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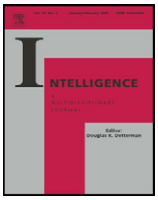

Contributions of associative learning to age and individual differences in fluid intelligence[☆]

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ABSTRACT

According to the cognitive cascade hypothesis, age-related slowing results in decreased working memory, which in turn affects higher-order cognition. Because recent studies show complex associative learning correlates highly with fluid intelligence, the present study examined the role of complex associative learning in cognitive cascade models of data from adults aged 30–80 years. Path analyses revealed that an extended cascade model, in which associative learning mediated the relation between working memory and fluid intelligence, provided an adequate fit to the data. Moreover, an alternative extended cascade model, one with an additional path from speed to fluid intelligence and separate learning and secondary memory components, provided an excellent fit. These findings establish a role for complex associative learning in the extended cognitive cascade underlying age and individual differences in fluid intelligence.

1. Introduction

Age-related changes in fluid intelligence (gF) are hypothesized to be the result of a cognitive cascade in which changes in processing speed lead to changes in working memory, which then result in changes in higher-order cognitive function (Kail & Salthouse, 1994). In children, developmental gains in processing speed are associated with increased working memory and improvements in reasoning and problem solving (Fry & Hale, 1996; Kail & Hall, 1999), whereas in adults, age-related slowing is associated with decreased working memory and a decline in reasoning ability (Gregory, Nettlebeck, Howard, & Wilson, 2009; Salthouse, 1996). However, despite considerable research, it is still not completely clear why age and individual differences in working memory are associated with differences in higher-order cognitive abilities, particularly reasoning and gF.

2. Working memory and fluid intelligence

Various hypotheses have been proposed to explain the relation between working memory task and gF. For example, Carpenter, Just, and Shell (1990) pointed out that the more difficult problems on the Raven's Advanced Progressive Matrices (RAPM), sometimes referred to as the "gold standard" of fluid intelligence tests, typically involve more rules. They argued that individuals with greater working memory do better on the RAPM because problems with more rules place a greater load on working memory. However, recent work has not supported this hypothesis. Unsworth and Engle found that the correlation between young adults' working memory and gF not only remained fairly constant as the number of rules that needed to be held in memory to solve a particular RAPM problem increased (Unsworth & Engle, 2005), it also remained fairly constant as the number

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of items to be remembered on the working memory task increased (Unsworth & Engle, 2006). Salthouse and Pink (2008) replicated the latter finding in a cross-sectional study of adults (ages 18–98 years). Thus, working memory predicts performance on both easy and hard RAPM problems about equally well, and *g*F predicts performance on easy and hard working memory trials about equally well. Taken together, these findings suggest that, the amount of simultaneous storage and processing required, although important, is not critical to the correlation between working memory and *g*F.

A second hypothesis regarding the relation between working memory and *g*F involves the ability to control attention. Engle, Tuholski, Laughlin, and Conway (1999) reported that short-term memory tasks, which primarily tap storage ability, were poor predictors of *g*F, whereas working memory tasks, which require coordinating storage and processing operations and thus are presumed to tap controlled attention, were much better predictors. Engle et al. concluded that the ability to control attention in the presence of distraction or interference is responsible for the relation between working memory and *g*F. Subsequently, however, Unsworth and Engle (2006, 2007) found that although recall of short series of items on short-term memory tasks are poorly correlated with *g*F, recall of longer series is as highly correlated with fluid intelligence as recall on working memory tasks. Indeed, Colom and his colleagues have long argued that basic short-term storage abilities are sufficient to account for the relation between working memory and intelligence, presenting reanalyses of key data sets as well as original data to make this point (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Colom, Rebollo, Abad, & Shih, 2006).

Thus, the controlled attention hypothesis, at least as originally proposed, does not appear to provide an adequate explanation for the relation between working memory and *g*F. Recently, Unsworth and Engle (2007) have supplemented the controlled attention account by suggesting that working memory performance relies on the ability to use controlled attention to retrieve information from secondary memory as well as to simultaneously store and process information, implying that the storage and retrieval aspects of working memory tasks may both be important for explaining the relation between working memory and *g*F.

Unsworth and Engle's (2007) new dual-component model is motivated, in part, by results showing that when the number of items to be remembered exceeds the capacity of primary memory, or what Cowan (2001) has called the focus of attention, simple working memory tasks (e.g., digit span) correlate as well with *g*F as complex span tasks (e.g., operation span). Unsworth and Engle hypothesized that this is because under such conditions, simple span tasks require retrieval from secondary memory, just as complex span tasks do, although in the latter case it is because the secondary processing task displaces items from primary memory. Further, Unsworth and Engle's hypothesis is supported by recent studies showing correlations between secondary memory and reasoning ability in both children and adults (DeAlwis, Myerson, Hershey, & Hale, 2009; Mogle, Lovett, Stawski, & Sliwiski, 2008). Other studies, however, suggest that working memory tasks continue to predict unique variance in *g*F even after controlling for the ability to retrieve information from secondary memory (Shelton, Elliot, Matthews, Hill, & Gouvier, 2010; Unsworth, Brewer, & Spillers, 2009). Thus, retrieval from secondary memory appears to explain part of the relation between working memory and *g*F but not all of it.

3. Learning and fluid intelligence

Successful retrieval of information from secondary memory depends not just on retrieval ability, but also on how well information is encoded and/or learned to begin with. Moreover, performance on both working memory and fluid intelligence tests depend on the ability to retrieve (the ability to retrieve to-be-remembered items in the case of working memory tasks, and the ability to retrieve rules in the case of *g*F tasks), with better encoding and/or learning leading to better performance. Therefore, the current study focuses on age and individual differences in learning and how they relate to differences in working memory and *g*F.

Working memory and performance on laboratory learning tasks are correlated in young adults (Kaufman, De Young, Gray, Brown, & Mackintosh, 2009; Tamez, Myerson, & Hale, 2008), and recent evidence suggests that working memory and learning may be correlated in older adults as well. Kirasic, Allen, Dobson, and Binder (1996) studied adults aged 18–87, and not surprisingly, they found that age was negatively correlated with processing speed, working memory, and learning. Importantly, they also found a strong positive correlation between working memory and learning. Further, path analysis revealed that age-related slowing negatively affected working memory performance, which in turn predicted differences in learning ability, but there was no direct effect of either age or speed on learning after accounting for the effect of working memory, suggesting that working memory mediates their effects on learning.

Shelton et al. (2010) suggested that the reason that working memory tasks predict how well individuals learn is because they provide retrieval practice, and retrieval practice benefits learning (Karpicke & Roediger, 2008). This suggestion was based on McCabe's (2008) finding that items from complex span tasks are recalled better after a delay than items from simple span tasks. McCabe argued that participants repeatedly retrieve items from secondary memory on complex span tasks, but not on simple span tasks, and that this covert retrieval practice leads to better learning of complex span memory items (see also Rose, Myerson, Roediger, & Hale, 2010). Applying this idea to individual differences, Shelton et al. suggested that the better individuals are at covert retrieval, the larger their working memory spans will be, and the better they will be at learning. This idea may be extended to age differences: If older adults are poorer at covert retrieval, then their working memory spans will be smaller and they will poorer at learning.

Several recent studies have reported correlations between learning ability and *g*F (Kaufman et al., 2009; Tamez et al., 2008; Williams & Pearlberg, 2006). For example, Williams and Pearlberg found that three-term contingency learning, a form of complex associative learning, was strongly correlated with *g*F ($r \approx .50$), and Tamez et al. and Kaufman et al. reported similar results. Taken together, these findings indicate that in young adults, at least, associative learning is