mental sets – "shifting" – the ability to flexibly switch back and forth between concurrent tasks, operations or mental sets.

This approach by Miyake et al. (2000) provides an influential taxonomy of working memory EFs, and this is supported not only by individual differences data but also by cognitive neuroscience studies (Nee et al., 2012). Furthermore, both the CES of Baddeley (2007) and EFs in this framework are comparable in many aspects, especially in their functional roles. For instance, Baddeley (2007) has viewed the CES as a domain-general mechanism that facilitates the action of domain-specific (two subsidiary storages) systems as well as an episodic buffer, with coordinated action solving the task in hand. Indeed, the CES or executive control, although conceived of as unified system is suggested to support several EFs (Baddeley, 1998; Baddeley, Sala, & Robbins, 1996). With the functional compatibility between the two theories, Miyake's EF model may offer an alternative means by which to understand the CES of WM. Additional approaches are in agreement overall, for example, Dehn (2014) recently supported the idea that both WM and general EFs involve inhibition, shifting, focusing, and updating. In addition, Logie (2011) also construes the CES as comprising a range of EFs that involve focusing, sustaining attention, task switching, updating, inhibition, encoding, and retrieval. Furthermore, in general, the complexities of the CES or EF have been accepted as non-unitary and it has been possible to fractionate the CES into sub-processes or subcomponents in different age groups (Baddeley, 1998, 2007, 2012; Baddeley et al., 2009; Brydges, Fox, Reid, & Anderson, 2014; Kemper & McDowd, 2008; Lehto, 1996; Willoughby, Wirth, Blair, & Family Life Project, I., 2012), albeit there seems to be evidence for unitary construct in very young age as inhibition, with shifting and updating loaded onto the same construct (Brydges, Reid, Fox, & Anderson, 2012; Brydges et al., 2014).

1.2. The EF components and intelligence

Broadly speaking the reason why WM is associated with intelligence has been explained in terms of the dominant role of WM executive control or EFs, as backed by evidence from cognitive neuroscience research (Braver, Gray, & Burgess, 2007; Burgess, Gray, Conway, & Braver, 2011; Duncan, 1995; Engle, Tuholski, Laughlin, & Conway, 1999; Gray, Chabris, & Braver, 2003). For example, Kane, Conway, Hambrick, and Engle (2007) have proposed that the executive attention mechanisms that contribute to WM span are crucial in supporting *gF* because of cognitive demands that go beyond storage and rehearsal functions. This includes the suggestion that, on higher order cognitive tasks, EF attentional control mechanism are required to simultaneously maintain mental representations as a means of dealing with interference or thought and action distraction during intellectual activity (Engle & Kane, 2004).

More specifically, it has been proposed that executive attention and control can explain higher scores on IQ test such as the Raven's Advanced Progressive Matrices (RAPM) because low WM participants are less successful at removing their attention from previously learned rules, resulting in deficiencies in searching new rules, or perseverating in attempts to retrieve and apply ineffective rules (Wiley, Jarosz, Cushen, & Colflesh, 2011). Concerning EF decomposition, the WM-intelligence network may hinge on the components of EFs measured by updating (Belacchi, Carretti, & Cornoldi, 2010; Engle et al., 1999; Friedman et al., 2006; Hull, Martin, Beier, Lane, & Hamilton, 2008; Osório et al., 2012; Atkinson & Berish, 2003; Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009), and inhibitory tasks (Benedek, Franz, Heene, & Neubauer, 2012; Burgess et al., 2011; Atkinson & Berish, 2003; Unsworth et al., 2009); for other aspects such as shifting, the results remain more mixed (Rockstroh & Schweizer, 2001; Salthouse, Fristoe, McGuthry, & Hambrick, 1998; Schweizer, Moosbrugger, & Goldhammer, 2005).

1.3. Temporary storage systems and intelligence

Because some studies have not specifically linked EFs to intelligence (Chuderski, Taraday, Nęcka, & Smoleń, 2012; Friedman et al., 2006; Hill et al., 2013), some researchers have focused on storage capacity, the functional capability for actively maintaining information or chunks of information in mind for subsequent 'online' processing or retrieval (Colom, Flores-Mendoza, Quiroga, & Privado, 2005; Shahabi, Abad, & Colom, 2014). The classical and more recent multicomponent models of WM (Baddeley, 2012; Baddeley & Hitch, 1974; Logie, 2011) stress the connection between main components — in which the CES orchestrates the slave systems specifically involved in short-term storage (STS), such as the as the phonological loop, and the visuo-spatial sketchpad, in turn fractionated further into sub-mechanisms.

Studies of STS mechanisms have indeed shown that STS may drive variation in *g* (Colom, Abad, Rebollo, & Chun Shih, 2005; Colom, Flores-Mendoza, et al., 2005; Oberauer et al., 2005), with one study by Grabner, Fink, Stipacek, Neuper, and Neubauer (2004) finding that STS even outperformed EFs in intelligence prediction. Further, Chuderski et al. (2012) demonstrated that storage capacity is a better predictor than the CES, here considered in terms of scope of attention, inhibition, and relational integration. When STS was partialled out the significant relationship between the scope of attention and *g* no longer existed. More recently, studies using large sample sizes and comprehensive cognitive constructs have demonstrated perhaps a more nuanced picture concerning the relative contributions of STS and EFs; EFs are the main predictor of *gF*, but verbal STS has been found to be the main predictor of crystallized intelligence (*gC*) (Dang, Braeken, Colom, Ferrer, & Liu, 2013; Martínez et al., 2011). Finally, within the overall WM system, the storage and processing components are related, but they both uniquely contribute to variance in *gF* (Logie & Duff, 2007; Unsworth et al., 2009, 2014).

1.4. The present study

It is evident that there is still a lack of clarity about the components and functions of WM that might contribute to intelligence or different types of intelligence. Furthermore, many studies have examined the CES of WM as a unitary construct (Dang et al., 2013; Martínez et al., 2011; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) or infer this construct from common variance between WM and STM (Conway et al., 2002; Engle et al., 1999; Unsworth & Engle, 2007) when considering the relationship with intelligence. There is a need for research that includes sufficient breadth of measurement of EFs and combines this with measures of STS in order to explore the different component contributions to intelligence within the same model, using a multivariate approach. Accordingly, our strategy for this study was to incorporate measurement of the three Miyake et al. (2000) EF constructs, namely inhibition, updating and shifting, combining this with proxy measurements of the main storage components of WM, here the phonological loop system