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ABSTRACT

Thirty grade 4 subjects were individually tested on a digit span test of working memory capacity (Case and Kurland) and the Reading Span Test (Daneman and Carpenter). The Reading Span Test was administered using sentences at a grade 2, grade 4, and grade 6 reading level. It was predicted that, as the decoding demands of the stimulus sentences in the Reading Span Test were increased, the amount of working memory capacity available for other reading tasks such as comprehension would decrease relative to a subject's working memory span as measured on the digit span test. This hypothesis was confirmed , providing support for the predictions of the LaBerge and Samuels model of learning to read. The results further support the Case, Kurland and Goldberg argument that working memory capacity is a function of the interaction between the amount of central capacity required for processing operations and the amount of working memory capacity left over for storage. However, these conclusions need to be qualified by the observation that sentence reading time and word meaning knowledge were not controlled in this study. (Author/PN)

THE DISTRIBUTION OF WORKING MEMORY CAPACITY IN READING

For Presentation at the Annual Meeting of the American Educational Research Association, Montreal, Quebec, Canada, 1983.

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ABSTRACT

Thirty grade 4 subjects were individually tested on a digit span test of working memory capacity (Case and Kurland, 1976) and the Reading Span Test (Daneman & Carpenter, 1980). The Reading Span Test was administered using sentences at a grade 2, grade 4, and grade 6 reading level. It was predicted that as the decoding demands of the stimulus sentences in the Reading Span Test were increased, the amount of working memory capacity available for other reading tasks such as comprehension, would decrease relative to a subject's working memory span as measured on the digit span test. This hypothesis was confirmed.

Two word descriptor: Reading Span

One of the theoretical assumptions of the LaBerge and Samuels (1974) model of learning to read is that new or unfamiliar reading vocabulary in a text should require the reader to give more conscious attention to the decoding process than might otherwise be the case. In other words, if the reader is forced to read words that cannot be decoded automatically, he/she must allocate short-term memory capacity to the decoding operations which might otherwise be used for comprehension. Thus less short-term memory capacity should be available for those aspects of reading comprehension that are not related to decoding. Although evidence that this may be the case has been observed in studies which have examined the relationship between decoding abilities and comprehension (Perfetti & Lesgold, 1977) few, if any, studies have directly examined the effect of decoding requirements on the amount of working memory capacity available for other tasks, such as comprehension.

Previous studies on the allocation of attentional capacity during reading have been mainly concerned with the effect of story structure on short-term memory capacity. For example, Britton, Ziegler and Westbrook (1980) looked at the use of cognitive capacity in reading easy and difficult text. It was concluded that more easily comprehensible passages filled cognitive capacity more completely because they called up more elements of the cognitive system, more memories and more images.

Alternatively, Britton, Glynn, Meyle and Penland (1982) examined the effects of text structure on the use of cognitive capacity by holding meaning constant and varying structure. The structure was varied by manipulating word frequency and syntax. The results of this study showed that aspects of the surface structure of a text, such as simplified syntax and topical sentences, tend to reduce the demand placed on the reader's central processing capacity.

The majority of studies of this type, however, have focussed on the increase in demand placed on the reader's short-term memory or working memory capacity as a result of increased comprehension demands. In contrast, the LaBerge and Samuels (1974) model predicts that for the subject who is learning to read, an increase in working memory demand may occur as a result of the attention which must be given to the decoding of relatively new words. Moreover, this model predicts that this type of attentional demand will take away some of the working memory capacity normally used in comprehending the text.

Of course, as Perfetti and Lesgold (1977) argue, it has been hypothesized for some time that the demands of decoding new or unfamiliar words interferes with the reader's comprehension processes. The problem with this hypothesis, however, lies in the observation that it is difficult to determine whether the reader's comprehension difficulties are the result of decoding interference or sentence and story structure factors. Moreover, it is difficult to tell precisely how much of a drain the reader is experiencing in terms of the working memory capacity available for comprehension. In other words, it is difficult to quantify this type of interaction.

Two recent studies in the literature on the development and use of working memory capacity in reading and nonreading tasks, however, suggest that it may be possible to overcome these problems. First, the research of Case (1974, 1978) and Case, Kurland and Goldberg (1982) has resulted in the development of an instrument which can be used to index the amount of available working memory capacity a subject has for storage after performing a simple dot counting operation. Second, the work of Daneman and Carpenter (1980) has resulted in means of measuring the amount of available working memory capacity a subject has left for storage after orally reading a sentence.

These two approaches have a number of things in common. First, both Case (1974, 1978) and Daneman and Carpenter (1980) operationalize short-term memory in a task which requires that attention be given to encoding operations and storage operations. Second, in both tasks the requirement of an ongoing encoding operation minimizes the subject's ability to rehearse the information being held in short-term store. Thus, working memory scores tend to be lower than the scores obtained on short-term memory tasks such as the WISC-R digit span task. Third, the rate of which a subject can perform the encoding operations in both tasks directly affects the amount of information the subject can retain in short-term store (Case, Kurland and Goldberg, 1982). In essence, slower rates of encoding are associated with lower working memory scores, suggesting that a greater amount of central processing capacity is being used for the encoding operations. Conversely, fast encoding performance tends to be associated with higher working memory scores, suggesting the development of encoding automaticity. Fourth, the encoding operations in both tasks are familiar to school aged children. For example, the counting by ones of the stickers in the Count the Spots Test (Case and Kurland, 1976) is a task which almost all nine year old children can perform without error (albeit at different rates). Similarly, the oral sentence reading requirements of the Reading Span Test (Daneman and Carpenter, 1980) is required almost on a daily basis in most elementary school reading lessons.

Two additional points are worth noting about these instruments. First, they both tap basic but different components of intelligence and of the elementary school curriculum. The Count the Spots Test requires an encoding and computational operation that is fundamental in the development of mathematical ability. On the other hand, the Reading Span Test requires a decoding operation that is a major component of verbal ability as it is measured in school settings. Second, performance on the Reading Span Test is highly correlated with the reading comprehension scores of adults (Daneman and Carpenter, 1980). It was on this basis that Daneman and Carpenter argued that a subject's reading span (the number of sentence ending words that can be recalled after reading a given number of sentences) is a good indicator of the amount of available working memory capacity he/she has left for the attentional demands of comprehension, after decoding the words of these sentences. Similarly, it can be argued that if the attentional demands of decoding are increased on a reading task, it is consistent with the theories of LaBerge and Samuels (1974), Case, Kurland and Goldberg (1982) and Daneman and Carpenter (1980), to hypothesize that a subject's reading span will decrease.

The purpose of the present study then was to examine the deployment of attentional capacity during oral reading. The distribution of working memory capacity was studied independent of and as part of the reading process. The trade off between the processing (decoding) and storage (comprehension) demands of working memory was examined as well. In addition, we were interested in examining the relationship between these two tests in terms of their relative performance demands.

With these general goals in mind, the following specific predictions were made:

(a) It was predicted that a subject's working memory score on the Count the Spots Test would be the same as or very close to a subject's working memory score on the Reading Span Test when the subject was reading sentences from this test below and at his/her reading grade level.

(b) It was predicted that there would be little or no difference between a subject's working memory scores on the Reading Span Test when the subject was reading sentences from this test below and at his/her reading grade level.

(c) It was predicted that there would be a significant difference between a subject's working memory scores on the Reading Span Test when the subject was reading sentences from his test at and above his/her reading grade level. Specifically, it was expected that a subject's working memory score on the Reading Span Test would decline when he/she was reading sentences above his/her reading grade level because of the increase in the attentional demands of decoding new and unfamiliar words.

The Experiment:

Thirty grade four students were randomly selected from the Brampton family of schools which is part of the Dufferin-Peel R.C.S.S. Board, Mississauga, Ontario, to act as subjects.

Methods and Procedures:

The subjects were given three tests;

(1) The Gates-MacGinitie Reading Test Form D, to ascertain their reading levels.

(2) The Count the Spots (Case & Kurland, 1976), to measure working memory capacity independent of reading.

(3) The Reading Span Test (Daneman & Carpenter, 1980) to measure the span of working memory during the reading process.

The Gates-MacGinitie Reading Test Form D was administered with raw, stanine, percentile and grade equivalent scores being calculated for the Vocabulary, Comprehension and Total Reading subtests. The test was administered in two separate settings on two consecutive days to the whole class. Approximately two weeks after the administration of the Gates-MacGinitie Test each subject was individually tested on the Count the Spots Test (Case & Kurland, 1976).

Each subject was presented with a set of white cards, one at a time. Each card had green and yellow sticker dots put on in a random arrangement. The subject was asked to count the green dots by pointing to each dot and counting aloud. The yellow dots were distractors. After the last card had been counted and removed, the subject was asked to recall the number of dots counted on each card. The card sets varied in size from one to five. A subject's working memory capacity was assumed to be equal to the maximum set size for which he or she could recall all the card totals on at least two out of three trials.

Immediately following the Count the Spots Test, the Reading Span Test (Daneman & Carpenter, 1980) was administered. On this test subjects had to read aloud a series of sentences on white cards at their own pace and then recall the last word of each sentence. The test was constructed from 45 sentences; 15 at Grade 2 level, 15 at Grade 4 level and 15 at Grade 6 level. Each sentence ended in a different word. The sentences were selected from the Nelson Language Development Reading Program - Evaluation Resource Book for Grade 2, 4 and 6. Passages were selected and the average number of words per sentence was calculated. Sentences were then equated on length and grammatical structure. The sentence cards were arranged by grades and in sets of one, two, three, four and five. Blank cards were inserted to mark the beginning and end of each set. Subjects were presented increasingly longer sets of sentences starting from 1 and going to 5 in each grade level set of sentences. The level at which a subject was correct on two out of three trials was taken as a measure of the subject's reading span at that grade level.

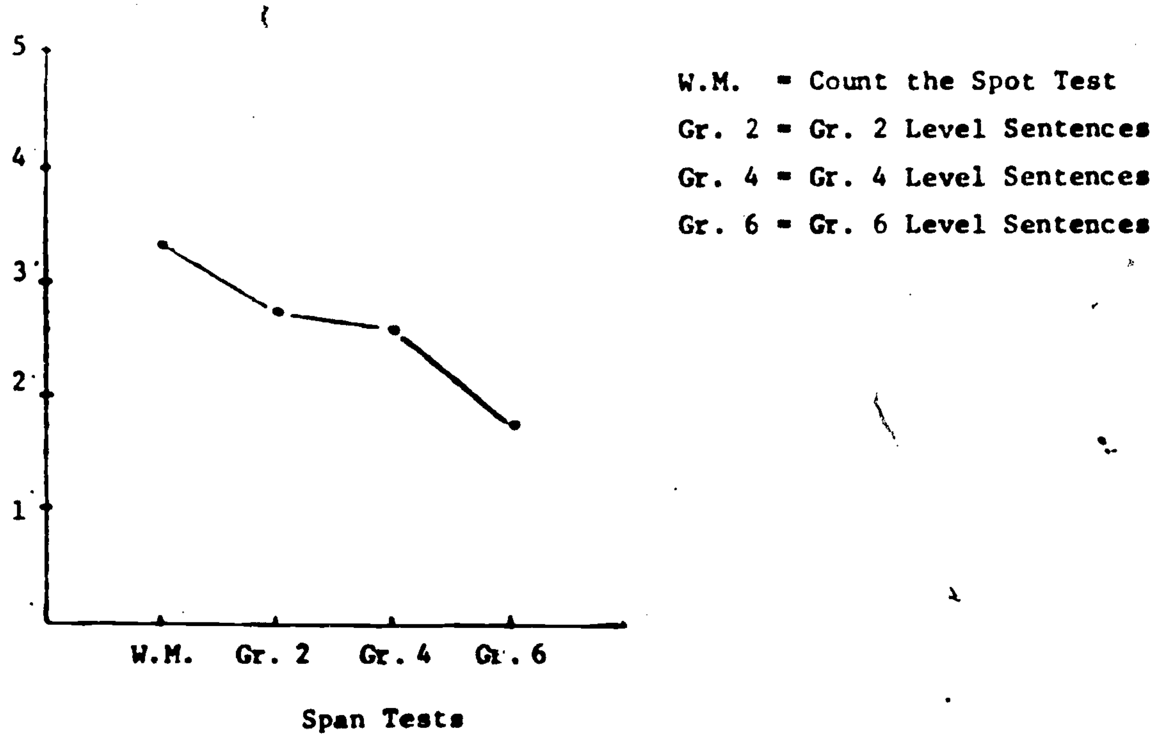
Results:

The Gates-MacGinitie reading scores indicated that there was a normal distribution of reading ability within the sample. Therefore, a repeated measures analyses of variance was performed on the differences between the working memory capacity scores on the Count the Spots Test and the working memory capacity scores on the Reading Span Test at each grade level of difficulty. The mean working memory capacity scores on each of these tests are graphed in Figure 1.

As can be seen, there was a small but significant drop in performance between the working memory capacity scores on the Count the Spots Test and the Grade 2 level Reading Span Test, $F(1,29)=9.4337, p<.01$.

As predicted, however, the shift in performance on the Grade 2 level Reading Span Test and the Grade 4 level Reading Span Test was very small and not significant, $F(1,29)=.12134$, $p<1$. Similarly as expected, there was a significant drop between the Grade 4 level Reading Span Test and the Grade 6 level Reading Span Test scores, $F(1,29)=43.5$, $p<.01$.

Figure 1



Working Memory Span Means

Additional analyses revealed a significant decline in performance between the working memory capacity scores on the Count the Spots Test and the Grade 4 level Reading Span Test, $F(29,1) = 18.7096$, $p < .01$, the Count the Spot Test and the Grade 6 level Reading Span Test, $F(29,1) = 106.6176$, $p < .01$, and the Grade 2 level Reading Span Test and the Grade 6 level Reading Span Test, $F(29,1) = 27.5985$, $p < .01$.

Discussion:

Taken as a whole then, these results provide support for the predictions of the LaBerge and Samuels (1974) model of learning to read. They also provide further support for the Case, Kurland and Goldberg (1982) argument that working memory capacity as operationalized on tasks such as the Count the Spots Test and the Reading Span Test is a function of the interaction between the amount of central capacity required for processing operations and the amount of working memory capacity left over for storage. These conclusions need to be qualified however, by the observation that sentence reading time and word meaning knowledge were not controlled in this study. For example, although the children in this study were told the name of a word when they required more than 15 seconds to decode it, it is still possible that it took much longer to read the Grade 6 level sentences than the Grade 2 and 4 level sentences and that this factor affected the subjects' ability to retain the ending words of the Grade 6 level sentences in short-term store. Similarly, it is conceivable that if the ending word of a sentence had a meaning that was unknown by the child, this type of word would be forgotten sooner than words with familiar meanings. Such words, of course, would be expected to occur with a greater frequency in the Grade 6 level Reading Span Test sentences than the Grade 2 and 4 level sentences.

One finding that was not expected was the shift in performance between the Count the Spots Test working memory span scores and the Grade 2 (and 4) level Reading Span Test working memory scores. What is suggested is that even on sentences two grade levels below a child's reading grade level, the decoding operations require more attentional capacity than a counting operation. Moreover, this difference also suggests that the decoding operations may not yet be fully automatic, even on easy to read sentences, for the Grade 4 child.

On the other hand, from a practical point of view, the results of this study are encouraging. Provided the effect that was observed is maintained when reading time and vocabulary meaning controls are applied, the procedures and tests used here show promise as a means of determining when decoding interference is affecting a reader's comprehension, when the reader does not have the working memory capacity required for comprehension inspite of successful or flawless oral reading performance, and when comprehension skills may be lacking. For example, using this approach we have found examples of learning disabled children who are able to read grade 4 level sentences flawlessly on the Reading Span Test but who nevertheless have a Reading Span Test score of only 1 in relation to a Count the Spots Test score of 3. A child with this type of performance profile clearly is experiencing decoding interference inspite of his/her oral reading performance. In this respect then it is hoped that the results of this study will lead to a better understanding of the reading process and more sophisticated diagnostic techniques.

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