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ABSTRACT

Research on working memory has revealed a developmental trend in memory performance, but a controversy exists as to whether the improved performance is due to a developmental increase in working memory total processing space (M-space), is the result of more efficient processing and storage of material, or is due to the use of "chunking" or other mnemonic strategies by older children. A study traced the development of working memory span and examined the relationship between metacognitive knowledge about reading and memory, M-space, and working memory performance in skilled and less-skilled readers. Subjects, 32 second, fourth, and sixth grade children, completed a series of memory and metacognition measures and M-space tasks. Results substantiated a developmental increase in working memory span performance. The pattern of grade and reader effects found for the span tasks suggests that the trend in working memory performance resulted from an increase in the processing efficiency of mental operations, rather than from an increase in the total processing space. Metacognitive ability was marginally related to working memory performance. (FL)

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Working Memory, M-Space and Metacognitive Development in Skilled and Less-Skilled Readers

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Abstract

Research on working memory has revealed a developmental trend in memory performance. Currently, controversy exists as to whether the improved performance is due to a developmental increase in working memory total processing space (M-space), is the result of more efficient processing and storage of material, or is due to the use of "chunking" or other mnemonic strategies by older children. It has been hypothesized that differences in working memory processes might account for the observed differences between skilled and less-skilled readers. In addition, it was hypothesized that metacognition about reading and memory processes might play a role in span increases by promoting efficient processing, thus allowing the storage function more working memory space. This study traced the development of working memory capacity and examined the relationship between metamemory, metareading, total processing space (M-space), and working memory performance in skilled and less-skilled readers in second, fourth, and sixth grade. Grade effects were found for all span tasks and both metacognitive measures, while reader-group differences were found for Forward Word Span, Listening Span, and the M-Space measure. Multiple regression analyses showed Listening Span to be the only measure predictive of reading comprehension in fourth and sixth grades. Implications for skilled/less-skilled reader differences and the role of metacognition are discussed.

Working Memory, M-space and Metacognitive Development in Skilled and Less-Skilled Readers

Three hypotheses have been offered concerning the growth of short-term memory span performance in young children. Memory span improvement has been explained as the result of a quantitative increase in the total processing space available in working memory (Pascual-Leone, 1970), as a result of increases in processing efficiency (Case, Kurland & Goldberg, 1982; Huttenlocher & Burke, 1976), and as a result of the use of mnemonic strategies and chunking (Trabasso & Foellinger, 1978).

Pascual-Leone (1970) postulated that a quantitative parameter could account for the seemingly qualitative improvement in memory span. His concept of memory-space or "M", is an index of the number of mental schemes that an individual can simultaneously employ during a problem-solving task. M-space describes the integrator mechanism responsible for combining and operating on stored schemes, thus enabling an individual to generate novel cognitive assertions. Tests designed to measure M-space demand transformations of the original material prior to recall (i.e. reordering or quantification), which provide a measure of the maximum scheme set size for which an individual can successfully execute the transformations and output the correct answer. Pascual-Leone explained that the developmental trends in recall performance indicated a maturational increase in the total processing space available. Developmental increases in M-space allow more total processing space for use by both the processing and storage functions, thus improving working memory span performance.

Several investigators (Chi, 1976; Dempster, 1978; and Trabasso & Foellinger, 1978) argue that the developmental trends observed in working memory span performance result from more efficient processing (i.e., mnemonic strategies or chunking) rather than from an actual increase in total processing space. Dempster (1978), testing children ages 7 to 12, found large age differences for recall of easily-chunked materials, but negligible age differences for recall of materials which minimized the opportunity for chunking, suggesting that the older children had acquired efficient processing strategies. Case et al. (1982) explained the developmental trend as a result of the basic processing functions becoming faster and more efficient. Adults and 6-year-olds were tested on a counting span task- a test of M-space. A linear relationship was found between increases in the speed of counting and the counting span. However, when adults were forced to count in an unfamiliar language, thus equating them with the 6-year-olds on counting speed, there were no differences in the counting spans. Case et al. (1982) attributed the developmental trend in span performance to the fact that 6-year-olds' basic processes were not operating at maximum efficiency; they required more space for processing, thus decreasing the amount of storage space.

Recent reading theories (Just & Carpenter, 1980; Kintsch & van Dijk, 1978) hypothesize that reading relies heavily on the working memory system which has two functional components in competition for the available space. Within this theoretical framework, Daneman & Carpenter, (1980) argue that differences in the trade-off between working memory processing and storage functions might account for skilled/less skilled reader differences. They hypothesized that inefficient processing of reading materials by less-skilled readers results in a large amount of attention being allocated to the processing functions, leaving little total processing space remaining for use by the storage function. The result is that less-skilled readers have a functionally smaller working memory storage component. Less information is stored, resulting in poorer recall of the reading material. They found that when tasks are specifically designed to tax both processing and storage components of working memory, college-age skilled readers, in comparison to less-skilled readers, had larger recall spans and made fewer and less serious comprehension errors.

Flavell (1977) and Brown (1981), suggest that metacognitive knowledge about reading and memory was related to the active use of strategies in cognitive tasks. Adequate metacognitive knowledge was viewed as important in allowing an individual to apply strategies appropriate to the context. Armbruster, Echols & Brown (1983) found that younger and less-skilled readers had a less adequate understanding of how factors such as the structure of the text, the nature of the reading task, and learner characteristics interacted to affect their ability to learn from reading. In addition, they appeared less adept at using knowledge that they did possess about the reading situation to enhance their learning. It might be hypothesized that adequate metacognitive knowledge about memory and reading could make the processing of information more efficient; more efficient processing would require less of the limited working memory's space, thus allowing more space for the storage function to operate. This, in effect, would serve to enhance the functioning of the working memory.

Specifically, the current study traced the development of working memory span in skilled and less-skilled readers in grades two, four, and six. The relationship between M-space and performance on working memory tasks designed to measure both memory capacity and processing efficiency was assessed across this age range. In addition, the possible interaction between metacognitive knowledge about reading and memory, total processing space of working memory (M-space), and span performance at each age was examined.

Method

Subjects

Ninety-six children enrolled in a predominantly middle-class suburban elementary school served as subjects. Thirty-two children (sixteen skilled readers and sixteen less-skilled readers) in grades two, four, and six were selected to participate. Their mean ages were 8.11, 9.93, and 11.69, respectively.

Materials

The Gates-MacGinitie Reading Test (comprehension test only) (1978) was administered to differentiate skilled and less-skilled readers. M-space was assessed using the Raven's Standard Progressive Matrices Test (1958). Memory measures included the standard Forward and Backward Digit Span tasks and Forward and Backward Word Span tasks (Daneman & Carpenter, 1980). The Word Span tasks consisted of series of one-syllable common nouns that were chosen to be semantically and phonetically unrelated. They were grouped in sets of three that consisted of two to eight words each. The children were required to recall the words of a set in the exact order of presentation or in the reverse order of presentation. The Listening Span task (Daneman & Carpenter, 1980) was specifically designed to tax both capacity and processing components of working memory. The task consisted of 100 sentences, approximately 8 to 10 words in length. Each child was presented with a series of sentences in five sets containing two, three, four, five, or six sentences. They were required to verify each sentence as true or false as it was presented, and to recall the last word of each sentence after all sentences in the set had been presented. The verification component was used to insure that subjects did not concentrate only on the final word of each sentence. The sentences consisted of declarative sentences of general knowledge (school-related, geography, modes of travel, plants & animals, etc.) appropriate to second graders.

Knowledge about memory (Metamemory) was evaluated using the Event Preparation and Story subtests from the Kreutzer, Leonard & Flavell (1975) metamemory battery. Knowledge about reading (Metareading) was measured by the Edwards' Concept of Reading Inventory (1977) which consisted of a series of 20 multiple choice statements about the characteristics of good readers. Tape recorders were used to present taped stimuli for the Word, Digit, and Listening Span tasks, and for recording the subjects' responses to the Metamemory and Metareading tasks.

Procedure

The tests were administered in the following order: Gates-MacGinitie Comprehension Test; Metareading; Forward/Backward Digit Span; Forward/Backward Word Span; Listening Span; Metamemory; and the Raven's Standard Progressive Matrices Test. The Gates-MacGinitie Reading Test and the Metareading measure were administered on the same day in a group session. A median-split was performed on the Gates-MacGinitie test scores; in each grade, the 16 highest scorers were classified as skilled readers and the 16 lowest scorers were classified as less-skilled readers. For each of the Digit and Word Span tasks, 2 practice sequences were given. Following practice, sets of increasing length were administered until a level was reached at which a subject failed to respond correctly on two out of three sets. If a subject responded correctly on at least two of the three sets he or she was assigned points which corresponded to that level (i.e. two out of three sets at the fourth level resulted in a score of four). A subject received an additional 1/2 of a point for correctly responding to one out of the three sets above his or her "stopping" level. For the Listening Span task, practice sentences were given until a child responded correctly to two sentences in a row. After meeting this criterion, subjects were presented with increasingly longer sets of sentences until they missed four sets of five in a row at the same level. Subjects were given scores corresponding to the level at which they were correct on at least three out of the five sets, and were assigned an additional .33 for a correct response at the next level or .66 for two correct responses at the next level. The Raven's Standard Progressive Matrices Test was administered individually and M-capacity estimates were obtained through the scaling methods developed by Bereiter and Scardamalia (1979).

Results

Separate 3 (Grade) X 2 (Reader) between-groups analyses of variance were performed for each test of working memory capacity and metamemorial awareness. Results are summarized in Table 1.

Insert Table 1 about here

A 3 (Grade) x 2 (Reader) analysis of variance performed on the Forward Digit Span measure resulted in a significant main effect for Grade, F (2,90) = 8.61, p <.001. A Duncan's multiple range test indicated that sixth-graders performed significantly better than second- and fourth-graders, who did not differ significantly from each other. A 3 (Grade) x 2 (Reader) analysis of variance performed on the Backward Digit Span task resulted in a significant main effect for Grade, F (2,90) = 4.34, p <.05. A Duncan's test determined that sixth-graders performed significantly better than second-graders on the task.

A 3 (Grade) x 2 (Reader) analysis of variance performed on the Forward Word Span task revealed a main effect for Grade, F (2,90) = 9.49, p <.001, and for Reader, F (1,90) = 11.91, p <.001. A Duncan's test revealed that children in grade six performed significantly better than children in grades two and four on the Forward Word Span task. In addition, skilled readers performed significantly better than less-skilled readers on the task. A 3 (Grade) x 2 (Reader) analysis of variance performed on the Backward Word Span measure revealed a main effect for Grade, F (2,90) = 11.45, p <.001. A Duncan's test revealed that sixth-graders performed better than second- and fourth-graders on the task.

A 3 (Grade) x 2 (Reader) analysis of variance performed on the Listening Span measure resulted in a main effect for Grade, F (2,90) = 29.44, p <.001, and for Reader, F (1,90) = 10.23, p <.01. A Duncan's test showed that sixth-graders and fourth-graders, while not differing significantly from each other, performed significantly better than the second-graders.

A 3 (Grade) x 2 (Reader) analysis of variance performed on the M-space measure resulted in a significant main effect for Grade, F (2,90) = 30.77, p <.001, and for Reader, F (1,90) = 5.95, p <.05. A Duncan's test revealed significant increases in M-space across the three grades. Sixth-graders performed significantly better than fourth-graders who, in turn, performed better than second-graders on the M-space measure. Skilled readers had a significantly larger M-space capacity than less-skilled readers.

Metacognitive Measures

A 3 (Grade) x 2 (Reader) analysis of variance performed on the Metamemory measure (Kreutzer et al., 1975) resulted in a main effect for Grade, F (2,90) = 23.64, p <.001, and a significant grade x reader interaction, F (2,90) = 3.30, p <.05. A Duncan's test indicated significant differences between all three grades; performance increased with grade. Duncan's tests also revealed that skilled readers performed significantly better than less-skilled readers in grade four; however, no significant reader differences were found for grades two or six. A 3 (Grade) x 2 (Reader) analysis of variance performed on the Metareading measure revealed a main effect for Grade, F (2,90) = 17.73, p <.001. A Duncan's test revealed that children's performance on this metareading measure was a direct function of their grade.

Individual Differences Analyses

Pearson correlation coefficients were computed between all measures for each grade. For second-graders, Gates-MacGinitie Comprehension Test performance correlated significantly with Metareading (r = .34, p <. 05) and Forward Digit Span (r = .42, p < .01). Forward Digit Span was correlated with Backward Digit Span (r = .57, p < .001), Forward Word Span (r = .33, p < .05), and Metareading (r =.49, p < .01). M-Space was correlated with Forward Word Span (r =.39, p < .05).

For fourth-graders, M-space correlated with Backward Digit Span (r = .31, p < .05). Listening span correlated with Gates-MacGinitie (r = .41, p < .05), Backward Digit Span (r = .44, p < .01), and Metareading (r = .30, p <. 05). Forward Digit Span correlated with Gates-MacGinitie (r =.33, p < .05), Backward Digit Span (r =.41, p < .01), Forward Word Span (r = .35, p <. 05), and Metareading (r =.35, p < .05). Finally, Backward Digit Span correlated with Metareading (r = .30, p <. 05).

Corresponding correlational results for grade six are summarized in Table 2. A clear pattern of correlation among the span measures is evident in this grade. M-space correlated with Gates-MacGinitie performance. Listening span correlated with Gates-MacGinitie, Backward Digit Span, and Forward and Backward Word Span measures. Forward Digit Span correlated with Backward Digit Span, both Forward and Backward Word Span, and Metareading. Backward Digit Span correlated with both Word Span measures and Metareading. Forward Word Span correlated with Backward Word Span and Metareading. Finally, Backward Word Span correlated with Metareading.

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Insert Table 2 about here

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A step-wise multiple regression analysis for predicting Gates-MacGinitie comprehension test performance was conducted for each grade separately. All span measures, M-Space, and metacognitive measures were entered as variables.

For second-graders, Forward Word Span was predictive of reading comprehension performance, $\underline{F}$ (1,30)= 6.25, $\underline{p} < .05$. Listening Span was found to be predictive of reading comprehension performance in both the fourth ($\underline{F}$ (1,30)= 5.90 $\underline{p} < .05$) and sixth grades ($\underline{F}$ (1,30)= 11.05, $\underline{p} < .01$).

Discussion

The results substantiate a developmental increase in working memory span performance. The pattern of grade and reader effects found for the span tasks and M-space suggest that the developmental trend in working memory performance results from an increase in the processing efficiency of mental operations, rather than from an increase in the total processing space.

Although a significant growth in M-space was found, this measure was not found to be consistently correlated with performance on the span tasks (in fact, only one significant correlation occurred per grade). If a developmental increase in the total processing space was responsible for increased span performance, M-space would be expected to correlate strongly with performance on span measures. Specifically, a larger M-space capacity would allow relatively more working memory space to be allocated for use by the storage component. The failure of this measure to correlate with span performance argues against any developmental increase in total processing space.

The grade effects found on the more simple working memory span tasks (Forward Digit and Forward Word) can explained either in terms of a developmental growth in the use of chunking and other higher-order mnemonic processes (Cavanaugh; Chi; Dempster cited in Case et al., 1982) or by a processing efficiency explanation (Case et al., 1982). However, the grade effects obtained for the Backward span tasks, and especially for Listening Span performance (in which the heavy processing and storage demands severely reduce the possibility of mnemonic strategy use or chunking) cannot be explained in terms of a developmental increase in the use of mnemonic strategies. On those tasks which require not only storage, but operations on the stored material prior to output, the results are best understood in terms of differences in processing efficiency (Case et al., 1982).

Significant reader differences found for Forward Word Span and M-space, and Listening Span measures support the hypothesis (Daneman & Carpenter, 1980) that skilled/less-skilled reader differences reflect differences in the trade-off between the processing and storage functions of working memory. More efficient processing of the materials by skilled readers could account for the observed differences by allowing them to allocate less working memory capacity to the processing function, thus allowing them a relatively larger amount of storage space which they could use to store words in the Word Span task, and to store more of the products from processing of the Ravens' stimulus items which comprise the M-space measure. The reader group differences in Listening Span performance is especially noteworthy. The Listening Span task is designed to place heavy demands on the processing component, to the relative decrement of the storage component. This makes the task the most likely to demonstrate the processing/storage trade-off. For the less-skilled readers, their inefficient processing abilities and the task's heavy processing demands taxed the processing component greatly, resulting in relatively less storage capacity than that of the skilled readers. This explanation is supported by the multiple regression analyses which showed Listening Span to be the only measure predictive of reading comprehension performance in the fourth and sixth grades.

The role of metacognition (Metamemory and Metareading) in the performance of the working memory tasks is somewhat equivocal. Metareading correlated with performance on two span tasks in second and fourth grade, and with four measures in the sixth grade. The interaction of grade and reader on the

Metamemory task suggests that metamemory develops more slowly in less-skilled readers and becomes equivalent to that of skilled readers around sixth grade. These results suggest a possible strategic deficit among less-skilled readers concerning the knowledge of and tendency to apply memory strategies. The correlations between measures of metacognition and working memory performance offer support for the link between metacognition and strategic reading and memory behavior (Brown, 1981; Flavell, 1977). There was a significant difference across all grades on both the Metareading and Metamemory measures. Older childrens' greater metacognitive awareness concerning reading appears to have contributed to their performance on memory span tasks, while metamemorial awareness did not. This is probably a function of he Metamemory task, and it appears that the subtest of the Kreutzer, et al. (1975) battery used here was inadequate as a measure of metamemorial awareness. Future research might obtain more consistent results using a more extensive battery of metacognitive tasks.

In summary, developmental trends were found in working memory performance across grades two, four and six. Support was obtained for the position that developmental trends in span performance and some skilled/less-skilled reader differences in span performance were due to differences in the efficiency of the processing component (Case et al., 1982) of working memory. Finally, metacognitive ability was marginally related to working memory performance.

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Table 1

F Values for 3 (Grade) X 2 (Reader) Analysis

Measure	Grade (2,90)	Reader (1,90)	Grade X Reader (2,90)
Forward Digit Span	8.61***	2.50	0.01
Backward Digit Span	4.34*	3.29	0.79
Forward Word Span	9.49***	11.91***	0.01
Backward Word Span	11.45***	1.05	0.60
Listening Span	29.44***	10.23**	0.59
M-Space	30.77***	5.95*	1.70
Metareading	17.73***	1.68	0.69
Metamemory	23.64***	0.02	3.30*

*p<.05 **p<.01 ***p<.001

Table 2

Pearson Correlation Coefficients Between Working Memory Span Performance, M-Space, and Metacognitive Measures for 32 Sixth Grade Children

	Digit span		Word span		Listening			
	Forward	Backward	Forward	Backward	Span	M-space	Metareading	Metamemory
Forward Digit		.65***	.71***	.59***	.35*	-.13	.33*	-.16
Backward Digit			.69***	.67***	.49**	.15	.44**	-.17
Forward Word				.68***	.51***	.08	.35*	-.15
Backward Word					.31*	.29	.31*	-.11
Listening Span						.11	.21	.08
M-Space							-.27	-.06
Metareading								
Metamemory								