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The modeling of temporary storage and its effect on fluid intelligence: Evidence from both Brown–Peterson and complex span tasks

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ABSTRACT

The aim of the current study was to achieve a purified representation of the capacity for the temporary storage of information and to examine its relationship with fluid intelligence by means of a novel approach combining experimental manipulations and statistical modeling. A sample of 221 university students completed versions of the Brown–Peterson task and of the complex span task. In each task we manipulated the demands to storage capacity by including three treatment levels in the storage subtask. The distractor subtask was also manipulated. The fixed-links modeling approach was applied to separate the core process representing temporary storage from the auxiliary processes and to link them to measures of fluid intelligence. The results revealed a high correlation between the temporary-storage latent variables of the two tasks. The correlation between fluid intelligence and temporary storage was substantial for both storage tasks. A general temporary-storage latent variable extracted from the two storage tasks accounted for over a quarter of the variance of fluid intelligence. In contrast, the effect of the distractor subtask on memory performance proved to be independent of fluid intelligence. These results suggest that temporary storage is a relevant cognitive process regarding fluid intelligence, whereas coping with distraction is not.

1. Introduction

We define temporary storage as the capacity to hold a small amount of information in a highly accessible state for a short time, which has been investigated in the frameworks of both short-term memory and working memory (e.g., Atkinson & Shiffrin, 1968; Baddeley, 1992; Cowan, 2008). The temporary storage of information is crucial for completing many cognitive tasks since information must be stored for a short time span and must be highly accessible for further processing. Although the importance of information that is readily available for processing and easily accessible is obvious, the evidence concerning its importance for intelligence is not unanimous (e.g., Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002). Furthermore, there is usually no attempt of separating temporary storage from the contributions of other cognitive processes that may lead to the impurity problem in a memory task. Therefore, the major aim of the current study is two-fold: to achieve a purified representation of temporary storage and to examine its relatedness with fluid intelligence by combining experimental manipulations and advanced statistical modeling in considering two distinct memory span tasks, the Brown–Peterson task and the complex span task.

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1.1. Theories on temporary storage

Temporary storage has been considered as an important component within the frameworks of short-term memory and also working memory. For example, in the multi-memory model proposed by Atkinson & Shiffrin (1968), short-term memory (STM) serves as an intermediate agency between sensory memory and long-term memory. Information is transferred from the sensory memory to STM by the assignment of attention. This information can be further transferred from STM to long-term memory if it is rehearsed or processed in an elaborate way. STM has two main characteristics: capacity limitation and temporal decay. It only allows the maintenance of a very limited number of items of information, e.g., seven items plus or minus two according to Miller (1956), and the information lasts for less than about 20 s unless the transient representation is renewed within that timeframe (Peterson & Peterson, 1959).

Temporary storage also plays a key part in the conceptualization of working memory (WM), which is frequently defined as a brain system responsible for temporary storage and manipulation of information (e.g., Baddeley, 1992, 2012). In the influential multicomponent model of WM proposed by Baddeley & Hitch (1974), the two domain-specific storage components, phonological loop and visuospatial sketchpad, are assumed to be responsible for the temporary maintenance of verbal and visuospatial information. In a slightly different way, Cowan (2008) viewed the phonological loop and visuospatial sketchpad as aspects of the activated long-term memory. This alternative account indicates that within the activated portion of memory there is only a smaller subset of items that is in the focus of attention. The focus of attention has a capacity limit of four chunks, each of which may contain more than a single item (Cowan, 2001).

1.2. Temporary storage and fluid intelligence

Temporary storage has been assumed to be crucial for complex cognitive operations that are necessary for completing intelligence tasks (cf. Carpenter, Just, & Shell, 1990), complex learning (e.g., Anderson, Fincham, & Douglass, 1997; Sweller, 2005) and reading comprehension (e.g., Haarmann, Davelaar, & Usher, 2003), among which the relationship between temporary storage and fluid intelligence has received most attention. Fluid intelligence represents one's ability to reason and to solve problems in novel situations (Horn & Cattell, 1967). According to a detailed analysis of performance when completing Raven's Progressive Matrices Test, a frequently used Gf measure, individuals have to generate and maintain several intermediary goals, sub-goals, and hypotheses for arriving at a solution when solving a matrix problem. Since there is a capacity limitation for the number of items that one can maintain, individuals with large capacities are able to solve more complex problems than those with small capacities (Carpenter et al., 1990).

Consistent with the analysis of the Raven test, a few empirical studies indicate positive correlations between temporary storage and measures of fluid intelligence (e.g., Colom et al., 2008; Colom, Flores-Mendoza, Quiroga, & Privado, 2005; Cowan et al., 2005; Martínez et al., 2011; Stauffer, Troche, Schweizer, & Rammsayer, 2014; Unsworth & Engle, 2007a; Unsworth, Fukuda, Awh, & Vogel, 2014; Unsworth, Redick, Heitz, Broadway, & Engle, 2009; Wang, Ren, Altmeyer, & Schweizer, 2013). For example, the study of Colom et al. (2008) observed a latent correlation of .73 between short-term memory and intelligence. In a recent study on the relationship between visual STM and intelligence, Stauffer et al. (2014) showed that individual differences in visual STM retention are positively related to intelligence ($r = .36$ at the latent level). However, there were also studies that used versions of simple span tasks and found only a correlation of .18 between STM and fluid intelligence (e.g., Conway et al., 2002). Furthermore, a number of studies have focused on the speed of STM scanning assessed by the Sternberg task (e.g., Neubauer, Riemann, Mayer, & Angleitner, 1997; Sheppard & Vernon, 2008). A recent review showed that the correlation between the speed of STM scanning and fluid intelligence is only −.15 (Sheppard & Vernon, 2008). However, the STM scanning may reflect just the speed of access to information stored in short-term memory rather than the storage capacity.

One reason that may account for the mixed results is the impurity of the scores obtained by the memory tasks. It has been proposed that most cognitive measures cannot be claimed as completely pure measures of the construct of interest (cf. Miyake et al., 2000; Schweizer, 2007). For instance, the simple span task has been frequently used as a measure of STM (Colom, Rebollo, Abad, & Shih, 2006; Conway et al., 2002; Engle, Tuholski, Laughlin, & Conway, 1999). This task, according to Conway et al. (2002), captures not just the capacity of STM, but also processes associated with attention control. These processes are considered as the WM-specific. In a similar way, Stauffer et al. (2014) conducted a detailed analysis of the visual change detection task and identified four distinct processes of visual STM that are described as STM retention, STM scanning speed, basic aspects of information processing (e.g., the detection and encoding of visual information) and basic processing speed. They found that only the STM retention and basic processing speed are related to intelligence.

1.3. The present study

Given the concern noted above, the current study attempts to achieve a purified representation of temporary storage and to examine its effect on fluid intelligence by employing a novel approach that combines both experimental manipulations and statistical modeling.

The measures adopted by this study were the Brown–Peterson task and the complex span task, both of which have been claimed to assess temporary storage either within short-term memory or working memory (e.g., Jarrold, Tam, Baddeley, & Harvey, 2011; Jonides et al., 2008; Unsworth, 2010; Unsworth & Engle, 2007b). Brown–Peterson task is a classical measure of the temporary storage function of short-term memory (Brown, 1958; Peterson & Peterson, 1959). The task requires an individual to recall a series of letters after a brief delay during which one has to perform distractor tasks (e.g., the mental addition). The complex span task has been frequently used in investigating the storage property of WM (e.g., Engle et al., 1999; Kane et al., 2004). These two tasks show differences regarding the placement of storage and distractor subtasks: the distractor subtask is a single block in the Brown–Peterson task whereas in the complex span task it is split up to be interleaved with the storage items. A number