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The studies centered on investigations of differences in text processing strategies associated with differences in the capacity to keep information active in memory (working memory capacity). A series of experiments showed that readers low in working memory capacity try to compensate for this deficit by forming very concrete interpretations of a text. Such readers will use a goal to guide comprehension at the expense of less goal-relevant information. Expository text was also used to determine if differences in working memory affect what is learned from instructional text. The results showed that readers low in working memory span have less ability to keep the overall topic in mind as they read. These readers do attempt to compensate by reinstating the topic in memory at the end of the text. The results showed that theories must address how working memory resources are flexibly allocated during reading.			
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LEARNING FROM TEXT: A COGNITIVE CONTROL PERSPECTIVE

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SUMMARY

The research supported by the grant was designed to uncover basic principles of cognitive control over comprehension. Cognitive control refers to the processes involved in managing information during task performance. This project addressed how people adapt their text processing to the type of text being read and to their own information processing limitations. The studies centered on investigations of differences in text processing strategies associated with individual differences in the capacity to keep information active in memory, typically referred to as working memory. A series of experiments showed that readers low in working memory capacity try to compensate for this deficit by forming very concrete interpretations of a text. In addition, such readers will use a goal or initial framework to guide comprehension at the expense of less goal-relevant information. These results were not limited to narrative text. Expository text was also used to determine if differences in working memory could affect what is learned from instructional text. The results showed that readers low in working memory span have less ability to keep the overall topic in mind as they read. These readers do attempt to compensate by reinstating the topic in memory at the end of the text. The results were consistent with theories of comprehension that claim that working memory serves as a mental work space for integrating information. However, the results further showed that theories must address how working memory resources are flexibly allocated during reading.

RESEARCH OBJECTIVES

This research was designed to uncover basic principles of how readers manage their text comprehension processes. In particular, this phase of the research investigated how individual differences in working memory (WM) constrain or determine comprehension management processes. Working memory refers to an individual's ability to actively manipulate information in short-term memory. The specific objectives were to determine:

- (1) whether WM limitations influence the process of integrating information with prior knowledge.
- (2) how WM limitations constrain comprehension processes involved in learning from expository text.

STATUS OF THE RESEARCH EFFORT

WM and Information Integration

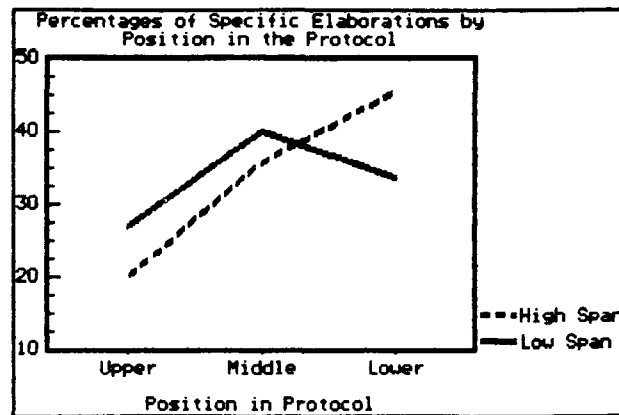
The way that prior knowledge is used to understand a text has been a central issue in comprehension research since the early 1970s (e.g., Bransford & Johnson, 1973). If WM plays the role of

the workspace in which information is integrated, then individual differences in WM capacity should be associated with different strategies for information integration based on knowledge outside the text itself. This issue was explored in the study that led to the AFOSR grant. Whitney, Ritchie, and Clark (1991) attempted to isolate processing differences associated with WMS based on the notion that readers buffer recently processed information to achieve local (sentence-to-sentence) coherence and they buffer other concepts needed for global (thematic) coherence (Kieras, 1981; Just & Carpenter, 1987; Rayner & Pollatsek, 1989). We investigated whether readers with low WM capacity would be forced into a tradeoff between maintaining local and global coherence when they read difficult, ambiguous prose.

The subjects were separated into low and high WM span groups based on their performance on the Daneman and Carpenter (1980) reading span test. From among 24 people who took the span test, the eight highest and lowest scorers were used as subjects. They were asked to read a series of ambiguous texts, such as Bransford & Johnson's (1973) "Washing Clothes" passage. While reading, the subjects were asked to "think-out-loud" (TOL) about their interpretation of each passage. Of course, verbal reports must be interpreted cautiously. Nevertheless, if post-hoc reconstructions are avoided, the TOL methodology is useful for studying some on-line processes in comprehension (e.g., Ericsson & Simon, 1984; Fletcher, 1986; Olson, Duffy, & Mack, 1984).

The subjects' protocols were recorded, transcribed, divided into idea units, and classified. Over 80% of the idea units produced could be classified as paraphrases of the text, general elaborations, or specific elaborations. It was only in the latter category that the span groups differed. The low span readers gave specific elaborative interpretations in 23% of their idea units. The high spans did so in only 12% of their idea units. This difference in the concreteness of interpretation was significant ($p < .01$). Such a strategy makes sense for low span readers because concrete representations are easier to hold in memory than abstract ones (Sanford & Garrod, 1981).

An additional analysis helped to clarify the nature of the processing differences between high span and low span subjects. If multiple interpretations of the ambiguous texts are held in memory and tested against later information, then the specific elaborations that occur should be found mainly toward the end of the protocol when more evidence is available that allows the reader to be specific. The percentages of specific elaborations by position in the protocol are shown in the figure below. It is clear that only the high span subjects are deferring concrete interpretations until late in the passage. There was no reliable trend in the data for the low span subjects.



To provide more rigorous evidence for differential use of inferences associated with WM capacity, we examined whether readers' make predictive inferences. For example, if a text says someone fell from the 30th floor, do we infer that they are dead? Because this is a controversial issue, particularly with regard to methodology, we performed a series of experiments with different methods. These experiments showed that, normatively, readers do make such inferences when key concepts are emphasized in the text. This study is in press in Memory and Cognition (see Appendix). We have also collected data showing that low WM span readers are more elaborative than others, but make fewer connective inferences to achieve global coherence within the text. We had high and low span readers complete word stems after reading priming or control sentences. The stems could be completed with a word related to the inference implied by the action in the sentence. For example, after "Bill stepped on a piece of glass" subjects might fill in the stem "C ____" with the word "cut." Three types of primes were used in addition to control sentences: coherence primes that required the inference, foregrounded primes in which the noun critical to the inference (eg., glass) was the subject of the sentence, and backgrounded primes in which the critical term was not the subject. The control primes used all the same content words so that the results could not be based on single word priming. The data (in percentage of stems completed with the inference target) are shown in Table 1.

Table 1: Priming of Predictive Inferences

Sentence Type	Span	
	Low	High
Coherence	18.75	29.16*
Foreground	23.95*	28.12*
Background	22.91*	14.58
Control	12.50	13.54

Note: * indicates cell mean is different from control at $p < .05$.

The low span subjects are not making required inferences, but instead are making elaborative inferences even when they critical terms are not the focus of the text. We recently completed two other experiments to further investigate the relationship between WMS and the increased use of elaborative inferences. In one experiment, we replicated the TOL study, but with a manipulation of WM capacity. Thirty subjects listened to the six passages and after each major event (two or three sentences) of a passage they provided TOL protocols. For half the passages, the subjects had to keep a six digit sequence in mind while listening to each story event. The subjects reported the digits before giving their impressions of the meaning of the passage. On the other trials, the subjects were given the digits at the end of each story event and immediately repeated them. Thus, the brief delay in providing the TOL was kept constant, but for half the stories there was a WM load during comprehension. The percentage of idea units generated during TOL that could be classified as specific inferences did vary with the load manipulation (11.5% in the no load condition and 15.1% in the load condition, $F(1,27) = 5.25$, $p < .05$).

We have further analyses to perform on the new TOL data, but the preliminary results provide some additional support for the notion that as WM capacity decreases, subjects compensate by forming more definite interpretations. Of course, it would be unwise to place too much confidence in data that require as much subjective interpretation as is necessary for TOL protocols. However, we obtained more direct evidence for increased concreteness with lower WM capacity in a study of instantiations. Instantiations are inferences about the referents of general terms. Whitney (1986) found that readers tend to make such elaborative inferences in sentences like "The fish attacked the swimmer." In this example, "shark" was significantly primed as compared to a condition in which "shark" followed a sentence that controlled for priming due to simple word associations. In the new study we tested for instantiations among high and low span readers.

The methodology was not based on a priming task, because we

wanted to see if the inferences were actually incorporated into the text representation, rather than momentarily activated. So we presented the critical sentences in the contexts of brief paragraphs and tested subjects' later recognition memory for the critical sentences. Subjects were presented with either the exact sentence they had seen, with a paraphrase, with a sentence containing the instantiation, or with a sentence that was a fundamental meaning change (see Table 2). The subjects, 32 low spans and 32 high spans, were to say "yes" only to exact reproductions of the sentences they saw before. Obviously, however, there were many "false" recognitions of sentences that involved only a slight change from the original. Based on Kintsch et al. (1990) and Schmalhofer and Glavanov (1986), the strength of the textbase representation (without elaborations) can be measured as the subjects' ability to distinguish paraphrases from sentences containing the elaborative inferences. The strength of the situational model (with elaborations) can be measured as the ability to distinguish the instantiation sentences from the meaning change sentences.

Table 2: Example of Materials Used in the Instantiation Study

Passage read:

The teacher and her class went outside after lunch. The teacher saw the animal in the yard. She knew the children would want to play with it during recess.

Recognition Probes (in addition to the verbatim probe):

The teacher saw the animal on the lawn. (paraphrase)

The teacher saw the dog on the lawn. (inference)

The teacher saw the snowman on the lawn. (meaning change)

The data are presented in Table 3. The values are d 's with the instantiation sentences used as false alarms and paraphrases used as hits in order to determine the strength of the textbase. The instantiation sentences are the hits and the meaning change sentences are the false alarms in order to determine the strength of the situational model. These data are averaged across two-day and four-day delays between reading and recognition testing because the pattern was the same at each interval. When the inference involved an atypical member of the category (such as "chicken" for the sentence "The guest saw the bird that roasted on the grill"), neither low span nor high span subjects incorporated the inference in memory (cf., Whitney, 1986). This is clear from

the finding that the textbase representation is much higher than the model representation for inferences involving atypical exemplars. For inferences involving typical exemplars, we see a significant difference such that the low span subjects show a lower textbase representation and a higher model representation, while high spans show the opposite pattern. Once again, the low span subjects are more likely to go beyond the explicit text to form a definite interpretation.

Table 3: Strength of Textbase and Situational Model Representations for High Span and Low Span Subjects (in d' units)

<u>Span</u>	<u>Typicality of the Implied Exemplar</u>			
	<u>Typical</u>		<u>Atypical</u>	
	<u>Textbase</u>	<u>Model</u>	<u>Textbase</u>	<u>Model</u>
Low	.48	.81	.85	.38
High	.74	.45	.66	.46

The next project on the integration objective examined how strategies are affected when the subjects are given a goal to direct reading (Lee-Sammons & Whitney, 1991, see Appendix). This study allowed us to examine tradeoffs between global and local processing under conditions in which comprehension could be guided based on a priori information. Previous research on the effects of goals or perspectives on comprehension had obtained two conflicting patterns of data. Some studies indicated that goals guide retrieval but do not guide encoding. Other studies found evidence that goals do guide the comprehension process.

We conducted two experiments using text passages stimuli similar to those used in other research on the influence of goals on comprehension. The data of primary interest from the first experiment are the percentages of idea units recalled on the second attempt that were not recalled on the first attempt with and without a switch in reading goal.

Low and medium span readers actually recalled significantly less new information in the switch condition. Among high span readers, the recall of new information was not significantly related to the correspondence between the encoding and retrieval conditions. Clearly, the degree to which the subjects were bound to the original reading goal varied inversely with WM span.

In the second experiment, we used a similar passage but it was somewhat longer. We also had a no-goal condition in which subjects got the same instructions as in the goal conditions

(read carefully for good comprehension), but without a specified reading goal. We tested high span and low span subjects on two types of recall tasks. Half the subjects were given an immediate recall test and half were given a cloze completion test. In a cloze test, subjects are given a text with every fifth word deleted and asked to fill in the appropriate words.

Previous research has shown that cloze completion is affected generally by variables that influence sentence processing but not variables related to global, thematic processing. Therefore, we would not expect a variable that affects thematic processing, such as a reading goal, to affect cloze completion performance unless the variable induced a tradeoff between emphasizing global and local coherence. This suggested to us that for low spans we should find fewer cloze completions in goal irrelevant information. For high spans, cloze completion should be the same for goal relevant and goal irrelevant information. We again found that low span subjects were more bound to the reading goal in recall. In addition, the cloze data revealed the predicted tradeoff. One aspect of the high span's data is notable also. In both the recall and cloze data, providing a goal resulted in better overall performance than not receiving a goal. This suggests that the goals were not ignored by high span readers, but using the goal did not necessitate any processing tradeoffs.

In general, these experiments show that low span readers may be more likely to guide their reading in a "top-down" fashion based on prior knowledge or perspectives. This result could be critically important to understanding distortions and other comprehension problems associated with reading challenging text.

Understanding Expository Text

Like most of the researchers in this area, we have usually used narrative text as the stimuli in our experiments. However, not only does this neglect much of the reading that people actually do, but there are important theoretical reasons to extend research on WM management to expository text. Unlike narratives, expositions are organized around a variety of different structures. To complicate comprehension further, different sub-structures may be embedded within the same exposition. Because readers must determine the topic structure in a more on-line dynamic fashion in expositions (Britton, Glynn, & Smith, 1985; Lorch, Lorch, & Matthews, 1985), expository text offers a unique opportunity to study dynamic processes in WM management (cf., Fletcher, 1986). In addition, by relating different text comprehension strategies to what is learned from text, we can begin to understand the real impact of WM constraints on text processing.

The first study on expository text that we conducted

examined how reading goals and text organization affected high and low span readers. Robert Bramucci and I adapted a historical text on the development of railroads so that it contained idea units relevant to two goals: (1) understanding the time line along which development occurred, and (2) understanding the two conflicting views on whether railroads should be developed. High and low span readers were given one of the two goals to guide their reading and recall for the passage was tested. The total percentage of idea units recalled varied as a function of WM span and goal. There was no span effect when readers were given the goal of comparing the conflicting views (recall was 47% for highs and 43% for lows). When given the time line goal, however, high spans recalled much more than the low spans (35% and 57%, respectively). Note that there were no interactions with specific idea unit type (comparison or time line). Therefore, both span groups attempted to integrate all the information into each goal. We believe that the differential effectiveness of the two goals for each span group reflects intrinsic differences in the WM load required by different text organizations. We will explore the implications of this hypothesis in future work.

The pilot study that we have recently completed builds on the foundation of the previous work, but moves it ahead in an important way. Rather than just inferring what information was buffered based on recall patterns, we have directly examined information accessibility on-line.

The subjects read 24 brief expository paragraphs adapted from various non-technical science and hobby magazines. The paragraphs were organized with a simple hierarchical structure that allowed us to detect possible tradeoffs in macroprocessing and microprocessing. The first sentence was a topic sentence and it was followed by six supporting details. The subjects read each text in a self-paced, sentence-by-sentence fashion. Subjects were interrupted occasionally by a probe item that required a true-false judgment. The probes were concerned with the topic sentence or one of the details. They were presented either immediately after the related sentence or after a two-sentence or four-sentence lag. Probe type (topic or detail) and lag were manipulated within-subjects and different versions of the experiment were used so that each passage appeared in each condition. Of course, an individual subject saw only one version. Each paragraph ended with a filler probe item randomly drawn from one of the details. The filler probes made it difficult to determine any pattern in the nature of the probes. In addition, after each block of trials, the subjects were given a brief multiple choice test involving both topics and details of the paragraphs. The questions were given in order to encourage the subjects to read normally for comprehension. A block of six practice trials were used to acquaint subjects with the procedure and to orient them to the types of questions they would be asked.

We had originally intended to use reaction time to the probe as the dependent variable. Using a similar design, Glanzer and Nolan (1986) found a lag effect for details but not for topics. That is, after a lag of three sentences, probes to details were answered more slowly than in the immediate condition. However, we found that a number of subjects showed speed-accuracy tradeoffs when given unlimited time to respond to the probes. Consequently, we used a deadline procedure in which subjects had to respond to each probe (of 12-14 words) within 3.5 secs. Therefore, error rate was the dependent variable used. We pretested the probes and found that both high and low spans could read the probes in this time and have approximately 500 msec to make a decision. We have also found that high and low span subjects do not differ in sentence reading speed in a self paced reading procedure (Whitney & Bramucci, 1992). Thus, the present results are not compromised by baseline differences in reading rates.

We have data from 20 high span and 16 low span subjects. The cell means are shown in Table 4. There are several notable features of the data. First, the two span groups performed equally well in the lag 0 condition for topic probes. This confirms that the task is not too speeded for either group. Second, data from the high span subjects replicate the results of Glanzer and Nolan (1986)-- no lag effect for topics but a significant lag effect for details. Third, there are two interesting features of the data for low span subjects. They show what appears to be a topic reinstatement effect. That is, for the low span group, topic probes show a marked lag effect after two sentences, but at the four sentence lag (at or near the end of the passage) there is no longer a lag effect. This may be a paragraph wrap-up process analogous to the sentence wrap-up process posited by Just and Carpenter (1980; 1987). Low spans may not be able to buffer topics on-line throughout a paragraph, so they retrieve the topic from memory at the end of the paragraph to do macrostructure processing. This hypothesis will be explored in the studies proposed below. The other notable feature of the low span subjects' data is their difficulty with detail probes. Though the data from the high span subjects suggests that the detail probes are not more difficult than the topic probes, the low span subjects perform so poorly at lag 0 as to preclude finding lag effects for details. We are currently investigating whether low spans' poor performance on details is also a reflection of processing tradeoffs.

Table 4: Mean Proportions of Correct Responses
in the Probe Study

Span	Lag		
	0	2	4
TOPIC PROBES			
Low	.73	.55*	.70
High	.78	.78	.80
DETAIL PROBES			
Low	.64	.58	.62
High	.84	.77	.72*

Note: * indicates significant lag effect (cell mean less than lag 0 at $p < .05$)

The most general conclusion supported by the data collected so far is that processing is adapted flexibly to fit the ability of the reader so that different qualitative patterns of performance are associated with quantitative differences in WM span. More specifically, our hypothesis that low span readers would use inferences to actively compensate for poor WM capacity was supported in several different experiments. We have also begun to show that these compensatory processes spill over into the expository domain and result in qualitative differences in buffering topic information. These data strongly argue for a view of comprehension in which different subprocessors are organized ad hoc to fit current reading conditions (e.g., type of text) and the reader's ability. I am in the process of fleshing out a specific proposal along these lines.

PUBLICATIONS RESULTING FROM THE GRANT

Lee-Sammons, W.H., & Whitney, P. (1991). Reading perspectives and memory for text: An individual differences analysis. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 1074-1081.

Whitney, P., Ritchie, B.G., & Crane, R.S. (in press) The effects of foregrounding on readers' use of predictive inferences. Memory & Cognition.

PAPER PRESENTATIONS

Ritchie, B.G., & Whitney, P. (1990). The effects of foregrounding on spontaneous generation of predictive inferences. Paper presented at the Psychonomic Society Convention, New Orleans, LA.

Whitney, P., & Bramucci, R. (1991). Cognitive control and reading expository text: Goal Manipulations and working memory. Paper presented at the Psychonomic Society Convention, San Francisco, CA.

MANUSCRIPTS IN PREPARATION

Whitney, P., Waring, D.A., & Bramucci, R. On babies, bathwater, and schema theory: A cognitive control perspective on comprehension. To be submitted to Reading Research Quarterly.

When additional data has been collected, manuscripts based on the experiments discussed above will be submitted to Journal of Memory and Language and Memory & Cognition. (With Bill R. Ritchie as co-author).

PROFESSIONAL PERSONNEL

A graduate student, Bill R. Ritchie, was supported by this grant. He completed his masters thesis with support from this grant and was awarded the M.S. degree. He is nearing the completion of his Ph.D. His dissertation topic follows directly from his work on this grant. The topic is the question of the underlying nature of differences in WM capacity.

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