The relationship between working memory and cognitive functioning in children.

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Abstract

One-hundred and forty-four Year 1 children (51% boys and 49% girls, mean age 6) from Queensland State primary schools participated in a study to investigate the relationship between working memory and cognitive functioning. Children were given two tests of cognitive functioning (the School-Years Screening Test for the Evaluation of Mental Status (SYSTEMS) and the Kaufman Brief Intelligence Test (K-BIT)) and the Phonological Loop (PL) subtests of working memory from the Working Memory Test Battery for Children (WMTB-C) (Digit Recall, Word List Matching, Word List Recall and Non-word List Recall). The two cognitive tests correlated at $r = .59$. Results showed a high correlation between SYSTEMS and the Phonological Loop (PL) component of working memory ($r = .67$). The K-BIT also correlated reasonably with the PL component ($r = .54$). The SYSTEMS and K-BIT showed various levels of correlation with the working memory subtests. A recursive measurement model showed a strong relationship between working memory and cognitive functioning ($\beta = .83$), the degree of fit for the model was very high at GFI = .965.

For some time, working memory has been known to contribute to the acquisition and processing of language, as well as supporting a whole range of complex everyday cognitive activities including reasoning, language comprehension, long-term learning, and mental arithmetic.

Modern theories of memory contend that the working memory system is divided into multiple components: each component has different capabilities to deal with certain types of information. An example of the multi component approach is Baddeley's research (1981; 1990; 1992). He divided working memory into three major parts: the central executive, the articulatory or phonological loop, and the visuo-spatial sketchpad. It is proposed that the central executive working memory has an overseeing role: it is the control centre of the system; it therefore selects and operates the appropriate cognitive processes. Additionally, the central executive has a storage function with the result that capacity limitations are applicable to this part of the system. Storage also occurs elsewhere in the system, the articulatory loop maintains verbal material through subvocal rehearsal and the visuo-spatial sketchpad conserves imagery and spatial material through visualisation. Lately, a modality-neutral storage component, the episodic buffer, has been put forward to deal with abstract representations of events (Baddeley, 2000).

The Phonological Loop

While less may be known about the functioning of the central executive, research analysing the operations of the slave systems has made significant progress. Because previous research suggested that speech played an important role in short-term memory, Baddeley and Hitch (1974) began investigating a speech based slave system that was peripheral to the central executive, the phonological loop. For instance, prior research by Conrad and Hull (1964) indicated that memory for a list of consonants that had similar sounds, such as B, C, T, G, V, was poorer compared to memory for a list of consonants that had different sounds, such as H, K, L, M, W. This suggested that items were encoded by their sounds, even when the items were presented visually.

Baddeley (1986; 1974) formulated the phonological (or articulatory) loop, which comprises one of two slave systems of his working memory model. The phonological loop consists of two components, a phonological store that holds acoustic or verbal information for one to two seconds, and an articulatory control process that maintains information in the phonological store through subvocalised rehearsal. The articulatory control process can recode visually presented information into a phonological code via subvocalisation (Baddeley, 1992). Thus, the presentation of a picture or written word can be stored in the phonological loop by subvocally repeating the name of the object or the word.

The phonological loop processes verbal or acoustic information and temporarily stores this information through subvocal rehearsal (Baddeley, 1992). Visual information, such as a picture of an object, also can be processed in the phonological loop by vocally or subvocally rehearsing the name of the object. Interfering with the rehearsal of information can reduce dramatically the amount of information recalled and can be used to simulate the performance of recall tasks of neuropsychological patients with impaired memory (Vallar & Baddeley, 1984). In summary, support for a separate phonological slave system within the working memory model is evidenced by the following facts: information is encoded according to sound (Baddeley, Thompson, & Buchanan, 1975), prevention of subvocal rehearsal of information greatly impairs recall performance (Murray, 1967), and the length of time to articulate an item influences how many items can be remembered (Baddeley et al., 1975).

Just as working memory contributes to the acquisition and processing of language, so too does cognitive function. Cognition involves brain activity through thinking (Ellis & Hunt, 1989) that may also be described as information processing. According to Black (2001) cognitive functioning in children may be taken to mean “cognitive manipulation as well as general information and skills” (p.19). In the current study, cognitive functioning involves activity of the brain in the form of thinking and is tested through the retrieval and manipulation of information with the School-Years Screening Test for the Evaluation of Mental Status (SYSTEMS) (Ouvrier, Hendy, Bornholdt, & Black, 2000) and the Kaufman Brief Intelligence Test (K-BIT) (Kaufman & Kaufman, 1990).

There is little evidence of research, with only few exceptions (Cohen & Sandberg, 1980; Cornoldi, Vecchia, & Tressoldi, 1995) that focus exclusively on the relationship of working memory to cognitive functioning in children. This lack of relevant research on children is surprising, given the recent interest in the relationship of individual differences in working memory and intelligence. For example, Just and Carpenter (1992) have proposed a capacity theory of working memory in which individual differences in the working memory are the consequence of differing levels of available activation. The greater the capacity of an individual’s working memory, the more information the individual has simultaneously available for use in solving problems. This theory has been applied to both the verbal comprehension (Just & Carpenter, 1992) and figural pattern recognition such as that required by the Raven’s Progressive Matrices (Carpenter, Just, & Shell, 1990).

One major shortcoming evident in previous studies relating working memory and intelligence is that the tasks used to operationalise the two constructs are nearly indistinguishable. In the present study, the use of the newly developed working memory test battery aims to minimise the overlap with intelligence test tasks of the same category, in particular with reasoning tasks. This goal can only be approximated because there is no clear-cut, agreed upon definition of the class of potential intelligence test tasks.

While intelligence tests are far from ideal, to date they remain the best available instrument for revealing a child’s cognitive functioning. In fact, researchers point out that intelligence tests predict more of the important life variables than any other psychological construct including school success, language development, and many more (Bracken & Walker, 1997). A recent survey of Australian psychologists (Thompson, 2003) indicated that brief cognitive assessments are often used to provide a quick measure of intelligence and to assess learning disabilities, developmental disabilities and neuropsychological problems. It can be argued that brief cognitive assessments are even more important for children, particularly in clinical cases (Ades, 1990).

The assessment of working memory in children is a relatively new field. Similarly, there is an obvious lack of research involving the relationship between working memory and cognitive functioning in children. This study aims to explore this relationship with a particular focus on the Phonological Loop component of working memory and is believed to be the first of its kind in Australia utilising a newly developed working memory test battery.

Method

Participants

One-hundred and forty-four Year 1 children (73 boys and 71 girls) from seventeen State primary schools in Queensland were recruited to participate in the study during the second half of 2002. The mean age of the group was 6.41 years (SD = .37 years, range 5.71 years to 7.67 years).

Procedure

All children were tested individually in a quiet area or room within the school by a Guidance Officer trained in psychometric assessment and the use of standardised test instruments. The order in which the tests were administered was held constant. Children were given two tests of cognitive function: the School-Years Screening Test for the Evaluation of Mental Status (SYSTEMS), (Ouvrier et al., 2000), and the Kaufman Brief Intelligence Test (K-BIT), (Kaufman & Kaufman, 1990). They also were given several tests of working memory from the Working Memory Test Battery for Children (WMTB-C), (Pickering & Gathercole, 2001). No feedback was given on performance.

Tests of Cognitive Function

School-Years Screening Test for the Evaluation of Mental Status (SYSTEMS), (Ouvrier et al., 2000). The SYSTEMS screening test of cognitive functioning is for children aged 5-12 years. It was developed to indicate children's general cognitive functioning following the Mini-Mental Status Examination (MMSE). The SYSTEMS cognitive screening test for children has 46 items and takes 5-10 minutes to administer. Items include a range of cognitive tasks including orientation, registration, attention, calculation, repetition, memory, language, commands, reading, writing and copying.

Ouvrier et al. (2000) outline the item selection and the age-appropriate cut-off scores derived from a large representative sample (N = 630) of children aged 5-12 years. The scores below the cut-off values indicate that full cognitive assessment is required and suggest cognitive impairment. Ouvrier et al. (2000) report strong correlations (N = 42, r = .98) between SYSTEMS with the Stanford-Binet Intelligence Test for Children (Thorndike, Hagen, & Sattler, 1986). The test is reliable in terms of internal consistency, unbiased by socio-economic indicators (Australian Bureau of Statistics, 1990) and gender, and the test scores increase with age.

Research by Spencer, Bornholt and Ouvrier (2003) showed that the test has high reliability and that cognitive functioning is stable over time.

Kaufman Brief Intelligence Test (K-BIT), (Kaufman & Kaufman, 1990). The K-BIT has two subtests, Vocabulary and Matrices, and can be administered to individuals ages 4 to 90. The Vocabulary subtest contains two parts: (a) Part 1 (Expressive Vocabulary; 45 items) requires the naming of pictured objects and is administered to all subjects and (b) Part 2 (Definitions; 37 items) requires the individual "to provide the word that best fits two clues (a phrase description and a partial spelling of the word)" (p. 5) and is administered to subjects 8 years or older. Only Part 1 was used in this study. The sum of the two Vocabulary raw scores (in this case one Vocabulary raw score) is converted to a standard score (mean = 100; SD = 15) by use of a table. The Matrices subtest has 45 items of the usual multiple-choice matrix analogies type. The sum of the Vocabulary and Matrices' standard scores is converted to a total test score called the IQ Composite (mean = 100; SD = 15). The K-BIT manual reports an internal consistency coefficient of .92 for the total sample and test-retest reliability coefficients greater than .90 for each age group.

Tests of Working Memory

Working Memory Test Battery for Children (WMTB-C), (Pickering & Gathercole, 2001). The WMTB-C is composed of 9 subtests, each of which primarily taps one of the three components of Baddeley and Hitch's (1974) working memory model. Three subtests measure the central executive, two subtests measure the visuo-spatial sketchpad and four subtests measure the phonological loop. It is suitable for use with children aged between 5 and 15 years. Test-retest reliability coefficients ranging from .45 to .83 for the Years 1 and 2 age group. The following phonological loop subtests were administered:

Digit Recall This test has the same structure as the Backwards Digit Recall test, except that the children are asked to recall the digits in the same sequence to the one spoken to them (i.e., forwards) rather than in backwards order. Both raw and standard scores were recorded. The test-retest reliability of the test is .81 for children aged 5 to 7 years.

Word List Matching On each trial of this test, the child listens to a spoken sequence of familiar one-syllable words. Following a brief interval, the same words are presented again, either in the identical sequence, or with the position of two of the words within the sequence reversed. The child has to judge whether the same sequences are the same or different. The number of words in each list increases over successive blocks of trial, following the same structure as outlined for the Backwards Digit Recall test. Both raw and standard scores were recorded. Test-retest reliability is .45 for children aged 5 to 7 years.

Word List Recall On each trial of this test, the child listens to a spoken sequence of short (one syllable) words for immediate recall. This test has the same structure as the Backwards Digit Recall test, except that the children are asked to recall the words in the same sequence to the one spoken to them. Both raw and standard scores were recorded. The test-retest reliability of the test is .80 for children aged 5 to 7 years.

Nonword List Recall On each trial of this test, the child listens to a spoken sequence of short (one syllable) nonsense words for immediate recall. This test has the same structure as the Backwards Digit Recall test, except that the children are asked to recall the words in the same sequence to the one spoken to them. Both raw and standard scores were recorded. The test-retest reliability of the test is .68 for children aged 5 to 7 years.

Results

Cognitive functioning

The two tests of cognitive functioning appeared to have reasonable concurrent validity. They were apparently measuring the same thing. The partial correlation, controlling for age, between the two tests (SYSTEMS and K-BIT) of cognitive functioning was reasonable at pr = .59.

Relationship between working memory and cognitive functioning

Working memory and cognitive functioning were compared by correlating the various tests, controlling for age. Table 1 shows that the working memory sub-tests correlated better with SYSTEMS than with the K-BIT.

Table 1: Correlations between working memory and cognitive functioning measures.

Working Memory	Cognitive Functioning	
	SYSTEMS	K-BIT
Digit recall	.62	.51
Word list matching	.57	.49
Word list recall	.52	.42
Nonword list recall	.45	.29

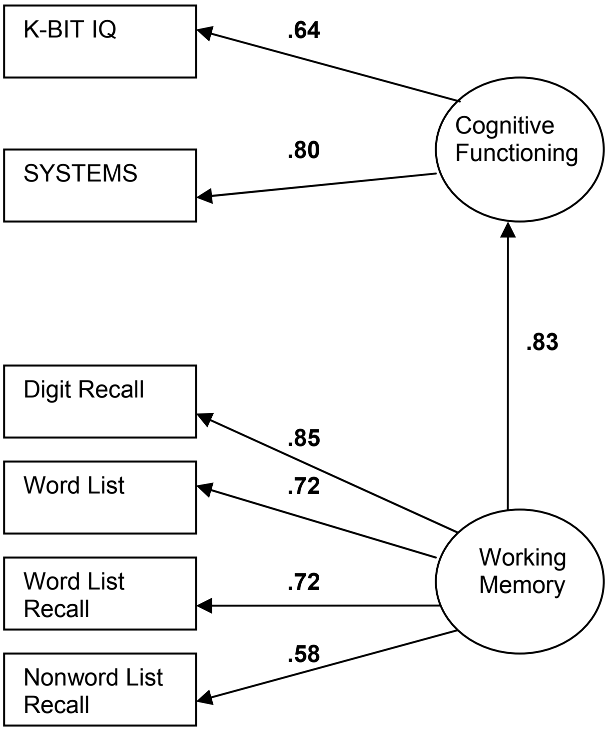
The highest correlation was between SYSTEMS and the subtest of Digit Recall (pr = .62). The SYSTEMS correlated well with the overall component score for the Phonological Loop (PL) of working memory (pr = .67), whereas the correlation between PL and K-BIT was pr = .54.

A model of working memory and cognitive functioning

A recursive measurement model, shown in Figure 1, details the proposed relationship between working memory and cognitive functioning.

Assessment of the model (according to (Byrne, 2001)) showed that the model had feasible parameter estimates (all correlation estimates < 1.00), appropriate standard errors, appropriate critical ratio levels (all CRs > 1.96), all regressions weights were significant, a reasonable model of fit was established (χ^2 = 13.498,df = 8, p = 0.096) and the model had a high goodness of fit index (GFI = .965). Of note is that all standardised factor loadings of the model were high (λ >.50) and the path coefficient suggests that there is a large effect (Kline, 1998) between working memory and cognitive functioning (β = .83).

Figure 1: The measurement model of working memory and cognitive functioning.



Discussion

The current study suggests that working memory may impact on cognitive functioning. Baddeley (1981; 1990; 1992) argues that working memory is composed of multiple components. One of the components proposed by Baddeley is the phonological loop. According to Baddeley (1986) in the phonological loop acoustic or verbal information is held and rehearsed.

The current study found that the component of working memory called the phonological loop appears to contribute to levels of cognitive functioning in children. Of note is that this relationship may actually be indicating the nature of cognitive functioning testing, where the test is administered verbally and requires children to utilise acoustic and verbal information. Although, it appears that the brain activity involved with cognitive functioning, including the knowledge of general information, thinking skills and the manipulation of information requires a person to have a good working memory base and specifically reasonable phonological loop capacity.

It would appear that when any assessment of cognitive functioning is administered to children, initial psychological testing may also need to include an analysis of working memory such as with the test battery for children developed by Pickering and Gathercole (2001) introduced in this study.

As this is an initial study into the relationship between working memory and cognitive functioning, further research is required to confirm this relationship and perhaps look at the impact of academic achievement over time on this model.

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