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# Does the modality of measures influence the relationship among working memory, learning and fluid intelligence?

Florian Zeller *, Tengfei Wang, Siegbert Reiß, Karl Schweizer

*Goethe University Frankfurt, Department of Psychology, Theodor-W.-Adorno-Platz 6, 60323 Frankfurt a. M., Germany*

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ABSTRACT

The current study examined the influence of modality on the relationship between learning and fluid intelligence in order to provide an account of disparate research results: on one hand there are results suggesting a moderate relationship between learning and fluid intelligence, whereas on the other hand there are results proposing no such relationship. We applied both figural and verbal measures for tapping learning and fluid intelligence and compared the correlations. Further, working memory, which also was measured by figural and verbal tasks, was included as a common cognitive source and therefore expected to explain the correlation between learning and fluid intelligence. Results showed that there was a substantial correlation between learning and fluid intelligence when the measures showed the same modality. Working memory, showing the same modality, explained this relationship to a larger extent than when working memory showed a different modality. These results suggest that modality has an impact on the relationships between fluid intelligence, learning and working memory.



## 1. Introduction

Investment Theory (Cattell, 1963) describes Cattell's idea of the development of intelligence as long-term effect of fluid intelligence on crystallized intelligence. Fluid intelligence refers to the ability to solve problems in new situations where previous knowledge or experience is of little avail, whereas crystallized intelligence is a function of acquired knowledge that is based on prior experience. Both are included in the most recent models of the structure of intelligence (e.g., McGrew, 2009). Since crystallized intelligence heavily draws on the acquired knowledge base, a revised version of Investment Theory includes learning as mediator (Schweizer & Koch, 2002). However, whereas the link between learning and crystallized intelligence is obvious, the relationship between fluid intelligence and learning needs further specification. A recent study suggests that working memory may serve as the source that drives the relationship between fluid intelligence and learning (Wang, Ren, Altmeyer, & Schweizer, 2013). This source suggests modality-unspecific processing, which is contradicted by evidence indicating that modalities stimulated by applied measures influence the relationship between fluid intelligence and learning (e.g., Alexander & Smales, 1997). Therefore, an intriguing question is whether the relationship between the two constructs is affected by domain-general or domain-specific properties of working memory. The present study seeks to answer this question by examining the relations between fluid intelligence, learning, and working memory taking into account different modalities of measures.

### 1.1. Relationship between learning and fluid intelligence

Theories of intelligence highlighted the ability to learn as an important aspect of intelligence since the time of the early conceptualization of intelligence (Buckingham, 1921). In particular, Investment Theory implies that the acquisition of specific crystalized abilities such as vocabulary and arithmetic knowledge is mainly due to the investment of fluid intelligence and this investment is realized via learning (Schweizer & Koch, 2002). However, the empirical findings regarding the correlations between performance on learning and fluid intelligence measures are inconsistent. For instance, Woodrow (1938, 1946) found rather weak or no correlations between performance in a variety of learning tasks and intelligence scores, whereas more recent studies reveal significant relationships of fluid intelligence with associative learning (Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009; Tamez, Myerson, & Hale, 2012; Williams & Pearlberg, 2006) and complex learning (Ren, Wang, Altmeyer, & Schweizer, 2014; Wang et al., 2013).

The inconsistency regarding the relationship between fluid intelligence and learning may partly be due to the differences between the modalities to which the measures refer. In an investigation of the relation between learning and fluid intelligence, Alexander and Smales (1997) administered a battery of verbal and figural measures of learning and fluid intelligence to 45 adults. They found that the sum score of verbal and figural learning tasks was significantly correlated with that of

* Corresponding author.
*E-mail address:* zeller@psych.uni-frankfurt.de (F. Zeller).

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verbal and figural fluid intelligence ($r = 0.48$). A closer inspection, however, revealed that the correlation of verbal learning with verbal fluid intelligence ($r = 0.56$) was significantly higher than with figural intelligence ($r = 0.03$), suggesting that the modality of measures may contribute to individual differences in learning and fluid intelligence.

If the modality of measures exerts an influence on the relationship between learning and fluid intelligence, the question is: Which cognitive processes cause this relationship if modalities are similar, but diminish it if not? We consider working memory as a potential cognitive basis of the overlap between the two constructs since it has been considered as one of the most powerful predictors of fluid intelligence and learning, and there are both domain-general and domain-specific accounts of working memory (Kane et al., 2004).

### 1.2. Working memory as cognitive basis of fluid intelligence and learning

Working memory refers to a system that is responsible for temporary storage and manipulation of information. It is assumed to be indispensable for a series of complex cognitive abilities such as reasoning, learning and reading comprehension (Baddeley, 1986). In the past two decades, the relationship between working memory and fluid intelligence has been vastly investigated. Meta-analytical research based on a great number of studies estimated that working memory and fluid intelligence share from approximately 25% (Ackerman, Beier, & Boyle, 2005) to 72% (Oberauer, Schulze, Wilhelm, & Suss, 2005) of variance at the latent level. Recent studies reveal that working memory contributes to the learning of categories (Wang, Ren, & Schweizer, 2015), abstract rules (Wang et al., 2013) and associations between words or figures (Kaufman et al., 2009).

However, there are two main lines of arguments suggesting different patterns of the relationship between working memory and higher-order cognitive abilities. One line of studies proposes that working memory is domain-specific in nature, which has been highlighted by the multi-components model of working memory. In this influential model proposed by Baddeley and Hitch (1974), working memory consists of two domain-specific storage components responsible for storing different modalities of information. According to this view, verbal and visuospatial working memory should be related to verbal and visuospatial cognitive abilities respectively. However, the other line of studies insists on the domain-general nature of working memory, i.e., executive attention (Engle & Kane, 2004), which characterizes the relationship of working memory and higher order cognitive abilities. Both arguments have been supported by empirical studies. In line with the domain-specific account, Shah and Miyake (1996) demonstrated that the reading span task predicted verbal aptitude tests ($r = 0.45$) more strongly than did the spatial working memory task ($r = 0.07$). In contrast, the spatial working memory task was more strongly correlated with visuospatial aptitude tests than the reading span task. However, Kane et al. (2004) indicated that verbal and visuospatial working memory measures reflected a primarily domain-general construct, which served as a strong predictor of general fluid intelligence but a weak predictor of domain-specific reasoning. Although the two lines of arguments seem to oppose each other, they are not mutually exclusive depending on the preferred concept of working memory. Working memory may comprise both a domain-general component as well as domain-specific component. Or, if a more restrictive concept of working memory is preferred, working memory may be seen as domain-general but recruits domain-specific processes when working on a task.

### 1.3. The current study

The current study focuses on how different modalities of measures affect relationships among working memory, learning and fluid intelligence. Specifically, we examined whether the relationship between learning and fluid intelligence could be better explained by working memory when the modality of the measures was taken into consideration.

## 2. Method

### 2.1. Participants

The sample consisted of 145 university students who either received course credits or financial rewards for taking part in the study. About one third (34.5%) of the participants were male, and the age ranged between 18 and 49 years ($M = 24.23$, $SD = 5.08$).

### 2.2. Measures

#### 2.2.1. Exchange Test (EX)

The Exchange Test was employed as a measure of visuospatial working memory (Schweizer, 1996, 2007). Each item consisted of two rows of four symbols. The symbols in each row were identical but presented in different orders (see Fig. 1). Participants were asked to mentally exchange the adjacent symbols in one row until the symbols showed the same sequence in both rows, and count the number of necessary exchanges. Regarding the example presented in Fig. 1 one can move the cross-symbol three times successively in order to get it from the very left to the very right side. After that, one additional exchange was necessary based on the newly generated sequence of symbols: the circle and the flower symbol had to be exchanged. Accordingly, a total of four exchanges was necessary for this item. Participants should press the response key as soon as they finished the (mental) reordering and enter the counted number. In total, the test included five treatment levels requiring one to five exchanges. There were 12 items in each treatment level. Both accuracy and reaction time were coded.

#### 2.2.2. Backward counting task (BC)

The BC task was used to measure verbal working memory. Via headphones, a sequence of two, four, or six numbers was presented to the participants. Afterwards, participants had to enter these numbers in reversed order via the keyboard. The percentage of correct responses was computed.

#### 2.2.3. Star counting task (SC)

This task was adapted from the SC task which was originally designed to assess the central executive property of working memory (de Jong & Das-Smaal, 1990; de Jong & Das-Smaal, 1995). Since number updating was required it was considered as a task to tap verbal working memory. For each item, a starting value and five rows containing five symbols each were presented (see Fig. 2). For every star (*) within the sequence of symbols, the participants should either add or subtract one from the starting value, depending on whether the star was preceded by a plus (+) or a minus sign (−). In between there were diagonal slashes (/) which should be ignored. The SC test included two treatment levels: the easier treatment level demanded plus counting only, whereas in the more difficult treatment level both plus and minus counting were required. For each treatment level 12 items were included. The difference in reaction time between the second and the first treatment level served as dependent variable.

**Fig. 1.** Illustration of an item of the Exchange Test requiring four exchanges.