CONCEPTUAL AND EMPIRICAL RELATIONSHIPS BETWEEN WORKING MEMORY AND INTELLIGENCE

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Introduction

Brief overview of working memory and intelligence

What is working memory? Research in this topic has been growing in recent years, resulting in a proliferation of theories and models of working memory. Miyake and Shah (1999) rightly observed that despite the familiarity of the term working memory, it is “… not easy to figure out what working memory really is.” For instance, cognitive psychologists do not always make the clear-cut distinction between working memory and short-term memory. In view of this state of confusion, Miyake and Shah saw the need to systematically compare and contrast different models of working memory, with the aim of clarifying common misconceptions and misinterpretations of the different models. Although different theorists offer their own ideas about the specific mechanisms of working memory, they generally agree that working memory is “… the theoretical construct that has come to be used in cognitive psychology to refer to the system or mechanism underlying the maintenance of task-relevant information during the performance if a cognitive task.” (Miyake & Shah, 1999).

Garlick (2002) noted that intelligence can be defined in many ways. Thus, it comes as no surprise that there is no consensus regarding its definition. The field of intelligence has developed in recent years to include more modern conceptualizations of intelligence, such as Sternberg’s (1997) idea of analytic, practical, and creative intelligence. In this paper, the scope of intelligence will be limited to psychometric intelligence, whereby intelligence is measured using mental ability tests (Sternberg, Lautrey, & Lubart, 2003). It is important to note that psychometric intelligence does not cover all the capabilities of humans; it is limited to human intellectual abilities. At present, theorists have yet to agree on the fundamental nature of intelligence; whether it is a unitary or multi-factored construct. In the early part of this century, Spearman (1904) observed that intellectual tasks show positive manifold, whereby all tasks are positively correlated with each other to varying extents. Spearman concluded that this finding indicates that there is a general factor, labeled g, that is common to all tests of intellectual ability. In other words, if an individual’s performance on two different intellectual tasks is positively correlated, these tasks are assumed to measure the same kind of intellectual ability.

However, Cattell (1987) disagreed with Spearman’s view of a unitary factor of intelligence. Cattell contended that two separate abilities could be discerned, namely fluid intelligence and crystallized intelligence. He described fluid intelligence tasks as tasks that depended heavily on an individuals’ capacity to reason, manipulate abstractions, and discern logical relationships. The Raven’s Progressive Matrices (RPM) is commonly used to assess fluid intelligence. The RPM consists of 60 patterns composed of abstract shapes, lines, and nonverbal figures, each of which is missing a piece. For each pattern, 6 pieces are presented as choices and individuals are required to choose the piece that fits best in the empty space. Crystallized
intelligence, on the other hand, involves the application of intelligence to learning acquired through education and experience. Tests of crystallized intelligence include Vocabulary and General Knowledge tests.

**Working memory and intelligence: The common link?**

Based on the brief description of intelligence and working memory, it is clear that both are conceptually different from the other. Intelligence refers to the extent to which individuals are able to perform complex cognitive tasks successfully while working memory serves as an important cognitive resource during the performance of complex cognitive tasks. Thus, working memory is often considered a lower-order cognitive ability, while intelligence is regarded as a higher-order cognitive ability.

Conceptual differences notwithstanding, both working memory and intelligence have been shown to be empirically related to academic achievement. In 1904, Alfred Binet and his colleagues developed a measure of intelligence to predict academic achievement in French public schools (Thorndike, 1997). Since then, a major application of intelligence tests remains to determine whether a child’s low level of academic achievement is due to mental retardation or some other cause. In light of the well-known substantial correlation between intelligence tests and academic achievement, Reschly and Grimes (1995; as cited in Flanagan, Andrews, & Genshaft, 1997) indicated that it is appropriate to use measures of current intellectual functioning to estimate current and future academic performance. Flanagan, Andrews, and Genshaft cited several predictive validity investigations using the Wechsler Intelligence Scale for Children – Third Edition, the Kaufman Assessment Battery for Children, and the Stanford-Binet Intelligence Scale: Fourth Edition, which show that intelligence accounts for approximately 25% to 65% of the variance in children’s academic achievement. These findings support the claim that a full scale score from an intelligence test predicts academic achievement moderately to well.

Jurden (1995) examined the relations between tests of working memory and a range of complex cognitive abilities to test the validity of the unitary view of working memory. In this study, Jurden used a reading span task as a measure of working memory, whereas academic achievement was measured by participants’ college entrance examination scores on English, Mathematics, Reading, and Science Reasoning. Regression analyses showed that working memory accounted for 15% of the variance in English, 6% in Mathematics, 7% in Reading, and 8% in Science Reasoning. Further, de Jong and Das-Smaal (1995) reported that working memory is involved in tasks that are indicative of school achievement, such as reading comprehension and arithmetic.

The empirical evidence cited here suggests the possibility that working memory and intelligence are related to each other at some level of analysis even though these constructs are conceptually different. Several theorists have attempted to elucidate the link between working memory and intelligence. Depending on their theoretical slant, researchers postulate different kinds of links between working memory and intelligence. However, most theorists have focused their hypotheses on the central executive component of working memory and fluid intelligence. Currently, there are at least 10 different models of working memory in the research literature. Unfortunately, it is beyond the scope of this paper to address each of these models in detail. The present discussion regarding the relationship between working memory and intelligence will be

**Baddeley and Logie’s multi-component model of working memory**

Baddeley and Logie’s (1999) model provides a theoretical framework for conceptualizing the role of temporary information storage in the performance of a wide range of complex cognitive tasks. Baddeley (2000) described the working memory as a “…limited capacity system allowing the temporary storage and manipulation of information necessary for such complex tasks as comprehension, learning, and reasoning”. The multi-component model comprises an attentional control system known as the central executive, which is aided by two subsidiary slave systems, the phonological loop and the visuospatial sketchpad. The phonological loop and visuospatial sketchpad is responsible for the rehearsal and storage of verbal and non-verbal (visual and spatial) information, respectively.

In 1986, Norman and Shallice (1986) formulated the Supervisory Attentional System (SAS) model to explain how attentional control of action occurs. Norman and Shallice argued that human action is principally controlled by an extensive series of schemas and habits that use environmental cues to allow the performance of routine tasks, such as driving from point A to B. However, in certain circumstances, the SAS is able to interrupt and modify such ongoing, habitual behavior by systematically biasing existing probabilities so as to make one line of action more likely and another line less. In his effort to delineate the central executive’s attentional control characteristics, Baddeley (2002) borrowed from Norman and Shallice’s SAS model. Consequently, Baddeley described three possible processes of the central executive, namely the ability to focus attention on information relevant to the task at hand, ability to divide attention between two tasks, and the capacity to switch attention. In the context of Baddeley and Logie’s (1999) model of working memory, the capacity of working memory is defined as the ability to focus attentional resources effectively in the performance of cognitive tasks.

**The multi-component model: Its relation to fluid intelligence**

de Jonge and de Jong (1996) adopted Baddeley’s (2002) model of the central executive in their study on the relationship between working memory and intelligence. To reiterate, Baddeley claimed that the most important function of the central executive is to activate and inhibit processes in working memory. In line with Baddeley’s view, de Jonge and de Jong used the Star Counting Test (SCT; de Jong & Das-Smaal, 1995) to examine the relationship between this particular function of the central executive and fluid intelligence. The SCT is a counting task, which requires participants to count several rows of stars and alternate between forward and backward counting when they encounter a plus and minus sign, respectively. In short, the SCT measures individuals’ capabilities to activate, modulate, and inhibit the relevant counting process while performing the task. de Jonge and de Jong used a figural analogical reasoning test and categorical thinking test as measures of fluid intelligence. The figural test assesses individuals’ ability to abstract the rule that was used to change figure A to figure B and to use the same rule to determine which figure emerges after figure C was altered using the same rule. On the other hand, the categorical test requires participants to determine the common feature among three pictures of objects, and to choose two other objects that share the same feature with the other three objects.
de Jonge and de Jong (1996) used confirmatory factor analysis to determine the relationship between working memory capacity and fluid intelligence. They found that the correlation between these factors was 0.18, which was rather low, compared to the substantial correlation of 0.66 between working memory capacity (measured using the SCT) and fluid intelligence that was reported by de Jong and Das-Smaal (1995). To account for these differences, de Jonge and de Jong explained that the tests that were chosen for their study did not measure the targeted constructs adequately. Taken together, these results suggest the possibility that there is a relationship between the capacity to activate and inhibit processes in working memory and reasoning ability.

Engle, Tuholski, Laughlin, and Conway’s (1999) controlled attention framework

Engle and his colleagues (Engle, Tuholski, Laughlin, & Conway, 1999) formulated another influential model of working memory, which has been labeled the controlled attention framework. Engle et al. (1999) made a conceptual distinction between short-term memory (STM) and working memory. Specifically, STM consists of items from long-term memory that are above some threshold of activation. Working memory, on the other hand, consists of the items in STM and a controlled attention component. The central executive was identified as the source of controlled attention (Engle et al., 1999), which activates traces from long-term memory through processes of controlled retrieval, activation, and inhibition. In other words, the central executive is one of the components within working memory. Within this theoretical framework, working memory capacity “… reflects the ability to maintain the activation of knowledge units in the focus of attention.” (Engle et al., 1999).

According to Engle et al. (1999), the ease at which elements can be retrieved from memory depends on their levels of activation. At high levels of activation (the active state), elements can be retrieved quickly. Elements in the active state will drop to the inactive state if attention is distracted away from these elements. In situations where there is relatively little interference from competing information, there is a greater chance of successfully retrieving elements in the inactive state. However, under conditions of high interference, it is likely that the retrieval process will be hindered by competing elements. Thus, the capability for controlled attention is particularly important in situations involving interference or distraction in order to ensure that “… the goals and details of the current task [can] be maintained in the active state.” (Engle et al., 1999). For instance, controlled attention is required when task goals may be lost unless they are actively maintained in working memory, where there is value in maintaining some task information in the face of distraction or interference, and when controlled, planful search of memory is necessary or useful.

The controlled attention framework: Its relation to intelligence

Engle et al. (1999) were interested in assessing the relationship between the controlled attention component of working memory and higher order cognitive functioning, such as fluid intelligence. Working memory capacity measures consist of complex span tasks, such as operation span task and reading span task. Complex span tasks require participants to perform a processing task (e.g. calculate arithmetic strings) and retain words or digits to be recalled later. In other words, participants must constantly shift attention between the representation and storage of the list items and the so-called processing component of the task. Cattell’s Culture Fair Test
and Raven’s Progressive Matrices were used as measures of fluid intelligence. Measures of STM capacity were also administered; the tasks consist of forward and backward word span tasks. STM tasks can be performed with relatively little removal of attention from the representation of list items.

In order to test the hypothesis that working memory relates to fluid intelligence, the technique of structural equation modeling (SEM) was used since it allows researchers to specify and test a specific pattern of relationships among latent variables. The SEM analysis revealed that working memory was indeed significantly related to fluid intelligence (path coefficient = .49), even after removing the common variance among working memory and STM (refer to Appendix A). Statistically controlling for the variance shared between working memory and STM tasks leave a residual consisting of a component representing the controlled attention component of the central executive (Engle et al., 1999). Thus, the significant correlation between working memory and fluid intelligence suggests that the critical aspect of working memory that drives the relationship between working memory and fluid intelligence is the controlled attention component or central executive. This result further suggests that as the amount of practice on a task increased, which presumably leads to a decrease in the need for controlled processing, the correlation between task performance and measures of general abilities will also decrease. It is interesting to note that Ackerman (1988; as cited in Engle et al., 1999) found a strong relationship between task performance and general abilities when the participants were not practiced at the task.

Recently, Conway, Cowan, Bunting, Therriault, and Minkoff (2002) conducted a similar study as that of Engle et al. (1999). Conway et al. (2002) were interested in testing two opposing hypotheses regarding the primary predictor of fluid intelligence. Some theorists argued that processing speed accounts for the relationship between WMC and fluid intelligence while others posit that WMC is the primary predictor of fluid intelligence. Proponents of the former view contended that processing speed determines capacity because the faster the rate of processing information, the greater the amount of information that can be processed in one unit of time. Conway et al. used measures of working memory capacity, STM capacity, and fluid intelligence that were similar to those used by Engle et al. Processing speed was defined as the speed at which encoding, transforming, and retrieving processes take place. Measures of processing speed include digit-symbol substitution, digit and letter copying, and pattern and letter comparison tasks; these tasks were chosen because they place minimal demands on memory and attention. Results of SEM analysis revealed that the relationship between working memory capacity and fluid intelligence is strong and significant (path coefficient = .60; refer to Appendix B). However, the path between processing speed and fluid intelligence was not significant (path coefficient = .18). Clearly, Conway et al.’s (2002) finding parallels those of Engle et al. (1999).

Conway et al. (2002) postulated two possible explanations to account for the results of their study. One of the possible explanations is similar to Engle et al.’s (1999) argument that the link between measures of working memory capacity and fluid intelligence is the demand for controlled attention. The other explanation is based on Ericsson and Kintsch’s (1995) theory of long-term working memory, which suggests that individual differences in strategy use contribute to outcome variance in measures of working memory capacity and fluid intelligence. According to Ericsson and Kintsch’s framework, greater working memory capacity is merely the result of greater domain-specific experience, which is associated with a more sophisticated repertoire of strategies. This results in more efficient knowledge representations, which translates into greater capacity and flexibility. Thus, this alternative view argues for the importance of prior domain-
specific experience, instead of controlled attention capacity, in explaining the empirical correlation between working memory capacity and fluid intelligence.

Conclusion

The empirical studies reviewed above show that working memory capacity is reliably correlated with fluid intelligence. The correlation coefficients fall within the range of .60 to .70, which suggests that these conceptually different constructs do share some similarities. Although Engle et al. (1999) and Baddeley and Logie (1999) argue for different theories of working memory, both teams postulate some aspect of attention as being the link between working memory and intelligence. It is interesting to note that researchers have focused their investigations on the kinds of skills and processes required to perform both working memory and intelligence tasks in order to substantiate the claim that working memory and intelligence are related to each other.

Where our own empirical results are concerned, it might prove useful to conduct a detailed task analysis to assess the extent to which our tests of intelligence and working memory tap similar processes and skills. The detailed task analysis could be extended to the math test to ascertain the degree of overlap among these measures of intelligence, working memory, and mathematical performance.

References


Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual difference in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake, & P. Shah (Eds.), *Models of working memory:*. 434


Appendix A
Path model of the relationships between working memory, short-term memory and fluid intelligence factors (Engle, Tuholski, Laughlin, & Conway, 1999).

![Diagram of path model](image)

*Figure 4.* Path model for Model D. Significant paths are indicated by an asterisk. OSPAN = operation span; RSPAN = reading span; CSPAN = counting span; BSPAN = backward span; FSPAN = forward span, dissimilar; FSPANS = forward span, similar; WM = working memory; STM = short-term memory; gF = fluid intelligence.
Appendix B
Path model of the relationships between working memory capacity, STM capacity, processing speed, and fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002).

Fig. 2. SEM2. WM: working memory; STM: short-term memory; SPEED: processing speed; gF: general fluid intelligence. Significant path coefficients are in bold.