Intelligence 61 (2017) 29–36

Contents lists available at ScienceDirect

Intelligence

Learning and retrieval processes predict fluid intelligence over and above working memory

Tengfei Wang [a,c,*], Xuezhu Ren [b], Karl Schweizer [c,**]

[a] Department of Psychology and Behavioral Sciences, Zhejiang University, Hangzhou, China
[b] School of Education, Huazhong University of Science & Technology, Wuhan, China
[c] Department of Psychology, Goethe University Frankfurt, Frankfurt a. M., Germany

ARTICLE INFO

Article history:
Received 3 August 2016
Received in revised form 14 November 2016
Accepted 24 December 2016
Available online 4 January 2017

Keywords:
Learning
Long-term memory retrieval
Working memory
Fluid intelligence

ABSTRACT

Previous studies have shown that the ability to learn and the ability to retrieve relevant information from long-term memory are closely related to fluid intelligence. However, it remains unclear whether the effect of learning and retrieval processes on intelligence is unique or merely due to the variance shared with working memory. The current study attempted to achieve a relatively purified representation of learning and retrieval processes and to examine whether they predict fluid intelligence beyond working memory. A sample of 220 university students completed a rule-based learning task, the Posner task, two working memory tasks and two fluid intelligence scales. Fixed-links models were used to separate the core processes representing learning and retrieval from the auxiliary processes and to link them with fluid intelligence. Results showed that the learning and retrieval processes contributed significantly to fluid intelligence ($r = 0.38$ and -0.35 respectively). More importantly, both learning and retrieval processes were still predictive of fluid intelligence when working memory was controlled for. These results suggest that the ability to learn abstract rules and the efficiency of retrieving information from long-term memory are two essential components underlying fluid intelligence in addition to working memory.

1. Introduction

A seminal study conducted by Carpenter, Just, and Shell (1990) suggests that two factors may be essential in solving Raven's Matrices: the ability to acquire and apply the rules and working memory capacity. Whereas the role of working memory in fluid intelligence has received a great amount of attention, the role of the ability to learn and apply rules has largely been neglected. Furthermore, the process of selectively retrieving relevant information (e.g., the appropriate rules) from long-term memory has also been regarded as crucial in completing measures of fluid intelligence (Unsworth & Engle, 2007). There are already empirical studies revealing a close relationship between fluid intelligence and performance on complex learning tasks (e.g., Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009; Williams & Pearlberg, 2006) and long-term memory tasks (e.g., Unsworth, 2010; Unsworth, Fukuda, Awh, & Vogel, 2014). However, it remains unclear whether the contribution of learning and retrieval processes to fluid intelligence is unique or merely due to the variance that is shared with working memory. Furthermore, the validity of some results may be questioned since the tasks used to assess specific cognitive processes can be suspected to be impure in nature. Therefore, the aim of the current study is two-fold: (a) to achieve a purified representation of the learning and retrieval processes by using a relatively novel approach combining experimental manipulations and fixed-links modeling, and (b) to examine whether they predict fluid intelligence above and beyond working memory.

1.1. Learning and fluid intelligence

Learning can be conceptualized as the acquisition of new information permanently or the modification of previously stored knowledge (Sweller, 2005). The ability to learn has long been contended as an integral component of intelligence in the early attempts to define intelligence (Buckingham, 1921). However, only a handful of studies were devoted to verifying this theoretical assumption and revealed a rather weak or no correlation between learning and intelligence (Woodrow, 1938, 1946). A common criticism of Woodrow's studies is that the learning tasks were rather simple and unlikely to be correlated with the complex intelligence tasks (Lohman, 1999). Consistent with this criticism, several recent studies indeed demonstrate that fluid

* Correspondence to: T. Wang, Department of Psychology and Behavioral Sciences, Zhejiang University, Tianmushan Road 148, 310028 Hangzhou, China.
** Correspondence to: K. Schweizer, Department of Psychology, Goethe University Frankfurt, PEG, Theodor-W.-Adorno-Platz 6, 60323 Frankfurt am Main, Germany.
E-mail addresses: tfwang@zju.edu.cn (T. Wang), K.Schweizer@psych.uni-frankfurt.de (K. Schweizer).

http://dx.doi.org/10.1016/j.intell.2016.12.005
0160-2896/

intelligence is more strongly related to the rate of learning complex associates (i.e., three-term contingencies) than simple paired-associate learning (e.g., Kaufman et al., 2009; Tamez, Myerson, & Hale, 2008; Williams & Pearlberg, 2006).

Besides the importance of establishing complex associations, the ability to learn abstract rules has also been assumed crucial in solving the items of intelligent tests. According to Carpenter et al. (1990) there are merely five rules underlying most items of Raven's Matrices. During testing individuals are supposed to maintain the rules acquired in completing the early presented items of the test and repeatedly use those rules while solving the later items (Verguts & De Boeck, 2002). Learning occurs in completing problems of intelligence tests since those previously detected rules might facilitate acquiring similar or more complex rules or rule combinations in solving the later presented problems. To put it differently, throughout the test individuals will familiarize themselves with the rules or strategies applied in previous attempts. Therefore, individuals who are able to acquire those rules and apply them fluently during testing are more likely to succeed in solving the items of Raven's Matrices than individuals who are not. Evidence consistent with this assumption comes from a study that linked performance on a rule learning task with Raven's Matrices. Results showed that the capacity to learn complex rules was highly correlated with the position component of fluid intelligence ($r = 0.78$), which was assumed to reflect individual differences in the ability to derive rules from early presented items and use them to solve later items (Ren, Wang, Altmeyer, & Schweizer, 2014).

Nonetheless, learning may be confounded with working memory in predicting fluid intelligence. Both theoretical accounts and empirical evidence suggest a relationship between learning and WM. For example, the four-stage model of skill acquisition (Anderson, Fincham, & Douglass, 1997) suggests that individuals attempt to develop declarative rules for solving problems in the first two stages. During these stages specific examples have to be maintained in working memory for generating abstract rules (see also Sweller, 2005). Some recent studies have directly investigated the relationship between working memory and the ability to acquire rules for categorization. Craig and Lewandowsky (2012) showed that working memory capacity was moderately related to a common category-learning factor based on two categorization tasks. Although the ability to learn abstract rules has been assumed to be crucial for solving intelligence problems (Carpenter et al., 1990; Ren et al., 2014), it is likely that the link between learning and fluid intelligence is merely due to its overlap with working memory.

1.2. Retrieval of information from long-term memory and fluid intelligence

Furthermore, there have been considerable research interests in memory retrieval and in exploring whether memory retrieval is crucial for performance of fluid intelligence tests (e.g., Beier & Ackerman, 2004; Carroll, 1993). Memory retrieval is regarded as the process of retrieving relevant information from long-term memory, and has been assumed important for high-order cognitive functioning. Solving problems of intelligence tests such as Raven's Matrices requires participants to test a set of hypotheses before arriving at the best solution. As the complexity of problems increases, more intermediary goals and hypotheses have to be generated and tested. Given that working memory only allows approximately four items to be held simultaneously (Cowan, 2010), the extra information is likely to be displaced from the focus of attention and transferred into long-term memory. Therefore, one has to retrieve relevant information efficiently from long-term memory in order to solve the reasoning problems (Shelton, Elliott, Matthews, Hill, & Gouvier, 2010). Empirical studies using measures of long-term memory and intelligence do report positive correlations between memory retrieval and fluid intelligence (Beier & Ackerman, 2004; Carroll, 1993; Unsworth, 2010).

Recent theoretical and empirical work regarding secondary memory has also highlighted the retrieval process and its role in working memory and fluid intelligence (Mogle, Lovett, Stawski, & Sliwinski, 2008; Shelton et al., 2010; Unsworth, Brewer, & Spillers, 2009; Unsworth & Engle, 2007; Unsworth & Spillers, 2010; Unsworth et al., 2014). According to Unsworth and Engle (2007) and Unsworth et al. (2014), secondary memory includes the abilities to encode information into long-term memory and to bring relevant information into the focus of attention. Empirical work suggests that secondary memory and working memory represent distinct, but related constructs, and individual differences in working memory are partly accounted for by variations in secondary memory (e.g., Shipstead, Lindsey, Marshall, & Engle, 2014; Unsworth, 2010; Unsworth et al., 2014). Since the memory retrieval process is one of the key processes implicated in completing secondary memory measures, it is assumed that memory retrieval is related to working memory which should be taken into consideration in examining the role of memory retrieval in fluid intelligence.

However, investigating the effect of memory retrieval on intelligence is complicated by the impurity problem associated with measures that have been used to assess the retrieval process. In previous studies the retrieval process was mostly tapped by the secondary memory or long-term memory tasks, in which participants were firstly presented with a set of to-be-remembered (TBR) items and required to recall or recognize them after a short delay (e.g., Shelton et al., 2010; Unsworth, 2010; Unsworth et al., 2014). Unfortunately, performance on these tasks not only reflects the process of retrieval per se, but also the other memory processes like encoding (see Lilienthal, Tamez, Myerson, & Hale, 2013; Mogle et al., 2008; Unsworth, 2010). According to the levels-of-processing model (Craik & Lockhart, 1972), for example, the accessibility of information stored in long-term memory is assumed to be a function of the depth of mental processing while storing information into memory. Therefore, there is a high possibility that individuals who perform well in the secondary memory tasks are better at forming elaborate and long-lasting memory traces via deep mental processing of the TBR items, irrespective of the capability of retrieval.

One solution that is assumed to avoid the potential confound of encoding processes with the retrieval process is to use over-learned information as the to-be-retrieved items to measure the retrieval process. The Posner task (Posner, Boies, Eichelman, & Taylor, 1969; Posner & Mitchell, 1967) is such a task that is especially in accordance with this demand. In the original Posner task, individuals are presented with pairs of items and are asked to determine whether the two items are "same" or "different" according to specific requirements. Highly overlearned letters are usually used as stimuli. For instance, one experimental condition is to determine whether "A" and "a" are semantically identical. This task requires one to access and retrieve the two letters embedded in an already available web of information. The reaction times obtained by the Posner task are usually used to represent one's efficiency of retrieval.

1.3. The present study

To summarize, accumulating evidence suggests that both learning and retrieval processes play an important role in fluid intelligence. Nonetheless, given that working memory serves as one of the most powerful predictors of fluid intelligence (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Martínez et al., 2011) and working memory is also related to complex learning (Craig & Lewandowsky, 2012; Wang, Ren, Altmeyer, & Schweizer, 2013) and long-term memory retrieval (Unsworth, 2010), it seems likely that there is an overlap between the contribution of learning and retrieval processes as well as working memory to fluid intelligence. The current study seeks to provide an answer to the question whether learning and retrieval processes uniquely predict fluid intelligence when working memory is statistically controlled.