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The influence of individual differences in working memory span (WMS) on comprehension of instructional text was examined. Results showed that readers across the range of WMS paid special attention to thematic statements when they read instructional texts. This was shown through longer reading times of sentences in the initial position of paragraphs. However, if comprehension of specific details was stressed by asking about details after each passage, then high WMS readers increased thematic processing in comparison to reading times obtained when the questions were asked about topics and details. Low WMS readers did not increase thematic processing when details were stressed. The increased thematic processing by high WMS readers was associated with better comprehension of both topics and details on a later surprise test of learning. Higher WMS may allow some readers to use integrative strategies not available to other readers. However, we obtained evidence that performance could be improved for low span readers by manipulating text characteristics.

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# Augmentation of Research on Cognitive Control

Grant no. F49620-92-J-0243

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October 25, 1995

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## RESEARCH OBJECTIVES

The research supported by this grant was designed to explore the control processes involved in managing information during the reading of expository text and to relate these control processes to the readers ability to use and apply information after comprehension. More specifically we were trying to investigate how individuals adapt their reading strategies to specific variations in the text and to their own information processing limitations.

Research from several laboratories has established that individuals who are low in working memory capacity often read in a qualitatively different fashion than individuals who are average or high in working memory capacity (Lee-Sammons & Whitney, 1991; Just & Carpenter, 1992). For our purposes, working memory capacity is measured as the individual's ability to actively hold and manipulate information in short-term memory. However, most of the previous research has focused on narrative or rather story-like materials. This project moved the focus to expository text. Unlike narrative texts, which follow a organizational pattern quite familiar to most people, expository texts vary greatly in their organizational patterns. Additionally, in many instance, individuals do not have much prior knowledge about the topics of expository materials. This makes expository texts useful for the study of how people flexibly allocate their working memory resources during text comprehension. In addition, by studying expository materials, we hoped to uncover some basic principles that would provide a foundation for applied attempts at optimizing learning from text.

In the three years of the AASERT grant, Desiree Budd (the supported student) and I had three specific objectives:

1. We wished to determine how readers that differ in working memory capacity adjust their reading strategies to meet the demands of the specific types of tasks.

2. We wished to see what effect the adoption of specific reading strategies has on the nature of memory representations constructed by readers.

3. We wished to development a theoretical framework that could account for the ways in which readers accomplish flexible control over various reading-related processes.

## STATUS OF THE RESEARCH EFFORT

### Tradeoffs in Expository Text Processing

Theorist generally agree that successful comprehension and good memory for text depends largely on a reader's ability to construct links among the various idea units in a text. Because expository texts are usually organized around a set of hierarchically related topics, to achieve an adequate understanding of expository text readers need to represent these topics in their memory, determine how the topics are related to each other, and determine how the details are related to the relevant topic (Lorch, Lorch, & Matthews, 1985; Lorch, 1993; Glanzer & Nolan, 1986). Thus, for comprehension to be achieved the readers must manage and integrate both topic and detail information within working memory. We reasoned that readers with low working memory capacity (low spans) might face tradeoffs between global, thematic processing and local, detail processing due to processing bottlenecks in working memory. That is, they could keep track of local sentence-to-sentence connections and learn about the details in a passage or they could determine how each sentence relates to the overall theme and learn more about the general theme of the passage. In contrast, readers with higher working memory capacities (high spans) would be able to perform both types of processing.

In the first year of the grant, we developed a set of expository passages organized in a simple hierarchical structure. That is, each passage began with a statement of the overall topic of the passage, which was followed by six independent supporting detail sentences. The passages were adapted from various non-technical science and hobby magazines. Our research in the first year established that if subjects are probed during reading with questions about either topics or details, both high and low capacity readers can answer the topic probes quickly and accurately even several sentence after they have read the topic sentence. This result suggests that both high span and low span readers were maintaining topic information in working memory throughout the comprehension process. In other words, high and low capacity readers were both performing thematic processing.

In the second year of the grant, we extended the results by running two additional experiments. In the first of these experiments subjects read passages and answered topic and detail questions about what they read. Sentence reading times and accuracy for both topic and detail questions were measured in two conditions: 1) when topic sentences were present and 2) when topic sentences were absent. The amount of decrease in reading time over the first four sentences was used as a index of thematic processing. We found that higher and lower span readers performed similar amounts of thematic processing in both the topic present and topic absent conditions, but when thematic processing was made more difficult by removing the topic sentence, lower span readers showed a tendency to do more poorly on questions about specific details in the passages. Apparently the extra difficulty of performing thematic processing when the topic was not explicitly stated in the passage resulted in poorer performance on the detail questions for lower span readers.

We also wanted to determine if subjects would alter the amount of thematic processing they performed in response to being oriented to learning detail information. Thus, we replicated the topic present condition of the first experiment, except that subjects expected to receive only detail questions. We found that the amount of thematic thematic processing, as measured by our thematic processing index, increased with working memory capacity. That is higher span subjects performed more thematic processing than lower span subjects. Also, the high span subjects in this experiment performed more thematic processing, than the high span subjects in the first experiment. The amount of thematic processing performed by lower span subjects did not differ across experiments. Thus, higher span subjects actually increased thematic processing in response to being asked only detail questions. More interestingly we found that not only did higher spans subjects perform increased thematic processing, but they also scored higher than lower span subjects on an incidental test of topic and detail knowledge.

Taken together the results from these experiments suggest that when text processing is easy, high and low span subjects use similar WM management strategies. However, for more difficult text processing tasks, high and low span subjects adopt different WM management strategies and these strategies influence what is learned from the text. These results are presented in greater detail in the forthcoming article by Budd, Whitney, & Turley (1995). [see appendix]

We also began testing whether the comprehension deficits experienced by the low WM capacity readers could be ameliorated. We tested memory for brief expository passages that ended in either a literal of metaphorical summary. We predicted that poor comprehenders would benefit from metaphorical summaries, which are easier to remember and hold in working memory. The results supported our prediction. These data are reported in Whitney, Budd, & Mio (in press). [see appendix]

The research we conducted in the first two years of this grant lead directly to the research we completed in the third year. We replicated the second experiment above using the topic absent version of each of the passages. In this case, however, we did not get any thematic processing differences between high and low span subjects. That is both high and low span subjects performed similar amounts of thematic processing. In addition we found that question accuracy for both detail and topic questions increased as the amount of thematic processing increased, and that this was true for both high and low span subjects. These data are also reported in Budd et al. (1995).

In the third year we also began testing a new priming paradigm that will allow us to map the effects of specific working memory strategies on the memory representation readers' construct for text. More specifically, this paradigm should allow us to determine under what conditions readers of different WM capacities use thematic information to facilitate integration of subordinate detail information into their text representation.

This priming paradigm was adapted from van den Broek and Lorch (1993). Subjects read passages and are given specific goals, such as answering detail questions or writing summaries for some of the passages. After the subjects finish reading all the passages, they perform a priming verification task. Target statements (paraphrases of the fifth detail sentence in each passage) are presented after a related prime sentence. The prime sentence is either a paraphrase of a) the topic sentence (topic prime), b) the first detail sentence (distant detail prime), or c) the fourth detail sentence (adjacent detail prime). Subjects are given five seconds to read and respond to the probe. The observations of interest are the differences in response accuracy among the three conditions.

According to extant reading theories, readers who adopt strategies that support high levels of thematic processing should construct direct connections in memory between the topic of a passage and each supporting detail in that passage, as well as direct local sentence-to sentence connections. While readers who adopt strategies that supports mostly local processing (sentence-to-sentence connections) are less likely to construct direct connections in memory between the topic of the passage and distant details supporting that topic. If this is true, then we would expect the readers who adopt reading strategies that support thematic processing to have high levels of accuracy in both the topic prime and adjacent detail prime conditions and lower accuracy in the distant detail prime condition. While we would expect the readers who adopt reading strategies that support mostly local processing to have high accuracy in the adjacent detail prime condition and lower accuracy in the topic prime and distant detail prime conditions. Preliminary data (N=55) using this paradigm indicates that readers show the predicted trends.

Our previous research showed that subjects adopt reading strategies according to their specific reading goals and working memory limitations. In the future, therefore, we intend to expand the above priming paradigm to examine the nature of the memory representation that results from adopting a particular processing strategy, and the effect of working memory capacity on the efficiency of different reading strategies.

## Theory Development

In the third year of this grant we also completed the development of a theoretical framework, which proposes that flexibility in reading emerges form distributed activation control. Several researchers in the area of text comprehension have claimed that skilled readers adjust their comprehension process to fit the nature of the text they are reading and their current comprehension goals (e.g., Just & Carpenter, 1992; Vonk & Noordman, 1990; Zwann, 1994). We believe that adjustments of the comprehension system to such contextual constraints may also include adjustment by readers to their own working memory capacity limitations. This raises the question of how the comprehension system can be self-organizing to adapt to variety of contextual constraints. In the past, the control processes used to make these adjustments have often been assigned to a "central executive". In contrast we have developed a Distributed Activation Control (DAC) framework that provides a basis for understanding how the information processing system can make context sensitive adjustments, by using a set of distributed control processes. The architecture of the DAC framework is a hybrid of semantic network and a production system. DAC's utility is its ability to elucidate the idea that qualitative differences in comprehension processes emerge because the system adapts both to the nature of the reading task and to the working memory capacity of the reader. Additionally, DAC goes beyond just describing the adjustments that readers make in specific context and actually allows us to make predictions about what types of adjustments will be made in what contexts and what kinds of information will be learned from a text depending on the reader's characteristics and the comprehension goals. This theoretical framework is described in Whitney, Budd, Bramucci, & Crane (1995). [see appendix]

## REPORTS RESULTING FROM THE GRANT

### Conference Presentations

Whitney, P. , Budd. D., & Turley, K.J. (1994). Reading goals, working memory capacity, and thematic processing in expository text. Read at the 35th Annual Meeting of the Psychonomic Society, St. Louis, Missouri.

Budd, D., & Whitney, P. (1993). Allocation of working memory while reading expository text. Read at the 34th Annual Meeting of the Psychonomic Society, Washington DC.

### Published Manuscripts

Whitney, P., Budd, D., Bramucci, B. & Crane, B. (1995). On Babies, bathwater, and schemata: A reconsideration of top-down processes in comprehension. Discourse Processes, 20, 135-166.

### Manuscripts In Press

Budd, D., Whitney, P. & Turley, K. (1995). Individual differences in working memory strategies for reading expository text. Memory & Cognition. To appear in the November issue.

Whitney, P., Budd, D., & Mio, J.S. (in press). Individual differences in metaphoric facilitation of comprehension. In J.S. Mio & A. Katz (Eds.), Metaphor: Application and Implications. Hillsdale, NJ: Erlbaum.

### Professional Personnel

The graduate student supported by the AASERT grant was Desiree Budd. She began her dissertation last year and will complete her degree in the spring. Her dissertation is entitled "Individual difference in working memory strategies for reading expository text." It is a continuation of the research covered by this grant.

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# APPENDIX

DISCOURSE PROCESSES **20**, 135–166 (1995)

# On Babies, Bath Water, and Schemata: A Reconsideration of Top-Down Processes in Comprehension

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Problems with traditional constructionist views of comprehension, which are often based on schema theories, are reviewed in light of recent evidence that suggests that bottom-up processes are predominant in comprehension. Three alternative views of the role of top-down processing in comprehension are also reviewed: (a) the minimalist framework, (b) construction-integration theory, and (c) schema-assembly theory. Although each of these views has some merit, none of the views adequately addresses the context-sensitive nature of top-down processes in comprehension. A new theoretical framework is proposed that synthesizes elements from each of the three alternative views. The new framework focuses on how distributed activation control (DAC) is maintained by the comprehension system. It is proposed that some elements of schema theories remain important to comprehension if we are to understand how the flow of information activation is controlled in various reading contexts.

Over the past several decades, theories of text comprehension have differed widely with regard to the roles assigned to top-down processes. Some theories have placed great emphasis on the idea that preexisting knowledge guides the process of comprehension from the top down (e.g., Goodman, 1970; Schank & Abelson, 1977). Other theorists have given preexisting knowledge only a minimal role in guiding the comprehension process (e.g., Gough, 1972; Haviland & Clark, 1974). Although there is now broad consensus that comprehension involves an interaction of top-down and bottom-up processes, exactly what form that interaction takes, and relative importance of each type of process, remains unclear and controversial (cf. Rayner & Pollatsek, 1989).

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Two general questions about top-down processes have received considerable attention in the literature. First, to what extent is the knowledge base used to augment, or elaborate on, the information that is obtained from the bottom up? Second, to what extent do knowledge-based processes affect the flow of bottom-up information itself?

Examples of research addressing the first question can be found in the ongoing debate over the role of elaborative inferences in text comprehension (Graesser, Singer & Trabasso, 1994). Constructionist views of comprehension claim that the mental representation of text includes a model of the situation described (e.g., Graesser & Clark, 1985; Johnson, Bransford, & Solomon, 1973; Johnson-Laird, 1983). This model is constructed, not just from information directly associated with the text, but also from general world knowledge. In contrast to the constructionist view, several theorists have argued that readers form a representation that stays quite close to the information explicitly mentioned in the text (e.g., Alba & Hasher, 1983; Haviland & Clark, 1974; McKoon & Ratcliff, 1992). According to these theorists, comprehension is guided in a bottom-up fashion by the text itself, and, therefore, reading does not typically produce an elaborated model of the situation described by the text.

The second question about top-down processes, whether knowledge-based processes can alter the flow of bottom-up information, has produced an equally polarized debate. The strongest and most interesting version of this question is whether the general knowledge activated early in discourse processing can influence later lexical access. Some data suggest that discourse-level knowledge can affect early stages of access (e.g., Morris, 1994; Schwanenflugal & LaCount, 1988; Tabossi, 1988). Other data suggest that initial semantic activation is driven purely from the bottom up, so that any interaction with top-down activation occurs after the initial stages of lexical access (e.g., Forster, 1979; Kintsch & Mross, 1985; Stanovich & West, 1983; Whitney, McKay, Kellas, & Emerson, 1985).

Questions concerning elaborative inferences and lexical access have usually been treated separately by comprehension researchers. Nevertheless, for both questions, most investigators who posit a major role for top-down processes invoke some version of schema theory to explain how world knowledge is organized and deployed in comprehension (e.g., Bower, Black, & Turner, 1979; Graesser & Clark, 1985; Morris, 1994; A.J. Sharkey & N.E. Sharkey, 1992). Thus, debates over top-down processing have often centered on the evidence for and against schema-theoretic views of comprehension (e.g., Alba & Hasher, 1983; Kintsch, 1988).

Although schema-theoretic notions dominated much of the research on comprehension in the 1970s and 1980s, considerable evidence has mounted against claims that comprehension is a top-down, expectation-based process (cf. Kintsch, 1988). Consequently, there is a growing emphasis on the role of bottom-up processing in determining the content of a text representation and a corresponding decline in the use of schema-theoretic ideas as part of models of



comprehension (e.g., Kintsch & Welsch, 1991; McKoon & Ratcliff, 1989a, 1992; Potts, Keenan, & Golding, 1988; but see also Morrow, Bower, & Greenspan, 1990).

In this article, we consider whether schema-theoretic views of comprehension have outlived their usefulness. Our discussion is divided into three parts. First, we present a brief overview and critique of classic notions of how schemata may function to guide top-down processing in comprehension. Second, we assess three alternative views of comprehension and their implications for top-down processing: (a) the minimalist framework (McKoon & Ratcliff, 1992), (b) construction-integration theory (Kintsch, 1988), and (c) schema-assembly theory (e.g., Abbott, Black, & Smith, 1985; N.E. Sharkey, 1986; Whitney & Waring, 1991). Although each of the alternative views has merit, none of the extant views adequately addresses readers' flexibility in the use of top-down processes across varied contexts. Third, we present a new theoretical framework that represents a synthesis of key ideas from the three alternative views. We argue that this framework provides a more accurate picture of the role of top-down processes in comprehension.

## SCHEMA THEORIES AND THEIR CRITICS

There is, of course, no single schema theory. Instead, the term *schema* denotes a family of theories that have been widely (some may say wildly) used in the study of comprehension, memory, artificial intelligence (AI), social cognition, personality, and other topics. The term schema has been applied in so many ways, and in so many different contexts, that critics frequently claim that *schema theory* is vague and untestable (e.g., Brown, 1979). It is well known that Bartlett (1932), whose work influenced modern schema-theoretic views, lamented the ambiguous nature of the concept. However, at least in some recent comprehension research, schema-theoretic views have been proposed that are amenable to experimental tests.

### Support for Schema-Theoretic Views

For psychologists interested in language, early AI models of schemata were particularly important. Researchers in AI considered generic knowledge structures of various kinds, including scripts (Schank, 1975, 1978) and frames (Minsky, 1975), to be essential to understanding even the simplest materials. Schank (1978), in particular, argued that all levels of language comprehension are expectation driven, with bottom-up processing serving as a kind of backup to be used when expectations are violated. Many comprehension researchers adopted the notion that our knowledge of objects, events, and actions consists of schematic representations that specify the elements involved in stereotypical situations and the relations among those elements (R.C. Anderson & Pearson, 1984; Rumelhart & Ortony, 1977).

Traditional schema theories made two claims that were of particular importance to the study of text comprehension: (a) Schemata contain slots for variables that may be filled by default values and (b) schemata are used during encoding to guide processing and organize the mental representation.

The notion that schemata contain default values leads to the prediction that readers will infer the presence of some elements not directly stated in the text. Evidence that supported this claim came from studies in which participants' memory representations seemed to include elaborative inferences. For example, Paris and Lindauer (1976) found that participants falsely recognized probable instruments for actions as being explicitly present in sentences that they had read. Thus, a verb such as *dig* could activate a corresponding schema with a slot for an instrument. If no instrument is specified by the text, the slot is filled by the most probable instrument, *shovel*, for example.

The claim that schemata guide connections among text elements also received extensive support. For example, numerous studies found that if the reader was given a title that biased the interpretation of an ambiguous text, then memory for the text was increased but intrusions from world knowledge also increased (e.g., Bransford & Johnson, 1972; Dooling & Lachman, 1971). In addition, recall of texts that describe familiar actions, such as going to a restaurant, seemed to be affected by relevant schemata. Bower et al. (1979) found that the contents and ordering of actions recalled from a text were predictable from normatively defined scripts of common social activities. Thus, the data supported the notion that schemata organize the relations between elements in the text. Moreover, several theorists argued that the influence of schemata extended to the level of initial processing of individual word meanings (e.g., R.C. Anderson & Ortony, 1975; Bower et al., 1979).

### The Case Against Schematic Processing

Although schema theorists made claims about what was happening online during comprehension, the evidence supporting schema-theoretic views initially involved analysis of recognition and recall data. With these offline memory tasks, it is difficult to distinguish between processes that take place at encoding and processes that take place at the time of testing. For example, recall data are suspect because cues that are not processed at encoding can serve as effective recall cues (Corbett & Dosher, 1978).

As researchers began to use online methods to study comprehension, schema-theoretic claims about the comprehension process were qualified in important ways. In a study of instrumental inferences, Dosher and Corbett (1982) had participants read sentences that implied a likely instrument for an action. After each sentence, the probable instrument appeared as the target stimulus in a modified Stroop task. Thus, participants read *The man dug a hole* and then the target *shovel* appeared. The participants had to name the color in which the word was printed. Unless the participants were instructed to make instrumental inferences, reaction times to the targets were the same after instrument priming



sentences and control sentences. These data undermined the notion that verb frames serve as schemata with default values that are inferred if the text does not provide an explicit value for a slot in the schema.

The claim from traditional schema-theoretic views that schemata guide encoding processes was also undermined by several studies. For example, R.C. Anderson and Pichert (1978) found that, when participants were given a perspective to guide encoding of a passage, they recalled more perspective relevant information than perspective irrelevant information. However, when the participants were given a new perspective to use for a subsequent recall attempt, they recalled previously unrecalled information relevant to the new perspective. This suggests that perspective schemata were guiding retrieval but not encoding.

Kintsch and Mross (1985) investigated whether schemata could affect the initial sense-activation phase of lexical access. Participants read or listened to passages based on scriptal activities such as getting onto an airplane. When a key word was presented in the passage (e.g., *plane*), the participants immediately responded to a lexical decision target to determine what aspects of the meaning of the key word were primed. As long as the target was associatively related to the key word in the passage (e.g., *fly*), lexical decisions were facilitated relative to a target. However, when the target was thematically, but not associatively, related to the meaning of the word in the context of the passage (e.g., *gate*), there was no facilitation relative to control. Kintsch and Mross concluded that a schema that expresses the theme of a passage exerts no top-down influence on the early stages of activation of word meanings. However, A.J. Sharkey and N.E. Sharkey (1992) criticized the materials used by Kintsch and Mross, which were based on experimenter generated norms. Using materials based on participant-generated norms, A.J. Sharkey and N.E. Sharkey found evidence of schematic effects on lexical processing. Thus, although there is consensus that early versions of schema theory overestimated the degree of top-down processing in comprehension, it is less clear that we should discard the concept of schema altogether.

## ALTERNATIVES TO TRADITIONAL SCHEMA THEORIES

Each of the general views of comprehension discussed in this section differs, in varying degrees, from traditional schema-theoretic views in the relative emphasis on top-down processes. We summarize and evaluate the minimalist, construction-integration, and schema-assembly positions, in turn. Each view makes different predictions about the extent to which an elaborated model of a text is constructed and the extent to which preexisting knowledge affects the bottom-up flow of information, including lexical access. It is important to bear in mind that the effects of top-down processing on elaboration and lexical access are separable. Thus, different theoretical positions can, in principle, differ on one dimension and not the other. As a preview of the three positions, and as a bridge to the earlier section of this article, consider the relation between different theories of comprehension depicted in Figure 1.

Goodman's (1970) theory that reading is a "psycholinguistic guessing game" and Schank's (1978) script theory are no longer considered to be viable theories of comprehension, but they do help to illustrate that the elaborative dimension and the lexical dimension of top-down processing are, at least theoretically, orthogonal. Goodman believed that expectations drive the process of decoding print, but his view did not predict extensive elaboration beyond the text, at least not for skilled readers. In contrast, Schank's view was that top-down processes were ubiquitous at all levels of language processing, so his theory predicted a high degree of both knowledge-driven decoding and text-level elaborative inferences.

As Figure 1 also illustrates, the three current theories that are the focus of this section are more conservative than traditional schema theories with regard to the extensiveness of top-down processing. However, each of the three theories differs significantly from the others on both dimensions.

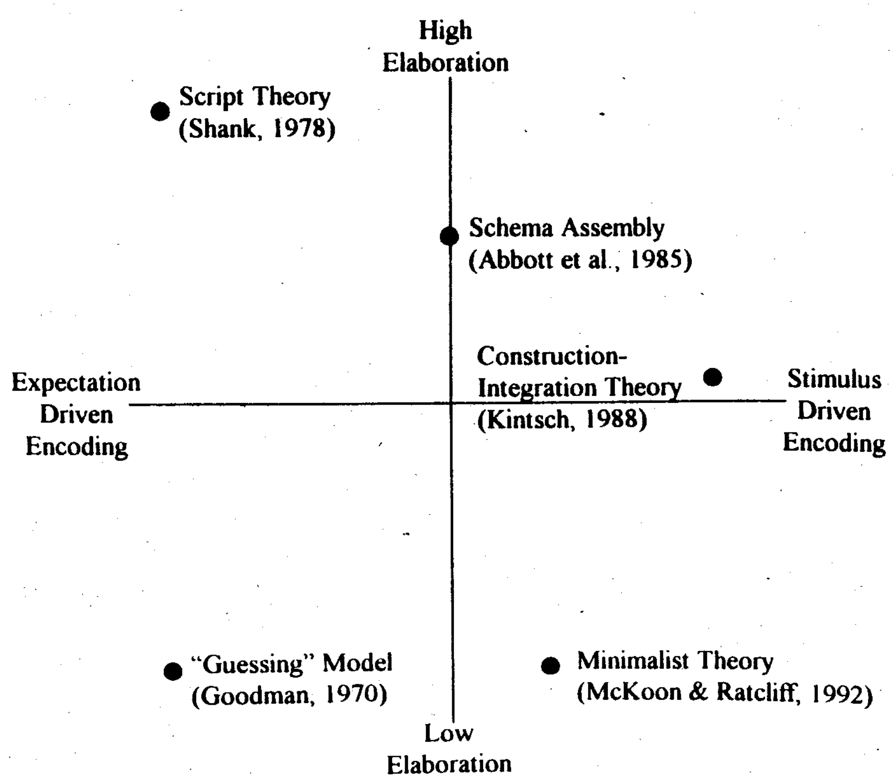


**Figure 1.** Positions of several theories of comprehension on the two dimensions of top-down processing.



### A Minimalist View of Processing

According to the minimalist view, unless the reader is using specific, goal-directed strategies, top-down processes play a very limited role in comprehension (McKoon & Ratcliff, 1989a, 1989b, 1992). McKoon and Ratcliff (1992) claimed that readers do not usually construct extensively elaborated representations of text nor do they reorganize text propositions around schematic templates. Instead, they claimed that only two types of inferences are constructed automatically: those that are quickly and easily available and those that maintain local coherence between concurrently processed portions of a text.

Obviously, the definition of automaticity is central to the minimalist view. McKoon and Ratcliff (1992) offered two criteria for automaticity: Automatic inferences are easy to generate and they are used across various contexts. Thus, the minimalist view predicts that a text representation will be elaborated only if the text activates a particular concept from the knowledge base very quickly and easily. Such a concept may then be stored as part of the text representation. For example, if a participant reads a text about animals being milked on a farm, the inference that the animals are cows may be stored because the strong associations among cows, milk, and animals makes the concept of *cow* readily available (McKoon & Ratcliff, 1989b). However, the minimalist view proposes that relatively few elaborative inferences are made because a very limited amount of information from the knowledge base is available quickly and easily enough to be inferred as part of the text representation (McKoon & Ratcliff, 1992). Consequently, the minimalist view does not allow for inferences generated by filling the slots of a schema with default values (McKoon & Ratcliff, 1989a).

Evidence that elaborations are not drawn online as frequently as first believed (e.g., Dosher & Corbett, 1982), is consistent with the minimalist position. In addition, McKoon and Ratcliff (1992) also argued that, although numerous studies have documented that information from the preceding proposition is available to assist processing of a new proposition (e.g., Keenan & Kintsch, 1974; Ratcliff & McKoon, 1978), there is less evidence that global connections are formed between more distant text elements. They based this claim on studies investigating whether superordinate goals of a character in a narrative are readily available later when the reader is processing actions related to a subgoal (e.g., Fletcher & Bloom, 1988). For example, Fletcher and Bloom (1988) studied how sentence reading times varied with the goal structure of brief narratives. The data indicated that participants focused their attention on the last proposition that was a likely causal antecedent without a consequence. McKoon and Ratcliff also reported several experiments in which superordinate goals did not appear to be maintained throughout reading of a text. These data suggest that readers emphasize local coherence rather than the construction of a representation that is based on information supplied from general knowledge or even information from earlier in the text.

It is somewhat more difficult to characterize the implications of the minimalist position for top-down influences on lexical access because, in contrast to the other views considered here, McKoon and Ratcliff (1992) did not draw a distinction between inferences and activation of meaning features of words in context. It is clear, however, that the minimalist position does allow for a very limited kind of top-down effect in which local sentence context can influence the encoding of meaning features of nouns. So, for example, when a reader processes a sentence about someone rolling a tomato, the property that tomatoes are round is encoded, even though this feature of *tomato* is not explicitly mentioned in the sentence (McKoon & Ratcliff, 1988, 1992). The minimalist view does not address whether local context affects the earliest stages of lexical access or only the later meaning integration processes.

Almost as soon as McKoon and Ratcliff (1992) proposed the mimimalist view, numerous criticisms appeared (e.g., Glenberg & Mathews, 1992). These criticisms are discussed at length by Singer, Graesser, and Trabasso (1994), so we only highlight a few of the major criticisms here.

One of the difficulties with the minimalist position is that it sets up a false dichotomy: either readers are as constructive in their processing as early schema theories would predict or readers process text with very restricted use of top-down processes. In contrast, theorists working from a more constructivist perspective have incorporated substantial limitations on readers as inference engines, while still proposing an important role for elaboration. For example, Singer et al. (1994) stated that inference generation is restricted generally to a search for the causal explanations necessary to construct a coherent situational model of the events described in a text (see also Graesser et al., 1994).

Another difficulty with the minimalist view is the definition of automaticity that underlies their claim that only local coherence is emphasized in forming connections among text elements. One of McKoon and Ratcliff's (1992) criteria for defining the minimal inferences that are constructed automatically online is that these inferences are easy to generate. They noted, however, that "some strategic inferences may be easy to generate, perhaps nearly as easy as minimal inferences" (p. 440). In addition, some kinds of bridging inferences that are constructed online routinely appear to be slow and resource demanding (e.g., Lesgold, Roth, & Curtis, 1979). This suggests that it may be difficult to distinguish automatic from strategic inferences on the basis of ease of generation.

Finally, a number of studies of inferences in text comprehension specifically refute the minimalist view of top-down processes. For example, the data from several studies support the contention that readers attempt to provide causal explanations for events in narrative text, even if the inferences require connections that are not based on local coherence. When reading texts with fairly complex goal structures, readers often connect goals and events that are quite distant from each other in the text (e.g., Long, Golding, & Graesser, 1992; Trabasso, van den Broek, & Suh, 1989). Elaborations that facilitate the construction of causal explanations, such as emotions or goals of characters, may be



generated quite often (e.g., Stein & Levine, 1991). In addition, causal sufficiency affects whether readers are willing to make predictions about the consequences of actions described in a text (Murray, Klin, & Myers, 1993; van den Broek, 1990, 1994). Several studies have shown that readers do make predictive inferences about central actions in a narrative when the causal consequences are compelling and the action is a major focal point of the passage (e.g., Fincher-Kiefer, 1993; Whitney, Ritchie, & Crane, 1992).

Given these problems with the minimalist view, what does it have to contribute to our understanding of top-down processes? We believe that the most important contribution of minimalist theory may be that it focuses attention on the variability of top-down processes across contexts. As McKoon and Ratcliff (1992) suggested, some types of inferences may be quite general across different contexts, whereas others are used only infrequently as a special strategy. Thus, the context sensitivity of top-down processes is an important issue to which any theory of top-down processing must be sensitive (see also Graesser & Kruez, 1993; van den Broek, Fletcher, & Risden, 1993; Whitney & Waring, 1991).

**Construction-Integration Theory**

Consistent with earlier theories of comprehension (e.g., Johnson-Laird, 1983; van Dijk & Kintsch, 1983), Kintsch (1988) argued that comprehension may result in both a text base and an integrated situational model of the text (in addition to a short-lived trace that preserves the surface form of the text). The model is constructed from explicitly stated information and from information inferred from the knowledge base. However, in Kintsch's theory, the knowledge base is a semantic network that has no schematic structures. Kintsch proposed that comprehension proceeds through two general phases: a construction phase based on bottom-up activation of information in a semantic network and an integration phase in which a situational model is constructed based on both top-down and bottom-up processes.

The construction phase consists of four stages. In the first stage, a propositional representation is activated based on context-independent access to individual word meanings. In the second stage, the activation spreads to associated information in the knowledge network. A third stage is used if particular reading goals require it: Specific goal-directed elaborations are activated based on information in the semantic network. In the fourth stage, connection strengths are assigned to all pairs of elements activated during the first three stages. Propositions derived directly from the text are connected with positive strength values proportional to their proximity in the text. In addition, the text-based propositions are linked by positive and negative connection values with propositions activated in the general knowledge network. Thus, the construction phase results in a network of interconnected concepts. However, because there are no schema-like structures to guide the activation process, the information activated during the construction phase may include a good deal of irrelevant information.

In the integration phase of Kintsch's (1988) model, the elaborated, and possibly incoherent, text base is modified based on positive and negative connections in the network of activated concepts. A model of the text is constructed as the network settles into a stable pattern of activation. This procedure is similar to that of several connectionist models in which irrelevant information is inhibited and critical concepts receive greater activation (cf. McClelland & Rumelhart, 1986). However, there is one very important difference between construction-integration theory and other views of top-down processing that make use of connectionist-style knowledge networks (e.g., Rumelhart, Smolenski, McClelland, & Hinton, 1986; Smolensky, 1986). In construction-integration theory, the initial construction phase is strictly from the bottom up. Only in the later integration phase of comprehension can knowledge affect the representation of text in a top-down fashion.

The moderate amount of elaboration predicted by construction-integration theory fits better with the evidence on inferences in comprehension than does the minimalist view of McKoon and Ratcliff (1992). In fact, recent constructivist approaches to comprehension (e.g., Graesser et al., 1994; Singer et al., 1994) could be implemented within the construction-integration framework. However, the fit between construction-integration theory and these more recent views of elaboration is not perfect. For example, Graesser et al. (1994) pointed out that construction-integration theory would have to be augmented with a special set of nodes to implement the idea that inference processes are directed toward the construction of causal explanations for actions. However, using this approach to augment construction-integration theory resembles the kind of schema-directed processing that Kintsch (1988) disavowed in proposing his theory.

Construction-integration theory makes its strongest claims, not about elaborative inferences but about the lack of top-down influences on lexical access. A number of studies have evaluated whether initial lexical processing is strictly from the bottom up. The key evidence concerns whether ambiguous words that occur in sentence or passage contexts show context-dependent or context-independent initial semantic access. If a participant reads, "The boy fished from the bank," is the financial meaning of bank accessed briefly, and then suppressed, or do we get direct access to the appropriate meaning of the word *bank?* According to the construction-integration theory, multiple meanings of *bank* will be activated during the construction phase regardless of the nature of the context in which the word occurs.

Consistent with the construction-integration theory, several studies have shown that multiple meanings of ambiguous words are initially accessed even in biasing sentence contexts (e.g., Onifer & Swinney, 1981; Till, Mross, & Kintsch, 1988). However, there is a growing body of evidence that whether lexical access is context independent or context dependent is a function of both the type of sentence context in which a word is embedded and the salience of the meaning that is implied (MacDonald, Pearlmutter, & Seidenberg, 1994; Paul, Kellas, Martin, & Clark, 1992; Simpson & Kreuger, 1991; Tabossi, 1988; Tabossi, Colombo, & Job, 1987; Van Petten & Kutas, 1987). Specifically, if there is a strong match between the features of meaning suggested by the prior context and the most salient meaning features of the ambiguous word, then meaning access can be selective.

A recent study by Vu, Kellas, and Paul (1994) nicely illustrates how potent the influence of top-down processing can be. Participants read simple subject-verb-object sentences in which the object was a lexically ambiguous word. Strength of biasing contexts was manipulated by using a subject or verb that instantiated a message level interpretation that strongly restricted the set of semantic features that were relevant when the ambiguous word was encountered. For example, in *The soldier approached the base,* the subject noun strongly constrains the relevant features of *base,* whereas *The man approached the base* leaves the object interpretable, but perhaps still ambiguous. Vu et al. found selective access of homograph meanings following the strongly biasing primes. Control experiments ruled out intralexical priming and prediction of the object noun as explanations of the effects. These data are consistent with McClelland's (1987) claim that top-down processes can sometimes direct the flow of information in lexical access. Similar results were obtained by Tabossi (1988) with strongly biasing contexts. However, if the contexts are only weakly biasing, then multiple access of ambiguous meanings is obtained.

Other studies have reached a similar conclusion in investigations of lexical access for unambiguous words. Schwanenflugel and LaCount (1988) showed that sentence contexts that strongly constrain the meaning features of later words affect lexical access in a top-down fashion. Though construction-integration theory allows for some top-down processing, the data on top-down influences on lexical access show that construction-integration theory, like the minimalist view of McKoon and Ratcliff (1992), underestimates the role of top-down processes in comprehension. In contexts that strongly constrain what information may follow, top-down processing can guide comprehension to a greater degree than either minimalist or construction-integration views have suggested. One way to view this pattern of evidence is that contexts vary in the degree to which they induce schematic processing. This is the approach taken in schema-assembly theory.

### Schema-Assembly Theory

The problem with traditional schema-theoretic views was their inflexibility. In some contexts, readers may process text in a very schema-driven fashion, whereas in other contexts, there is little evidence for schematic processing. Several researchers have suggested that the traditional schema theory can be modified to make it more contextually sensitive (e.g., Abbott et al., 1985; Rumelhart et al., 1986; Schank, 1982; N.E. Sharkey, 1990; Whitney, 1987). Such "schema-assembly" theories assert that some sets of nodes are so strongly connected in a semantic network that schema-style processing is approximated in some contexts. That is, something analogous to schemata may be assembled online to meet the demands of the current context.

Schema-assembly theories may be implemented either in distributed or localist connectionist networks. To be brief, we will consider only localist networks. The key features of this knowledge representation view are: (a) there can be activation and inhibition from both incoming text and from associated nodes in the knowledge base, (b) the nodes have different resting activation strengths that depend on frequency of activation, and (c) the activated assembly of nodes that is carried over from one processing cycle to the next (e.g., when a new proposition is input during reading) has a controlling influence on the flow of activation that results from new inputs. The latter feature is the most important difference between a schema assembly view and construction-integration theory. Only in the schema-assembly view can the context assemble a set of concepts that have sufficient connection strengths to other concepts so that the bottom-up flow of information is altered (cf. McClelland, 1987).

Modifications to the classic notion of the restaurant "script" (Schank & Abelson, 1977) can serve as simple examples of schema assembly. According to the traditional view, when a restaurant was mentioned in a story, the precomplied script would be retrieved with a set of default values for important slots. However, if we think of restaurant information as being stored in a network structure that only approximates the script notion, we get a much more flexible schema concept. Consider the following text segments:

(1) On their 10th anniversary, Suzanne and Robert went to the restaurant up on the hill.
(2) To discuss the merger, Jack scheduled a noon meeting for the partners at the restaurant up on the hill.

Sentence 1 suggests perhaps a generic "fancy" restaurant. Walker and Yekovich (1987) showed that after such a sentence some central concepts, such as *meal, table*, and *bill*, would be carried over in working memory (WM) as more sentences were input. Related, but normatively more peripheral concepts, such as *hostess* and *cocktails*, apparently receive little activation. Note that semantic attributes related to paying the bill would thus be in a very accessible state. Consequently, if the word *bill* occurred in a later sentence, we would not expect readers to initially activate the meaning of *bill* that refers to a part of a duck. Sentence 2 gives a somewhat different picture of the restaurant script. Because of the convergence of activation from our knowledge of business meetings and the infamous "three-martini lunch" with concepts associated with going to a restaurant, we get a somewhat different schema assembled. At least some of the same concepts would be considered central and peripheral as before, but now *cocktail* would also be a central concept. This would potentially control activation in ways that were not true for Sentence 1. For example, we now would expect that a later reference to *a drink* would be processed as an unambiguous reference to an alcoholic beverage.



As the preceding example illustrates, the schema-assembly view is consistent with the findings from studies of lexical ambiguity that were problematic for construction-integration theory. Because the schema-assembly process is driven by the current stimulus environment, these models are more contextually sensitive than traditional schema theories. However, in many cases, processing is less schematic, so that processing becomes a more balanced mixture of bottom-up and top-down processing.

Data from several other types of experiments are congruent with the schema-assembly view. For example, recent studies of lexical access of unambiguous nouns refute the claim that lexical access is independent of top-down influences from stored representations. N.E. Sharkey and Mitchell (1981, 1985) found evidence suggesting that texts that follow a well-known script speed the lexical access of script-relevant words. More recently, N.E. Sharkey (1990) showed that the degree to which lexical access is facilitated by top-down processes is consistent with a schema-assembly model.

Additional evidence for top-down effects on lexical access comes from a study by Morris (1994). Readers' eye movements were recorded as they read sentences in which message-level priming and intralexical priming could be separated. Morris found clear evidence that readers' fixations were speeded by higher order connections between the sentence and a target noun, even when prime and control conditions had the same lexical content. Morris argued that simply having *barber* and *trimmed* in a sentence result in intralexical priming of *mustache*. However, if a sentence begins, *The barber trimmed* . . . , then there is a higher order schema activated that feeds activation, beyond that expected from intralexical priming, to related targets like *mustache*. These data are not consistent with predictions from construction-integration theory, but they are consistent with a schema-assembly view. Similarly, Hess, Foss, and Carroll (1995) found that global discourse contexts had larger and more consistent facilitative effects on lexical processing than did local associative relations.

A schema-assembly view is also consistent with the context sensitivity of the generation of elaborative inferences. For example, the probability of making an elaborative inference depends strongly on the ease of accessibility of relevant information in memory (e.g., McKoon & Ratcliff, 1989b; Whitney, 1986). Thus, elaboration of a text may often be minimal in the sense described by McKoon and Ratcliff (1992), but inferences will be more extensive when the background knowledge accessed is well integrated and extensive. As noted earlier, readers appear to generate inferences about why certain events occur in a narrative because they have considerable knowledge of the causal connections between everyday events (Graesser et al., 1994; Graesser & Kreuz, 1993). Other relevant data come from studies of social cognition. When participants read about the behavior of someone in a brief narrative, elaborative inferences about the person's disposition appear to be minimal unless the behavior consistently points toward a certain trait or the person fits a stereotype that we have stored in memory (Belmore, 1987; Trope, 1986; Whitney, Waring, & Zingmark, 1992).

Stereotypes appear to function as schemata that automatically lead to elaborative inferences in text comprehension. Thus, making inferences about characters described in narratives varies on a continuum from schematic to data driven in the way schema-assembly theory would predict.

Although schema-assembly theory offers a reasonable means to address the question of how the text and the knowledge base interact, this is only part of the problem of explaining comprehension. For example, schema-assembly theory does not address the nature of the representations produced by the comprehension process. As noted earlier, there is considerable evidence that reading may result in both a text-base representation and a situational model of a text (Kintsch, 1988; Kintsch, Welsch, Schmalhofer, & Zimny, 1990).

In the next section, we present a general framework for addressing the flexibility of top-down processing. Our framework specifies how the processes proposed by schema-assembly theory can lead to multiple representations. In addition, it provides a mechanism for the central point on which minimalist, construction-integration, and schema-assembly theories agree: Readers are variable in their use of top-down processes across different reading contexts.

## DISTRIBUTED ACTIVATION CONTROL: A SYNTHESIS OF VIEWS

The context-sensitive nature of the reading process suggests that a central aim of comprehension research should be to determine how flexible control over processing is accomplished within the limited capacity-information processing system. We propose that flexibility in reading emerges from distributed activation control (DAC). In proposing the DAC framework, we have three specific goals in mind: (a) to demonstrate that the existing views of how knowledge is used in comprehension can be synthesized into a framework that accounts for the context sensitivity of top-down processing, (b) to show that the problem of understanding elaborative inference and the problem of understanding context effects on lexical access are part of the same general problem of controlling the activation of information during comprehension, and (c) to outline testable predictions that emerge from our framework.

### The General DAC Framework

We propose that the following principles are basic features of activation control during comprehension:

1. *Control processes are distributed.* There is no central executive that takes care of all control decisions. Instead, control is maintained in two ways: by online processes and by offline (planning) processes. Online control is based on the information that is active in WM at any given time. Concepts in WM control which concepts in the general knowledge base are activated or inhibited. Offline control processes refer to manipulation of activation based on strategies that a reader uses to accomplish a priori goals. For example, offline control processes would allow us to change the way we read depending on whether we wish to skim for particular information or develop detailed knowledge of the information in a text.
2. *Working memory constraints are limitations on the amount of information that can be activated at a given time.* Flexible control over comprehension must be accomplished within a limited capacity system. Like Just and Carpenter (1992), we conceive of WM as a dynamic part of the memory system rather than as a separate buffer. That is, those concepts that exceed a critical threshold of activation are considered to be "in WM." Resources for activating information, and manipulating information activated above threshold, are limited. Therefore, competition for attentional resources may necessitate trade offs between the storage and processing requirements of comprehension. As text processing becomes more difficult, less resources are available for maintaining particular concepts in a high state of activation across processing cycles (e.g., Just & Carpenter, 1992; Lee-Sammons & Whitney, 1991; Turner & Engle, 1989) and text representations may become less well integrated (Kintsch, 1993).
3. *The process of comprehension naturally produces multiple representations of text but the strength of the different representations varies with context.* It is clear that reading involves a variety of processes from visual to referential (Just & Carpenter, 1980, 1992; Kintsch, 1988; Kintsch & van Dijk, 1978). The different types of processors involved in reading leave behind different kinds of memory traces as by-products of their activity (cf. Craik & Lockhart, 1972). Like Kintsch (1988) and Kintsch et al. (1990), we suggest that reading a text results in a surface trace, a text base, and a referential model. The relative strengths of these representations varies with contextual factors, such as the type of text or the goals of the reader, that influence the allocation of attention during reading (Fletcher, 1994; Perrig & Kintsch, 1985; Schmalhofer & Glavanov, 1986).

### Operation of The DAC System

In this section, we show how the general principles of the DAC framework may operate during comprehension. It is beyond the scope of this article to formulate a complete computational implementation of DAC, particularly because our goal is to show the underlying connection between different problems in text comprehension. However, to make the discussion more concrete, and to facilitate comparison with other models, we show how the principles of distributed activation control may operate within a hybrid production system. This is the same basic architecture that is used in Kintsch's (1988) construction-integration theory, Just and Carpenter's READER model (1992), and Graesser et al.'s (1994) model of inferential processing. A diagram depicting the DAC system is shown in Figure 2.

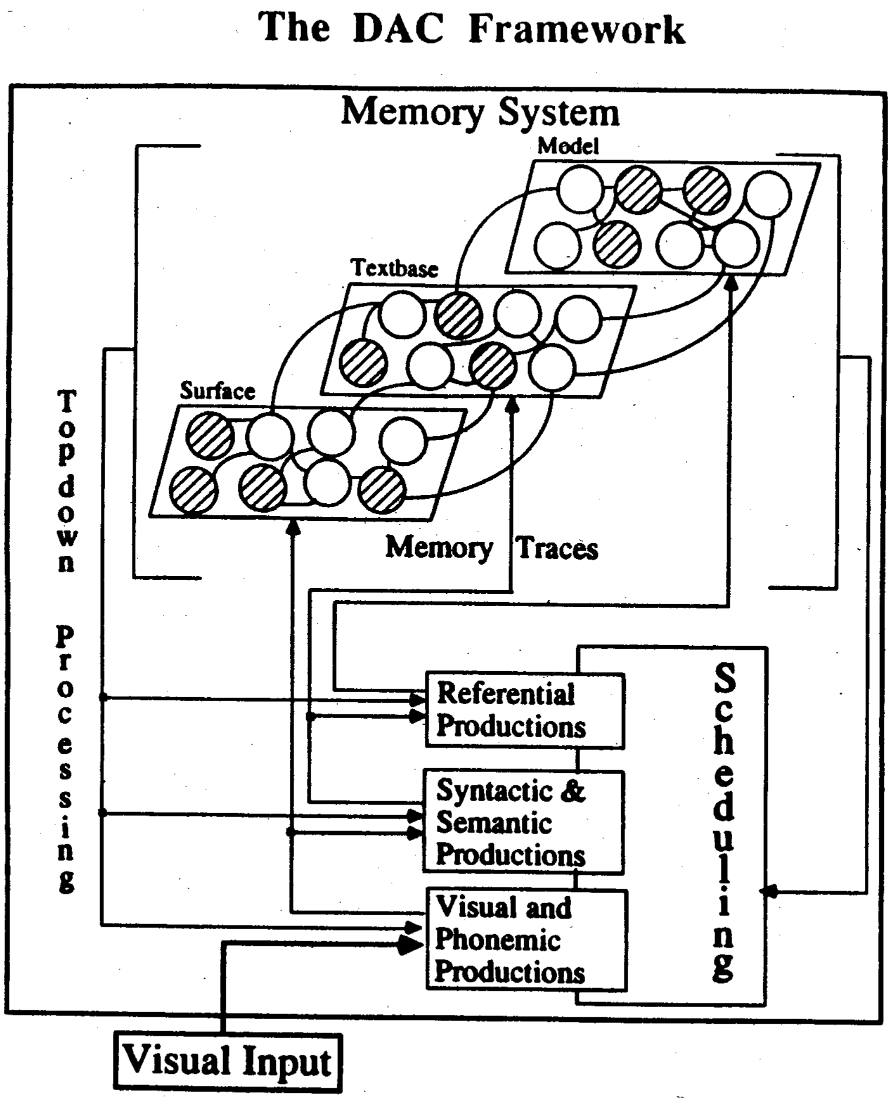


**Figure 2.** A schematic diagram of the DAC framework. The firing of different sets of productions produce three different representations. At any given time, a limited amount of information is highly activated. These are the hatched nodes in the diagram that represent information in WM.

At the heart of the DAC system are a series of production subsystems that manipulate the activation of levels of nodes in a schema-assembly network. Consequently, the DAC framework would occupy the same position in Figure 1 as other schema-assembly-based views. However, according to the DAC framework, there are several different types of codes represented in the knowledge



base (cf. Just & Carpenter, 1987, 1992). Visual input is acted on by a series of production systems that accomplish phonological, syntactic, semantic, and referential analysis. Productions that are satisfied (based on a match with information in WM) fire and their output becomes available for the next cycle of processing. It is the actions of the production subsystems that leave behind traces of their activity in memory: (a) lower level productions produce a surface trace, (b) syntactic and semantic processing produces a text-based representation, and (c) referential processing leads to the formation of a mental model of the text.

Just and Carpenter (1987, 1992) provided a cogent analysis of how productions at each level could accomplish the basic recoding processes of reading. Our concern here is with how such a system can be managed so that it is highly responsive to context. By recoding information, and manipulating activation strengths, the subsystems produce a stream of activated information. Activation spreads to preexisting knowledge, which is organized as a schema-assembly network. Within the stream of currently active information, some assembled structures exceed a threshold that allows for very rapid access and manipulation. This information, which is in WM, has a top-down effect on the information available to the lower level production subsystems. The limitations on WM are not a function of a fixed buffer size, but are due to limitations on the amount of information that can be activated above threshold and efficiently manipulated. Nevertheless, for convenience, we will continue to use the spatial metaphor of "in WM."

Within the DAC framework, basic online control of the reading process comes from management of activation levels based on excitatory and inhibitory connections between concepts in the schema-assembly network. When a particular set of concepts is activated, closely associated information is more easily accessed and information that tends not to cooccur, or is no longer needed, may be suppressed. The information that is maintained in WM determines which productions are fired. Thus, the same schema-assembly processes that we argued were necessary to account for context effects on elaboration and lexical access can guide the production systems that do the work of comprehension.

This type of online control is consistent with the recent data on context effects on both lexical access and elaboration. Both lexical-access processes and elaborative processes vary with context, but, more importantly, elaboration and lexical access are controlled by the comprehension system in the same way. The strength of connections among concepts in memory and concepts mentioned in the text result in a representation that controls the flow of activation as comprehension proceeds.

For example, the DAC model, unlike the construction-integration theory, proposes that some biasing contexts activate schema-like collections of concepts and these structures can engender top-down effects on very early stages of semantic access. That is, lexical access can be selective. Thus, whether lexical access is context dependent or context independent is jointly determined by two factors: (a) the baseline levels of activation of each meaning (dominance) and (b) how strongly the reading context biases a particular meaning (cf. McClelland, 1987; Simpson & Kreuger, 1991). In DAC terms, the distributed connections in memory determine whether processing is more from the bottom up or more from the top down. Lexical access is particularly influenced from the top down when contexts strongly bias a dominant meaning (e.g., Paul et al., 1992).

Next, consider the parallel between lexical access processes and the processes involved in elaborative inference. In some contexts, a sentence with a category term in it is elaborated so that a particular instance of the category is encoded. For example, *The animal ran up to the children in the yard* elicits the inference that the animal was a dog (e.g., O'Brien, Shank, Myers, & Rayner, 1988; Whitney, 1986). However, this inference requires that a typical member of the category be strongly implied. In contrast, even when the context is strongly biasing toward an atypical instance, participants are less likely to infer specific referents for general terms (Whitney, 1986). Once again, we see that the sentence context and the preexisting strengths of connections in memory jointly determine whether there are top-down influences on comprehension.

The inferential processing that leads to the construction of a causal model of events in a text could also be managed by online activation control processes. Our view is quite similar to that of Graesser et al. (1994), who sketched out some production rules that would result in the construction of a model of a narrative text that is based around causal connections. For example, if an explicit statement of an intentional action is encoded into WM, the conditional state of a particular production rule is satisfied. This production rule fires, which causes a search for plausible causal antecedents. A causal antecedent may then be activated in WM. This could result from either an increase in the activation of a recently read portion of the text, or, in cases in which the causal antecedent is not explicitly supplied by the text, from activation of relevant portions of the knowledge base.

The process of inferring causal antecedents may be aided by activation of sets of nodes that approximate generic scripts. Thus, if a text strongly implies that a singles-bar schema is appropriate, then the causal antecedent for a fist fight between two men may be quite automatically inferred by the reader. The same fight in another context, in which a relevant explanation is not readily supplied by a generic schema or by the text itself, may result in only a weak or partial inference, at least until more text is input (cf. Graesser et al., 1994). The basic idea is the same as for top-down effects on lexical access and elaboration of general concepts—the degree of top-down processing varies depending on both text constraints and on the nature of the information in the knowledge base that is activated by the text. Some sets of propositions are so tightly bound together, in terms of connection strengths, that a set of propositions is activated as a unit. This can result in top-down effects that are more potent than those predicted by either the minimalist theory or construction-integration theory.



Although we can understand much about top-down processing by considering online control, there must also be control established through planning functions. Unlike the minimalist framework, it is not assumed in DAC that there is a default mode of processing that characterizes reader performance across a wide range of contexts. Instead, according to the DAC framework, the reading process varies in a qualitative fashion from context to context. The online control processing discussed previously illustrates how reading can vary based on text-level variables. However, goal or task variables can also affect the reading process. Depending on the reader's expectations about how comprehension will be tested, reading can be either quite from the bottom up, from the very top down, or something in between. As Kintsch (1993) noted, "Although a minimum effort principle characterizes many readers in many situations (McKoon & Ratcliff, 1992), it is by no means impossible to get readers to be more careful (e.g., Graesser, 1981; Trabasso & Sperry, 1985). One modus operandi is no more natural than the other" (pp. 198–199).

In the DAC system, planning-based control is accomplished through the use of a production scheduler that, based on the information activated before reading begins, makes particular production subsystems more available. This could be implemented formally by manipulating the activation threshold that information must reach in order to satisfy the conditional portion of a production rule. The production scheduler would allow variations in reader goals to cause particular sets of productions systems to dominate information activation and therefore determine the content and strength of the different types of representation. Thus, if a reader knows that a test of verbatim memory will follow the reading of a text, then referential productions may be engaged infrequently. In this way, the a priori goals of the reader can determine the strengths of the different types of representations formed. For example, Schmalhofer and Glavanov (1986) found that reading a programmer's manual in order to do a programming activity resulted in a strong model representation of the text. However, when the reading goal was summarization, readers formed a stronger text base and a weaker model representation. Because control by planning affects processing before reading actually begins, it may allow for information management that does not take up WM capacity while reading.

An elegant study by Zwaan (1994) provides additional evidence that something akin to a production scheduler must be included in a theory of comprehension. Zwaan demonstrated that text genre exerts a powerful effect on readers' goals. Participants read the same texts, either as a literary story or as a news story. Both reading time and memory measures showed that reading differed qualitatively with genre. More resources were allocated to encoding accurate surface and text-base representations when participants believed they were reading a literary story. In contrast, when participants believed they were reading a news story, their attention was especially directed to causal coherence breaks and they made more inferences directed toward constructing a causal model of the text. In terms of the DAC model, information in WM about genre affected planning of the reading process. That is, genre information in WM made scheduling productions fire that influenced which comprehension productions were most likely to be used online when reading began. This is a process that could, in principle, operate either consciously and strategically or quite automatically. Automaticity of scheduling productions to fit particular tasks or genres would be expected to vary, as with any other skill, as a function of the amount of practice in executing a given set of productions. We mention this in order to avoid confusing online and offline control processes with the automatic and controlled distinction.

Thus, DAC is consistent with a growing body of evidence that the strength and content of different text representations varies with the reader's goal (see also Diehl, Mills, & Birkmire, 1993; Fletcher & Chrysler, 1990; Whitney & Waring, 1991). However, there is another reason to posit a production scheduler as part of the DAC system. A production scheduler seems necessary, not only because there are task and genre effects on top-down processing but also because there must be high-level productions that control which productions may be satisfied by the inputs into WM (Rumelhart & Norman, 1988). Otherwise, we would be constantly having to match all our different production systems with WM (Larkin, McDermott, Simon, & Simon, 1980). The production scheduler proposed here is simply an intermediate step in the nested productions that accomplish information processing. In Schneider and Detweiler's (1987) connectionist model of WM, similar functions are carried out by a special context module. Note, however, that the production scheduler does not result in central control of the overall process of comprehension. Online control takes place in all reading contexts, but the production scheduler can constrain online control in order to meet particular reading goals.

Of course, the production scheduler must have some limitations on its range of influence. After all, each processing cycle in reading must begin with the bottom-up flow of information from visual analysis. We question, however, the common assumption that there is a default mode of reading. The major goal of most theories of comprehension has been to specify the processes that take place in the default mode, although some theorists acknowledge that the default mode can be altered, usually through unspecified means, by special processing goals (cf. McKoon & Ratcliff, 1992). We hope that the DAC model spurs more interest in the extent to which the reading process varies with the reading context. As we discuss in the following section, we believe that the production scheduler can, at least, influence the relative strengths of the different text representations formed during reading.

### Predictions Generated by the DAC Model

Both the online and offline means of controlling information flow that are described in the DAC framework suggest that the comprehension process will vary qualitatively as a function of several text-based and reader-based factors. In particular, the utility of the DAC framework comes from its ability to specify the situations in which top-down processes will exert the greatest influence on text representations and the effect of reader-based factors on the qualitative nature of comprehension processes. Examples of relevant reader-based factors include individual differences in WM capacity and in background knowledge.



The predictive power of the DAC framework can be illustrated by considering the factors that affect the relative strength of the different representations of a text: the surface form, the text base, and the situational model. We noted earlier that there are data that suggest the relative strength of the text base and situational model vary with the goals of the reader (e.g., Fletcher & Chrysler, 1990; Schmalhofer & Glavanov, 1986). There is a more extensive literature on the loss of the surface representation of text (e.g., Gernsbacher, 1985; Graesser & Mandler, 1975; Sachs, 1974). Traditionally, the rapid loss of surface information has been attributed to integration processes in which an abstract code replaces the surface trace (e.g., Bransford, Barclay, & Franks, 1972). This explanation is inconsistent with the DAC framework. However, consistent with our framework, Murphy and Shapiro (1994) showed that the durability of the surface trace depends on the goals of the reader. Moreover, Murphy and Shapiro found that making material harder to integrate (by scrambling the sentences in a story) increased the loss of surface information. If integration of text concepts into a more abstract code replaces the surface information, then scrambling the sentences of the story should have improved retention of the surface form.

Murphy and Shapiro's (1994) finding is interesting because it appears to conflict with a number of other studies. Several experiments have suggested that surface loss increases with thematically organized materials (c.f. J.R. Anderson & Bower, 1973; Bransford et al., 1972). The DAC framework suggests a novel, and testable, resolution to this conflict. If participants are processing text in a very bottom-up fashion in order to construct a text base or model representation, then manipulations that affect integration (e.g. scrambled vs. normal text) will have the same influence on memory for meaning and memory for surface form (cf. Murphy & Shapiro, 1994). However, if participants are processing in a more top-down fashion, by using a well-integrated schema that directs the lower level processing, then conditions that increase integration will decrease the retention of surface information (cf. J.R. Anderson & Bower, 1973). In the extreme case, surface information may not even be accurately encoded because the participants "read" what they expect to see.

In a similar vein, the DAC framework calls attention to the issue of the types of comprehension questions that are included in studies of elaborative inference. Most studies of elaborative inference include some type of comprehension questions in addition to whatever measure of inference generation is used. Often, however, the nature of these questions is left unspecified. According to the DAC model, if the comprehension task consistently orients participants to the surface form of the text, or to information directly stated in the text, then elaborative activity will be relatively low. There have only been a few studies that directly investigated whether such task conditions can strongly direct inference processing, but they have supported our notion of offline control processes (e.g., Vonk & Noordman, 1990; Whitney et al., 1992).

As noted earlier, the DAC framework also makes testable new predictions concerning the relation between reader-based factors and top-down processing. Of particular interest is how the comprehension system adjusts to limitations in WM capacity because WM limitations affect what information is available to cause productions to fire. It is well established that individual differences in WM are correlated with reading comprehension performance (e.g., Daneman & Carpenter, 1980; Engle, Nations, & Cantor, 1990). However, from the DAC perspective we are more interested in how limitations on WM affect the qualitative nature of the reading process. If readers differ in their capacity for holding information in WM, then those readers with lower capacity will not maintain some information that would make certain productions fire. This should affect not just someone's reading ability but also the way that they read. Therefore, one test of whether the comprehension system functions as described by the DAC framework is to examine the processing trade offs that occur when the capacity of WM is exceeded (e.g., Budd, Whitney, & Turley, in press).

In contrast to the DAC framework, most theories of comprehension predict that poorer readers, particularly those with low WM capacity, will generate fewer inferences than good readers (e.g., Dreher, 1985; Graesser et al., 1994; Long, Oppy, & Seely, 1994; Yuill, Oakhill, & Parkin, 1989). The reasoning for this prediction was clearly articulated in Graesser et al.'s (1994) model of inference:

> Comprehension processes, including inference generation, slow down to the extent that demands on WM approach the upper bound of capacity limitations. When the demands on WM exceed the upper bound, there is a catastrophic deterioration of comprehension, and few inferences are constructed. (p. 380)

According to the DAC model, however, readers can deploy WM resources flexibly so that different representations are emphasized under different circumstances. Thus, we would expect high-capacity readers to generate more inferences than low-capacity readers only if the two groups of readers are using the same processing strategies. However, we should not expect readers to consistently trade inference incorporation for a more accurate text base. Instead, readers will, in some conditions, increase inferential processing as an adaptation to their WM limitations. For example, readers who have low WM capacity but are able to retrieve a relevant schema should, according to DAC, make heavy use of top-down processes to facilitate their lack of resources for other processes. This could lead to distortions in the text base, but still may represent a reasonable trade off to the readers.

Preliminary evidence for flexibility in trade offs between bottom-up and top-down processing comes from a study by Whitney, Ritchie, and Clark (1991). High- and low-WM-capacity participants (based on the Daneman & Carpenter, 1980, reading-span test) read a series of ambiguous texts, such as Bransford and Johnson's (1973) "Prison Escape" and "Washing Clothes" passages. While reading, the participants 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 online processes in comprehension (e.g., Ericsson & Simon, 1984; Fletcher, 1986; Singer et al., 1994).

The participants' protocols were recorded, transcribed, divided into idea units, and classified. The low-span readers gave specific elaborative interpretations in 23% of their idea units, about twice the rate of the high-span readers. 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 clarified the nature of the processing differences between high-span and low-span participants. If multiple interpretations of the ambiguous texts are held in memory and tested against later information, then the specific elaborations that occur should mainly be found toward the end of the protocol when more evidence is available which allows the reader to be specific. Only the high-span participants showed the pattern of increasing specificity of interpretation as more information became available. There was no reliable trend in the data for the low-span participants. Their specific elaborations were equally distributed throughout the protocols.

Does this mean that the low-span participants were processing in a top-down driven fashion? If so, they would form a definite interpretation early and force the remaining text into this scheme. Alternatively, the low-span participants could process sentences in relative isolation with little effort toward forming an overall interpretation. Both strategies seemed to be present in our sample because the low spans differed greatly on how many of their specific elaborations introduced new themes (see Whitney et al., 1991).

With the texts used in the Whitney et al. (1991) experiment, there was little to help the participants decide which type of trade off to adopt, so it is not surprising to find both strategies at work. Low-span participants who could retrieve a relevant thematic schema for a passage generated inferences that aided global coherence. Without such a guiding schema, the inferences generated were quite local. As the DAC model predicts, low-span participants seemed to use top-down processing as a strategy to compensate for their capacity deficits.

Another prediction generated by the DAC model is that if readers face trade offs between bottom-up and top-down processing, a priori tasks or goals which stress use of a schema should increase top-down processing. In DAC terms, the production scheduler will make referential processing a high priority. There is support for this prediction in studies of individual differences in use of a perspective as a schema to guide encoding. Lee-Sammons and Whitney (1991) examined how strategies are affected when the participants are given a goal to direct reading. The study was based on the paradigm introduced by R.C. Anderson and Pichert (1978), who had participants read a story about two boys skipping school. The boys enter the home of one of the characters and the home is described. Participants in the study were told to read the story from either the perspective of a burglar interested in robbing the home or the perspective of a potential buyer of the home. The description contained ideas relevant to each perspective (e.g., valuables contained in the home and that it had a leaky roof). As we noted earlier, the participants in the R.C. Anderson and Pichert study recalled the passage and then were asked to recall it again either from the same perspective or from the perspective not given at encoding. The critical finding was that the participants recalled previously unrecalled information following a shift in perspective. For example, even when participants read from a home buyer's perspective and failed to recall where valuables were in the home, these participants would recall the valuables on a second recall attempt in which they were retrieving the text from the burglar perspective. These data challenged the widely held idea that a schema, in the form of a perspective to take on a passage, guides the encoding process.

Nevertheless, there is some evidence that schemata can guide processing in some contexts. For example, Baillet and Keenan (1986) argued that Anderson and Pichert's (1978) results were an artifact of the relatively short passage and the brief time interval between study and test. They argued that goal effects were not obtained at encoding in the Anderson and Pichert study because participants were relying on a memory trace of the surface form of the text. With a longer text and greater time interval between the first and second recall attempts, Baillet and Keenan found evidence that goals guided the encoding process.

Lee-Sammons and Whitney (1991) believed that both patterns of data would be obtained in the same study if the performance of high- and low-span readers was contrasted. If the low-span readers use the goals as a guide to what trade offs in processing to make, then their data should resemble those of Baillet and Keenan (1986): A perspective shift should not aid the recall of previously unrecalled information. High-span readers do not face the same constraints, so we predicted that their recall patterns would be relatively independent of reading goal. Thus, the high-span readers data would resemble the results of the Anderson and Pichert (1978) study.

Lee-Sammons and Whitney (1991) conducted two experiments that used stimuli similar to those used by Baillet and Keenan (1986). The data of primary interest from the first experiment were the percentages of idea units recalled on the second recall attempt that were not recalled on the first attempt. We predicted that switching to a new perspective for the second recall attempt would not help lower span readers recall new information. The results showed that low- and medium-span readers actually recalled significantly less new information in the switch condition compared to the condition in which participants kept the same perspective for both recall attempts. Among high-span readers, the recall of new information was unrelated to whether the perspective was switched at retrieval.

The second experiment used a similar passage but it included a no-goal condition in which participants got the same instructions as in the goal conditions (read carefully for good comprehension) but without a specified reading goal. High-span and low-span participants performed two types of recall tasks. Half the participants were given an immediate-recall test and half were given a cloze-completion test. In a cloze test, participants 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 by variables that influence microprocessing but not variables related to macroprocessing (Kintsch & Yarbrough, 1982; Shanahan, Kamil, & Tobin, 1982). Therefore, we would not expect a variable that affects macroprocessing, such as a reading goal, to affect cloze-completion performance unless the variable induced a trade off 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.

The second experiment replicated the finding that low-span participants were more bound to the reading goal in recall. They recalled little information that was not relevant to the original reading perspective. In addition, the cloze data revealed the predicted trade off; low-span participants had fewer cloze completions for perspective-irrelevant information. One aspect of the high spans' data was 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 trade offs.

These data on differences in reading strategies associated with quantitative differences in WM capacity support the most fundamental aspect of the DAC framework: Qualitative differences in comprehension processes emerge because the system adapts both to the nature of the reading task and to the WM capacity of the reader.

We can also illustrate how the DAC framework can assist in formulating research questions by considering how it may need to be altered to accommodate future research on the issue of the format of situational models. As a simplifying assumption, we have considered activation control in DAC to reflect the deployment of a single, limited resource. However, if, as some data now suggest (Perrig & Kintsch, 1985), both text-type and subject preferences determine the format of the situational model, then two factors may be at work. Specialized productions may recode information into a visual–spatial format when relevant concepts become active in WM. In addition, the resources available for each format may differ, such that representing some information in one format frees resources needed for other activities. This would be similar to the functional separation of verbal and nonverbal systems in the dual-coding theory (Paivio, 1986). If there is such a separation, then participants' coding preferences would be expected to reflect which type of WM (verbal, visual–spatial) has higher capacity (cf. Baddeley, 1986). The possibility that participants may use a particular format of representation to free an alternate type of processing resource is largely unexplored. We hope that by exploring such issues we can better understand the role top-down processing plays in comprehension and we can elaborate on the DAC framework in order to formulate a model of the control of information processing in comprehension.

## CONCLUSIONS

The most general conclusion supported by the data on top-down processing is that such processing is adapted flexibly to fit the nature of the text being read as well as the goals and abilities of the reader. To understand the complex role of top-down processes in comprehension, we should not discard schema theory altogether. Instead, we must integrate three key ideas drawn from existing theories: (a) the concept of online schema assembly, (b) the concept of multiple coding, and (c) a concern with contextual sensitivity. The DAC system we have outlined is intended to provide a framework for this integration.

We do not claim that the DAC system is a fully specified theory. Instead, we view DAC as a general framework that integrates several important topics on comprehension. For example, the continuity between research on context effects on lexical access and research on knowledge-based inferences becomes clear when both domains are viewed as problems of control of activation. In addition, DAC serves as a guide to posing new questions about control processes in comprehension. Even at its current level of development, the DAC framework suggests some testable questions that allow for its evaluation.

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# Individual Differences In Working Memory Strategies for Reading Expository Text

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Running head: WM Management Strategies

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## Abstract

This study investigated whether individual differences in working memory (WM) span are associated with different WM management strategies during the reading of expository text. In experiment 1, probe questions were presented on-line during reading to determine whether thematic information was maintained in WM throughout comprehension. The data indicated that readers across the range of WM span maintained thematic information in WM throughout the reading of a given passage. In experiment 2, sentence reading times and accuracy for both topic and detail questions were measured in two conditions: when topic sentences were present and when topic sentences were absent. Subjects performed similarly across the range of WM span in the topic present condition, but lower span subjects performed more poorly on detail questions in the topic absent condition. In experiment 3, the topic present condition of the second experiment was replicated, except that subjects expected to receive questions about details only. Thematic processing and retention of topic and detail information all increased with span. Taken together these results suggest that, for more difficult text processing tasks, high and low span subjects adopt different WM management strategies and these strategies influence what is learned from reading the text.

Individual Differences in Working Memory Strategies for Reading Expository Text

There is growing evidence that individual differences in working memory (WM) capacity have profound influences on the process of text comprehension. It has been known for some time that measures of WM capacity that assess storage and processing limitations are highly correlated with performance on tests of reading ability (e.g., Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Daneman & Carpenter, 1980). Most evidence for this correlation comes from tests of WM similar to Daneman and Carpenter's (1980) reading span task. In this task, subjects must process a series of sentences while holding the final word of each sentence in their memory. However, exploring the relationship between WM capacity and reading holds promise not only for our understanding of individual differences in reading ability, but also for a greater understanding of both the general characteristics of working memory, and the normative process of comprehension.

For example, Engle and colleagues (Engle, Cantor, & Carullo, 1992; Turner & Engle, 1989) have shown that WM span tasks correlate with reading ability because they tap a general-purpose capacity for maintaining verbal information. Turner and Engle (1989) showed that the correlation between working memory and reading ability remains high even if the WM span task does not involve reading at all. In addition, Engle et al. (1992) ruled out the hypotheses that the WM-reading ability correlation exists only because more intelligent subjects simply use better strategies on both WM and reading tests. Thus, there is evidence that there exists a general working memory capacity that is used in a wide range of cognitive tasks (cf., Baddeley, 1986).

Of particular interest to the present research is the recent evidence that individual differences in working memory (WM) span are associated with *qualitative* differences in comprehension processes (e.g., Just & Carpenter, 1992; Lee-Sammons & Whitney, 1991; Perfetti, 1985; Whitney, Ritchie, & Clark, 1991). Just, Carpenter, and colleagues (Just & Carpenter, 1992; MacDonald, Just, & Carpenter, 1992) found that readers who score high on the WM span task (high spans) differ from readers who scored low (low spans) on a number of measures. For example, high spans were better able to maintain two possible interpretations of a syntactic ambiguity. In addition, high span readers, unlike low span readers, were able to use semantic information (animacy of a noun) to facilitate syntactic processing of relative clauses. The latter result, in particular, exemplifies how research on individual differences in WM can have an impact on normative theories of comprehension. If the syntactic processor is really an informationally encapsulated part of the cognitive architecture (Fodor, 1983), then use of semantic information to facilitate syntactic processing should not be associated with WM span (Just and Carpenter, 1992).

High span and low span readers also display qualitative differences in text-level comprehension processes. For example, Whitney et al. (1991) investigated whether WM span is related to the type of inferences made when subjects read difficult, ambiguous prose. Subjects were asked to "think-out-loud" about their interpretation of each passage as they read it. Low span readers made more concrete interpretations of the text. Low span readers also made their elaborations early in the text, while elaboration by high spans occurred later in the text. Whitney et al. (1991) concluded that the low span readers made their interpretations early because they did not have the capacity to wait until they had enough information to draw appropriate inferences.

Lee-Sammons & Whitney (1991) examined the effect of WM span and reading goals on comprehension of narrative text. Subjects read a story about two boys skipping school. The subjects read either from the perspective of a potential home buyer or from the perspective of a potential burglar, and later recalled the text either from the encoding perspective or from the perspective not given at encoding. Low span readers were poor at recalling information not relevant to the original encoding perspective, even when cued with the alternative perspective. High span readers recalled similar amounts of perspective-relevant and perspective-irrelevant information, regardless of cuing. Lee-Sammons & Whitney (1991) concluded that the degree to which subjects used the goal to guide their comprehension processes varied inversely with WM span.

Although previous research supports the conclusion that readers with different WM spans use qualitatively different WM management strategies to guide their comprehension processes (Lee-Sammons & Whitney, 1991; Whitney et al., 1991; Just & Carpenter, 1992), these findings have been largely obtained using narrative texts as stimuli. Little research has been done to determine if these WM span differences are present for expository materials.

One of the reasons that it is important to extend this research to expository text is that the study of the various WM management strategies used by readers to comprehend expository text can be applied to the problem of how to improve learning from text. If the adoption of particular strategies result in specific tradeoffs in text comprehension processes, then this is likely to lead to differences in what material is learned while reading an exposition. For example, several studies indicate that readers who use a thematic, or structural, strategy to comprehend text recall more top level information than readers who process text in a linear, element-by-element fashion (Meyer, Brandt, & Bluth, 1980; Marshall & Glock, 1979; Meyer & Rice, 1982; Reder & Anderson, 1980; Loman & Mayer, 1983). Thus, if we understand the tradeoffs that some readers make to comprehend expository text, then we might be able to manipulate reader strategies or text characteristics to enhance learning efficiency.

In a more theoretical vein, the study of the comprehension of expository text is a natural means to explore WM management. As Fletcher (1986) noted, the structure of expository text is far more variable and thus less predictable than that of narrative text (Black, 1985; Britton, Glynn, & Smith, 1985; Fletcher, 1986). In addition to its less uniform structure, expository text is often contains novel terms that are difficult to understand without specific background knowledge. The reader's lack of prior knowledge about the particular situation represented by an expository text, as well as the novel concepts associated with it, may place greater cognitive demands on the reader than those usually associated with narrative text (Kieras, 1982; Kieras, 1985). These demands may result in the adoption of management strategies for processing expository text that differ from those used to process narrative text.

The purpose of the present study was twofold. First, we wanted to determine whether similar emphasis was placed on thematic processing by readers with different WM spans. A central tenet of recent models of reading comprehension, is the idea that working memory plays a dual role in the establishment of coherence between various parts of a text (e.g., Kieras, 1982; Kintsch, 1988; Kintsch & van Dijk, 1978; Fischer & Glanzer, 1986; Sanford & Garrod, 1981). According to these models, readers maintain the most recently processed information from the text in WM in order to establish relations between adjacent clauses or sentences. Thus, WM plays a role in facilitating the comprehension of specific propositions by establishing coherence at a local level. However, texts are also coherent at a more global, or thematic level. Thus, most models of reading comprehension claim that topic information is maintained in WM to promote thematic processing (Glanzer & Nolan, 1986; Just & Carpenter, 1987; Kieras, 1982; Kintsch & van Dijk, 1978). In some circumstances, readers may not have the processing capacity to buffer both thematic and local information in WM. As a simple example, consider a low span reader who has difficulty extracting proposition-specific information while at the same time maintaining thematic information in WM. Such a reader might forgo maintaining thematic information in order to fully process particular details. Alternatively, the reader might perform shallow processing of the details in order to focus on the overall theme of the passage. In the Lee-Sammons and Whitney (1991) study, the low span readers apparently traded local processing of perspective-irrelevant information for more extensive processing of information relevant to the thematic perspective.

Second, we wanted to establish whether use of particular WM management strategies affect the type of information that is learned while reading expositions. Several theorists have suggested that when readers WM resources are severely limited, assembly and integration of propositions in WM are constrained, and the quality of the text representation suffers (Johnson-Laird, 1983; Just & Carpenter, 1987; van Djik & Kintsch 1983; Perfetti, 1989; Kintsch, Britton, Fletcher, Kintsch, Mannes, & Nathan, 1993). Accordingly, individual differences in WM capacity may be related to differences in what information is retained when reading expositions.

To somewhat simplify the study of WM management processes, we used passages with a two-level hierarchical structure. Each passage began with a topic sentence that stated a general proposition. This sentence was followed by several detail sentences, each of which independently supported the topic sentence. Because topic sentences generally occur in the initial position of expository passages, readers consider information mentioned first as more thematically important than information mentioned later, and therefore especially important to the overall representation of the text (Meyer, 1975; Kieras, 1982; Kieras, 1985; Lorch, Lorch, & Matthews, 1985; van Dijk & Kintsch, 1988). Kieras (1985) and others (Hare, Rabinowitz, & Schieble, 1989) have suggested that when reading passages with this simple hierarchical structure, thematic processing involves mostly recognizing that the pattern of details support some general concept. If the general concept is stated at the beginning of the passage, readers need only to adopt it, and then test it for adequacy against the remainder of the passage. However, if an obvious candidate for the topic does not occur first then readers must construct one while reading, test it for adequacy, and be prepared to modify it if new information arises that does not support the readers initial interpretation (Kieras, 1982; Hare et al., 1989, Smith & Swinney, 1992).

More specifically, this simple two level hierarchical structure allowed us to distinguish different WM management strategies by restricting the nature of the relational processing performed by readers. In general, relational processing involves the integration or organization of the individual propositions within a text (Einstein, McDaniel, Owen & Cote, 1990). Of course, integration can take place at a local level between adjacent sentences as well as at a more thematic level. Because the detail sentences described facts that were independent of each other except for their support of the theme of the passage, we could expect that most of the relational processing would be thematic and involve relating each detail sentence to the topic (Kieras, 1985; Hare et al., 1989).

Given the nature of the passages used in this research, there were three types of processes that our subjects could employ to retain information from the passages. They could perform item-specific processing of the topic sentences, which would help them retain the theme of a passage. They could perform item-specific processing of details, which is necessary to encode any particular detail. Finally, they could perform relational processing in which the specific detail information was related to the theme of the passage. According to Einstein et al. (1990), retention of information should be best when readers perform extensive item-specific processing in conjunction with extensive relational processing. Thus, relational processing performed by subjects in the present experiments was expected to aid retention of both topic and detail information.

Of course, our main interest was in whether the relative emphasis on each of these three types of processes varied with WM capacity. Based on the earlier research with narrative texts (e.g., Lee-Sammons & Whitney, 1991), we predicted that low span subjects, unlike high span subjects, would face tradeoffs between performing extensive item-specific and extensive relational processing. In the Lee-Sammons and Whitney (1991) study, the type of tradeoff that low span readers should make was evident because perspectives were given to guide comprehension. However, in experiments 1 and 2, we emphasized retention of topic and detail information equally, so that we could determine the direction that processing tradeoffs take when the experimental task does not suggest a particular direction to the tradeoff. In experiment 3, we emphasized the importance of detail information, to determine how high and low span readers would adapt their comprehension processes to fit the type of questions they expected to be asked.

Each of the experiments in this study followed the same general plan, though experiment 1 was based on a probe technique and experiments 2 and 3 focused on sentence reading times. For each experiment, we first examined the data from all subjects collectively to see if we had replicated prior research. We then tested whether the group results were qualified by an interaction with WM span. Most research in this area has tested for such interactions by arbitrarily creating high, medium, and low span groups and conducting an ANOVA. Although the data analysis then becomes very familiar, this artificial creation of groups often results in a substantial sacrifice in power (Cronbach & Snow, 1977; Pedhazuer, 1982). Rather than conducting an ANOVA based on an arbitrary grouping of the WM span range, we tested the significance of the regression weight that represented the interaction between WM span and the categorical independent variables in each experiment. Thus, the continuous nature of the WM span variable was maintained, which not only increased power, but also allowed us to better examine the range of WM span scores that are associated with differences in performance.

## Experiment 1

In an attempt to discover what type of information was being carried in WM during the reading of expository text, Glanzer and Nolan (1986) measured subjects' response times to true/false probe questions about specific topic and detail information contained in brief expository passages. Subjects read passages organized in the same hierarchical fashion as the passages in this study. The subjects' response times to the questions were used to determine whether topic and detail information was maintained in WM. When the probe questions were presented immediately following the related sentence, subjects answered both topic and detail probe questions quickly. However, when the probe questions were presented after three intervening sentences, response times to the detail probe questions increased and response times to the topic probe questions did not change. Glanzer and Nolan (1986) concluded that topic information was given a privileged role and carried longer in WM than detail information.

In Experiment 1, we used a probe deadline methodology that was modified from Glanzer

& Nolan's (1986) study to assess whether WM capacity was related to the tendency to maintain thematic information in WM. For instance, Glanzer and Nolan's results might be correct normatively, but inaccurate for lower span readers who might find it impossible to process each detail sentence fully while also maintaining thematic information in WM. Such readers would perform mainly item-specific processing, with little emphasis on relational processing. Alternatively, because relating the detail information to a general theme can benefit the retention of detail information (cf., Reder & Anderson, 1980; Risko & Alvarez, 1986), maintaining thematic information might be worth the WM "cost" to low span readers, and they might maintain thematic information just as higher span readers do.

In the present study, the subjects answered true and false probe questions about specific topic and detail information while they read the passages. Originally, we intended to use reaction time to the probe questions as the dependent measure (cf., Glanzer & Nolan, 1986). However, a pilot study indicated that several subjects were trading speed for accuracy when given unlimited time to respond. Therefore, a probe deadline procedure was used. Based on pretesting of the materials with a separate group of low and high span subjects, we allowed subjects in the main experiment 3.5 seconds to respond to the probe. Among pretested subjects, when the probe immediately followed the relevant sentence, both high and low span subjects could read and respond to the probe within the deadline with 70 to 80 percent accuracy. Consequently, mean proportion correct was our dependent measure in Experiment 1. The probe questions were presented immediately after the relevant sentence (lag 0), after two intervening sentences (lag 2), or after four intervening sentences (lag 4). We predicted that collapsed over WM spans, the accuracy data would replicate the results of Glanzer & Nolan (1986). That is, accuracy for topic probe questions would be constant across lag, and accuracy for detail probe questions would decrease with lag. More importantly, if thematic relational processing varies as a function of WM capacity, then the size of the lag effect for topic probes should vary with WM span.

# Method

## Subjects

The subjects were 96 undergraduate students from Washington State University who participated either for extra course credit or to fulfill a general psychology course requirement. All subjects were native speakers of English. All subjects completed two sessions. In the first session subjects were given the WM span test, as describe below. Each subject then returned on another day to complete the reading task. The WM span scores for this sample of subjects ranged from 15 to 55 (the maximum possible score is 60). The mean WM span score was 36.5, with a standard deviation of 9.8 .

## WM Span Test

Materials. The WM span test was adapted from one developed by Turner & Engle (1989). The materials consisted of response booklets for each subject and 15 overhead transparencies containing sets of unrelated sentences. There were 60 sentences in all, ranging from 10 to 16 words in length, each ending in a noun. Half of the sentences used active voice (e.g., "The group of fans walked to the baseball game, slipping and sliding on the icy surface."), and half were passive (e.g., "The wife was looked after by her adoring husband to make sure she received no harm."). Fifteen "nonsense" sentences were created from each of the two structure types by scrambling the last four to six words immediately preceding the final word. The number of sentences per transparency ranged from 2 to 6. There were three transparencies for each of the set sizes. Following the last sentence on each transparency was the phrase "RECALL WORDS". Each response booklet contained 30 pages, two pages corresponding to each transparency. The first page in the set was constructed so that the subject could indicate whether each sentence in the set made sense or not. The second page was blank except for the phrase "RECALL WORDS."

Procedure. The sentences were presented in order of increasing set sizes on an overhead projector. Individual sentences were presented at a rate of one every seven seconds. As each sentence was presented, the subject judged whether or not it made sense. After rating each sentence in a set, subjects turned to the next page in their booklets and tried to recall the last word of each sentence in the set. Subjects were credited with recalling a word only if the subject had also made a correct sense judgment for the corresponding sentence.

Reading Comprehension Task

Materials and Design. Twenty-four passages were adapted from articles in various non-technical science and hobby magazines. Each passage was organized in a simple hierarchical structure consisting of a topic sentence (a generalization of what the passage was about) and six supporting detail sentences. Three probe questions and one multiple choice question were constructed for each passage. One probe question was constructed for the topic sentence and one probe question was constructed for the first or second detail sentence after the topic sentence. The last probe question, which was a filler probe, was constructed for another detail sentence selected at random from the passage. Each passage ended in the filler probe so that subjects could not determine any pattern to the test probes. Probe questions were constructed to be paraphrases of explicit information contained in the related sentence, and were between 12 and 14 words in length. Half of the probes of each type were true and half were false. The multiple choice questions for the passages were constructed so that half the multiple choice questions tested topic information and half tested detail information. A sample passage and probe questions are given in Table 1.

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Insert Table 1 about here

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Six versions of each passage were created by crossing probe type (topic vs. detail) and lag (0, 2, or 4 intervening sentences). Six versions of the experiment were also created so that each contained an unique version of each passage, and each condition (probe type x lag) occurred equally often. Subjects were randomly assigned to versions.

Procedure. Subjects were given the reading comprehension task individually in sessions lasting between 40 and 60 minutes. The instructions and the passages were presented on personal computers with VGA monitors. The experiment was programmed using the MEL software system. A sentence-by-sentence, self-paced procedure was used. Subjects were given general instructions on how to control text presentation and they performed one practice block of six passages to familiarize them with the procedure and orient them to the type of questions that would be asked. Each trial began with a one or two word title that appeared on the screen (e.g. "Oil Spill"). The subject then initiated the presentation of the first sentence of the passage by pressing the space bar. After reading a sentence, the subject initiated the next sentence by pressing the space bar again. They continued in this manner until an entire passage was read.

Subjects were informed that they were going to read passages dealing with various topics, and that they should read each passage carefully in preparation for a test at the end of each block of six passages. They were also informed that true/false probes questions would appear at random intervals while they were reading, and that these probes were to help them determine how well they were reading the passage. Text sentences appeared left justified in black letters on a gray background. While probe questions appeared in white letters on a blue background. Subjects were told that they would only have 3.5 seconds to read and respond to the probe, and if they did not respond within the time limit, the response would be counted as incorrect. If the subject answered correctly within the time limit, then "Correct Response" appeared on the screen. If they responded incorrectly or failed to respond within the time limit, then "Incorrect Response" appeared on the screen in conjunction with a tone.

After every six passages the computer displayed a set of multiple choice questions pertaining to the six preceding passages. The questions appeared on the screen one at a time, and the subjects answered them by pressing the number key on the keyboard that corresponded to the best answer. However, due to a programming error, data from the multiple choice questions were not collected properly, so these data could not be analyzed.

## Results and Discussion

In analyzing the probe data, we had to remove any subjects who performed at chance levels at lag 0 because such floor effects would make the paradigm insensitive to lag effects. Accordingly, 24 subjects were replaced for failure to obtain a mean percentage correct above 50% at lag 0 for combined topic and detail probe questions. Five of the subjects who were replaced had relatively high span scores (above 46), while 8 of the replaced subjects were low in span (below 27). The rest of the replaced subjects scored within one SD of the mean span score.

The mean proportions of correct responses to topic and detail probe questions by lag (0, 2, 4) are given in Table 2. We first tested for lag effects in both topic and detail probes to see if we replicated Glanzer and Nolan's results in a set of analyses parallel to theirs, that is without removing variability due to individual differences in WM span. An alpha level of .05 was used for all significance tests.

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Insert Table 2 about here

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Despite using different materials and a probe deadline procedure rather than reaction time, we replicated the earlier results. The small decrease in performance on topic probes over lag was not significant, $F(2,190) = 2.03$, $MSe = .050$, $p > .10$. There were significant lag effects for detail probes, $F(2,190) = 12.23$, $MSe = .047$.

Overall, this same pattern was obtained across the range of WM span scores. Figures 1 and 2 show the performance on the probe questions plotted over WM span for topic and detail probes, respectively. The bin width used to plot the effects over WM span was chosen by starting with the lowest WM span score in the sample and selecting divisions that would insure that each mean represented at least 12 subjects. As Figure 1 suggests, there was a general increase in performance on topic probes with WM span, $F(1, 94) = 16.97$, $MSe = .037$. More importantly, there was no lag effect and no WM span x lag interaction (both $Fs < 1$). In contrast, there was a significant lag effect for detail probes, $F(2, 188) = 5.39$, $MSe = .247$. The main effect of WM span on answers to detail probes was marginal, $F(1,94)= 3.10$, $MSe= .051$, $p = .08$.

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insert Figures 1 & 2 about here

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Although Figure 2 shows that lag effects were consistently obtained over the whole WM span range, we did obtain a WM span x lag interaction for detail probes, $F(2,188) = 3.09$, $MSe=$ .046.. This interaction apparently resulted from an anomaly at the lowest WM span levels. For the lowest span subjects, the performance at lag 4 is considerable better than the performance at lag 2. The reason for this effect is unclear. It could represent some sort of end-of-passage rehearsal strategy to prepare for the late probe question, or it could be a spurious result. If the improvement in performance at lag 4 turns out to be a reliable effect that interacts with WM span, it would certainly be worthy of further study. However, for now, our main interest was in whether WM span would interact with performance on the topic probes, and clearly it did not.

The major result of experiment 1 is that regardless of WM span level, readers maintained topic information across sentences to a greater degree than they maintained detail information. Thus, the first experiment established that low span readers were not limiting topic maintenance in order to process details. If lower span readers were making such a tradeoff, we should have observed lag effects for topic probes at the lower levels of WM span. We found no such evidence, though the data from the detail probes clearly show we had sufficient power to detect both lag effects and interactions between WM span and lag. However, a possible objection to

Experiment 1 is that the paradigm used was invasive and interrupted subjects' normal reading behavior. Thus, the data might not reflect normal reading processes. Also, because we had to replace several subjects in the first experiment due to poor performance on the probe task at lag 0, it could be argued that the lowest span subjects used in experiment 1 were not representative of low span readers in general. Therefore, in Experiment 2, a non-invasive reading time measure was used to assess differences in WM management strategies.

Another purpose of Experiment 2 was to present the subjects with a somewhat more demanding reading task. Several researchers have found that when processing demands are minimal there are fewer differences between the performances of high and low span subjects (Just & Carpenter, 1992; Raney, 1993). For example, Raney (1993) found that reaction time to secondary task (tone detection) was similar for both high and low span readers when subjects read short, simple passages. However, when the text was longer and more difficult, and the total number of responses a reader was required to make to the secondary task were increased, the reactions time to the secondary task were longer for low span readers than for high span readers. Raney (1993) concluded that the processing demands associated with the shorter, easier passages did not exceed the resources of the low span subjects. Accordingly, in Experiment 2 we tested whether lower span readers would continue to perform thematic processing even when that processing was made more difficult by having subjects read some passages without topic sentences.

## Experiment 2

A wide range of studies have shown that readers typically assume that the first sentence of an expository passage is of special thematic importance. Initial sentences are rated higher in importance (e.g., Kieras, 1984) and they are usually remembered better than sentences at other serial positions (Kieras, 1981a; Meyer, 1975). A series of studies by Kieras (1981a, 1981b, 1982) showed that sentence position effects are also observed in reading times. For example, Kieras (1982) found longer reading times for topic sentences than for detail sentences with simple expository passages. Kieras (1982) also found that if the topic sentence was deleted so that the initial detail sentence now appeared first, then subjects read this detail sentence much longer than they did when it occurred as the second sentence of the passage.

Kieras (1982) attributed the longer reading time to the thematic processing that occurs because the first sentence is taken as the topic sentence. The effect of initial position was particularly pronounced in the condition in which the true topic sentence was deleted, perhaps because readers experienced greater difficulty in constructing a topic when one was not explicitly stated in the sentence. Support for this interpretation came from studies (Kieras 1984) in which reading times for initial sentences were consistently under predicted by a set of variables (e.g., length, number of new arguments, parsing difficulty) that predicted reading times for other sentences very well. Thus, the first sentence of a passage is processed longer than would be expected from its other properties. In the model developed by Kieras (1982), this additional processing time was taken as an index of thematic processing. Depending on the reading context, the additional time taken to process the first sentence can vary from approximately 500 msec to more than a second (cf., Kieras, 1981b; 1984).

If readers perform relational thematic processing, then we would expect that increased reading times would not be limited to the first sentence of a passage. Several studies, have shown that the first several sentences of a passage are read longer than later sentences. For example, Haberlandt and Graesser (1985) reported just such a serial position effect on sentence reading times, and this effect remained significant even when differences in the number of new arguments among the sentences was partialed out. Likewise, Olson, Mack, and Duffy (1981) found longer reading times for the first 3-4 sentences of well-structured passages. In a parallel "thinking out loud" experiment, it was shown that subjects were performing more thematic processing in these early sentences--drawing topical inferences and making predictions. These data are consistent with a model of comprehension in which readers establish a theme as early as possible and relate this theme to new information as more sentences are read (e.g., Kintsch & van Dijk, 1978). With successive sentences this integration process becomes easier as the thematic representation is refined and has a richer set of propositions to relate to new information (Haberlandt & Graesser, 1985; Haberlandt, 1984).

In the present experiment, we adapted the reading time paradigm used by Kieras (1982) in order to examine whether amount of thematic processing is associated with variations in WM span. Subjects read modified versions of the passages from Experiment 1. Half of passages were presented without a topic sentence. Reading times for the identical sentences in the topic absent and topic present conditions were collected and compared. Subjects were also required to answer one multiple choice question about each passage. Half the multiple choice questions were about topic information and half were about detail information. Unlike the studies done by Kieras (1982), in which comprehension was tested by having the subjects state the main idea of the passage, the comprehension task used in this study emphasized retention of both thematic and detail information. Thus, if a tradeoff became necessary, the direction of tradeoff was not dictated by the comprehension task, but, instead, the direction was left to the subject. If high and low span subjects use WM management strategies that utilize similar thematic processing, as suggested by the data from Experiment 1, then all subjects should take more time to read the first sentence in the passage than to read subsequent sentences in both topic-absent and topic-present conditions. Also, accuracy for topic questions should not vary by span. If the thematic processing carried out by low span subjects in the topic absent condition takes place at the expense of proposition-specific processing of detail information, then low span subjects would answer less detail questions correctly than high spans in the topic absent condition. Of course, as noted earlier, an emphasis on thematic processing may aid retention of details, but only if two conditions are met: the reader posses adequate resources to also perform adequate proposition-specific processing of detail information, and the thematic processing must be relational-- the theme and the detail must be associated in memory (cf., Einstein et al., 1990).

## Method

### Subjects

Seventy-two undergraduates from Washington State University participated for extra course credit or to fulfill a general psychology course requirement. All subjects were native speakers of English. Subjects were administered the WM span test used in experiment 1. The sample of subjects obtained was very similar to that of the first experiment. The WM span scores ranged from 15 to 53, with a mean of 35.5 and a standard deviation of 9.3.

### Materials and Design

The 24 passages from Experiment 1 were modified for use in Experiment 2. The topic sentence and the first detail sentence of each passage were altered so that mean reading times for each type of sentences in isolation were equated. Therefore, reading times differences between the first sentence in the topic present condition and the first sentence in the topic absent conditions could be attributed to sentence position effects and not to any differences in sentence length or difficulty. A pilot study using 26 subjects indicated that mean reading times for these new topic and detail sentences were 9086 ms (SEM= 230) and 9242 ms (SEM= 185), respectively. All other sentences in each passage were the same as those used in Experiment 1. Additionally, a topic absent and topic present version of each passage was created.

Two multiple choice questions were also constructed for each passage. Each question was constructed so that subjects had three alternatives from which to choose. One question asked about explicit detail information and one question asked about topic information. The detail questions were constructed so that they would require knowledge of the specific information contained in the related detail sentence (e.g. How many hours of training did most of the clean up workers receive?). The topic questions could be answered either directly from the information contained in the topic sentences or by using the detail sentences to infer the correct response. For example, the topic question for the passage in Table 1 was:

After the Exxon oil spill, the problems of the clean up, workers:

1. were given high priority and often put ahead of the needs of the wildlife endangered by the oil spill.

2. were low priority and often put behind the needs of the wildlife endangered by the oil spill.

3. were not given top priority, but were usually taken care of in a timely manner.

The independent variables of passage type and question type were manipulated within-subjects. Four versions of the experiment were created. Each version contained six trials of each passage type (topic present, topic absent) by question type (topic, detail) condition. Across versions, every passage appeared in each condition. Subjects were randomly assigned to versions at the beginning of the experiment.

Procedure

The subjects were given the WM span test in one session and returned on a later day to complete the reading comprehension task. The reading comprehension session lasted 40-60 minutes. The presentation of the passages was the same as in Experiment 1, except that there were no probe questions. Subjects were given general instructions on how to control text presentation and they performed one practice block of six passages to familiarize them with the procedure and orient them to the type of questions that would be asked.

Subjects were informed that they were going to read passages dealing with various topics of interest, and that they should read each passage carefully in preparation for a test at the end of each block of six passages. After every six passages, the computer displayed a set of multiple choice questions pertaining to the six preceding passages. Questions were displayed one at a time and there was one question per passage. Half of the questions were about detail information and half were about topic information. The computer recorded the subject's response to each question and gave the subject feedback regarding their accuracy.

Results and Discussion

Eight subjects (from various span levels) were replaced because their poor performance on the multiple choice questions suggested that they were not reading carefully. All of the other subjects scored above 50% correct on combined topic and detail questions. We first present the reading time data, and then the subjects responses on the comprehension questions are discussed.

Reading Times.

The analyses were performed on the mean reading times for each subject in each condition. Reading times for individual trials that were greater than 14000 msec and less than 2000 msec were eliminated from the analysis. Approximately 2% of the observations were eliminated. Figure 3 shows mean reading times in both the topic absent and topic present conditions over sentence position.

Insert Figure 3 about here

The data from the subjects taken as a group clearly replicate other data on sentence position effects (e.g., Kieras, 1985). The decline in reading time with sentence position is significant both in the topic present condition, $F(6, 426) = 30.92$, $MSe = 674,351$, and in the topic absent condition, $F(5, 355) = 49.26$, $MSe = 601,908$. As predicted by Kieras (1982), reading time for the first detail sentence was longer in the topic absent condition than in the topic present condition, $F(1,71) = 45.25$, $MSe = 517,493$.

To determine if there was converging evidence for our conclusion that all subjects were performing thematic processing in the first experiment, we needed to derive an index of thematic processing from the reading time data. Based on the data in Figure 3, it appeared that reading times declined and then leveled off at sentence position four. We checked the passages to see if this drop could be explained simply in terms of sentence lengths. However, the average number of syllables in the topic sentence was only 2.75 more than the average number of syllables in sentence four (SD difference= 12.62). This difference did not approach significance in a repeated measures *t*-test ($p > .20$). This suggested that we could take the average decline in reading time up to sentence four as an index of thematic processing. This procedure would remove most of the effects of factors other than thematic processing, particularly since all the detail sentences described independent supporting evidence for the theme and the more unfamiliar technical terms found in these passages occurred almost invariably among the detail sentences . Thus, even those sentences presented later in the passages included considerable new detail information, but no new thematic information. However, before calculating this index of thematic processing for each subject, we checked the assumption that the function in Figure 3 was representative of the reading time function across various levels of WM span. In Figure 4, the reading time data are displayed separately for groups formed from the upper and lower tertiles of span scores. Trend analyses on each of the functions displayed in Figure 4 showed a linear decline in reading time over sentence positions 1-3, and a quadratic trend when sentence position 4 was added to the analyses.

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insert Figure 4 about here

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Given that the general form of the serial position function was similar at each end of the continuum of WM span scores, we calculated, for each subject, the average decline in performance over sentence positions 1-4 in the topic present condition and positions 2-4 in the topic absent condition. Figure 5 shows this index of thematic processing plotted over span for both the topic present and the topic absent conditions.

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insert Figure 5 about here

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Consistent with the data from the first experiment, neither the topic present nor thê topic absent data varied with WM span (both *F*s < 1). Again, we found evidence that thematic processing was used similarly by subjects across the range of WM capacity. We should also note that the values in Figure 5 (approximately 500-1000 msec) fall closely in line with the estimates of thematic processing times obtained by Kieras (1981; 1982; 1985) under similar conditions. We also found that reading times were longer in the topic absent condition, in which the subject must infer the theme from the details, $t(71)= 4.53$, a finding which further suuports our contention that this index taps into thematic processing.

Comprehension Questions

Because the reading time data indicated that the amount of thematic processing did not vary with WM span, we did not expect to see a relation between answers to topic questions and WM span. The data shown in Figure 6 confirmed this expectation. There was no general effect of WM span on answers to the topic questions ($F< 1$), nor did WM span interact with the topic absent versus topic present condition ($F< 1$). Although there was a trend towards lower overall performance in the topic absent condition (M= .78 for topic absent and M= .85 for topic present), the main effect of this variable was not significant ($p > .20$).

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Insert figure 6 about here

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The more interesting question with regard to the comprehension questions was whether thematic processing engendered any cost or benefits to retention of details at some levels of span. The relevant data are shown in Figure 7. For the answers to the detail questions there was a significant interaction between the topic condition and WM span, $F(1,70) = 5.72$, $MSe = .022$. Only at the very low end of WM capacity did performance suffer in the topic absent condition. Increasing the difficulty of thematic processing by deleting the explicit topic sentence, does not appear to influence performance on the detail questions unless WM capacity is quite low.

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Insert figure 7 about here

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There are two important findings from experiment 2. First, the reading time data support the conclusion from experiment 1 that subjects across the WM span range performed thematic processing. Second, when thematic processing was made somewhat more difficult by leaving the topic unstated, there was a concomitant decrease in performance on detail questions for those subjects who were lowest in WM capacity. For these low span readers the difficulty of constructing the theme in the topic absent condition may have decreased the item-specific processing of details, which, in turn, would decreased their ability to perform relational processing between the theme and the details. These findings raise questions about what conditions foster differences in WM management strategies as a function of processing capacity. Throughout the first two experiments, subjects with different WM capacities appeared to be using a similar WM management strategies in terms of their relative emphasis on the processing of thematic information. The only difference obtained thus far was in the consequences of thematic processing for comprehension of particular details. However, in both experiments subjects were asked questions that explicitly required knowledge of the topics of the passages. Thus, it might be argued that the similarity in thematic processing we have seen across different span levels was due to the explicit demands of the comprehension questions. We explored this issue in the third experiment.

# Experiment 3

For experiment 3, we replicated the topic present condition of experiment 2, except that no questions about the topics of the passages were asked until a surprise test at the end of the experiment. Thus, we were interested in whether subjects would alter their thematic processing when they had no reason to expect questions about anything other than specific details. However, it is unclear whether most readers can altering their reading strategies to fit the type of comprehension test they receive (cf., Epstein, Glenberg, & Bradley, 1984). The data from experiment 2 suggest that for readers with higher WM capacity, increased thematic processing does not lower performance on questions about specific details. In fact, if retention of specific details is emphasized, a reasonable strategy for the higher span readers would be to use relational thematic processing to assist in retention of detail information (cf., Einstein et al., 1990).

## Method

### Subjects

We obtained 120 subjects from the same subject population used for the previous experiments. The WM span scores for this sample ranged from 15 to 55, with a mean of 34.7 and a standard deviation of 8.4.

### Materials and Design

The topic-present versions of the 24 passages from experiment 2 were used in the present experiment. The topic and detail multiple choice questions from experiment 2 were used as a surprise additional test of comprehension at the end of the study. In place of asking the multiple choice questions at the end of each block of six passages, we created true/false probe questions to follow the reading of each passage. These questions were used to orient the reader toward an emphasis on retention of details. Two true/false probes were created for each passage. Half the probes were true and half were false.

### Procedure

The passages were presented in the same manner as in experiment 2. The practice block of trials included the same type of true/false detail probes as in the rest of this study. After each passage, a probe question was presented in white letters on a blue background (sentences were presented in black letters on a light gray background). Subjects were given five seconds to respond to each probe, and the computer provided feedback regarding accuracy. Subjects were told that their task was to read each passage carefully so that they could answer questions that would occur at the end of each passage. They were not told about the multiple choice questions that they were asked to answer once they had finished reading all the passages. After a subject had completed all the trials, two blocks of multiple choice questions were presented-- one block of detail questions and one block of topic questions. The order of the blocks was counterbalanced across subjects. Each detail question asked about information different from that tested by the corresponding probe question for a given passage. Each block consisted of 24 questions, one question for each passage. Subjects were told that this surprise test was to further evaluate their memory for the text that they had just read.

## Results and Discussion

The treatment of the data for this experiment follows that of the second experiment. The same outlier criteria were used for the reading time data, and we performed the analyses first on the group data to check for replication of previous results before we explored the individual differences. In addition, we performed the analyses of both the reading time and question answering data separately over the counterbalancing variable, that is, for the 60 subjects who received the detail questions first and for the 60 subjects who received the topic questions first at the end of the experiment. The pattern of results was the same for each group, so all the analyses reported here are based on the full sample of 120 subjects.

### Reading Times

The general pattern of reading times as a function of sentence position was closely in line with the data from experiment 2. Figure 8 shows the data for the full sample and for the upper and lower quartiles of the WM span distribution. Obviously, the decline in reading times for the whole sample data is significant, $F(6, 714) = 249.4$, $MSe = 197{,}864$. Although the low span subjects have a shallower function, it is clear that the general pattern is the same as for the whole sample, and the same as for experiment 2.

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insert Figure 8 about here

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Based on the similarity of the functions in Figure 8 with each other, and with the data from experiment 2, we calculated the index of thematic processing for each subject in the same manner as the previous experiment. These data are shown as a function of WM span in Figure 9. The data are strikingly different from those of the previous experiment. Rather than the consistent thematic processing across WM span found in the previous experiment, there was a significant increase in thematic processing with WM span, $F(1, 118) = 9.24$, $MSe = 59{,}320$. In comparing the thematic processing times to those obtained in the second experiment, it is clear that the difference in the two studies is in the behavior of higher span readers. At lower levels of WM span, the subjects performed very similarly to the subjects in experiment 2. However, when retention of details was emphasized in experiment 3, the higher span readers responded with an *increase* in thematic processing in comparison to the earlier study, and in comparison to the lower span readers in the same condition. With orienting questions that increased the salience of the importance of retaining detail information, the higher span readers increase the amount of thematic processing, perhaps with the goal of using relational thematic processing to improve retention of detail information.

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insert Figure 9 about here

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Answers to Multiple Choice Questions

If the conclusion is correct that higher span readers are using relational thematic processing to aid retention of details, then the reading time data suggests that there should be a corresponding general increase in question answering performance with WM span. That is, performance on both topic and detail questions should increase with WM span. The relevant data are shown in Figure 10. Consistent with our interpretation of the reading time data, performance on both topic questions, $F(1, 118) = 20.48$, $MSe = .010$, and detail questions, $F(1,118) = 14.42$, $MSe = .016$, increased with WM span.

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insert Figure 10 about here

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## General Discussion

The purpose of the present study was to extend previous research by examining whether quantitative differences in WM span affect the comprehension processes that readers use to process simple expository text. Other researchers using narrative text have obtained data consistent with this hypothesis (Just & Carpenter, 1992; Perfetti, 1985; Lee-Sammons & Whitney, 1991; Whitney et al., 1991). The data from these experiments are in agreement with the general finding that performance differences among readers with different WM span are often small or negligible when the materials are easy, but larger when the task of comprehension is made more difficult (Just & Carpenter, 1992; Raney 1993). In the topic present condition of experiment 2, when the experimental materials were easier to process, high and low span subjects used similar WM management strategies, that resulted in similar accuracy for both topic and detail information. However, when thematic processing became more difficult, for example in the topic absent condition of experiment 2, performance differences became more apparent. This interaction between WM span and task difficulty lends support to the common theoretical assumption that WM plays a central role in the coordination and management of information processing in comprehension (e.g., Carpenter & Just, 1992; Kintsch, 1988; Sanford & Garrod, 1981 ).

More specifically, we found that across the range of WM span, readers construct and maintain thematic information in WM. This finding is inconsistent with theories that claim that readers only maintain local coherence relations (McKoon & Ratcliff, 1992) but consistent with the hypothesis that in at least some reading contexts, readers attempt to maintain some thematic propositions in WM in order to maintain global coherence at the passage level (Kintsch, 1993; Trabasso & Suh, 1993; Whitney et al., 1991). Perhaps more importantly, the present data show that such global coherence processes, or what we have called here "relational thematic processing," can improve retention of the *details* of a text, as shown by the data from experiment 3 (see also McDaniel, Einstein, Dunay, & Cobb, 1986). However, the present results also show that not all thematic processing improves retention of detail information. Thematic processing was greater in the topic absent condition than in the topic present condition of experiment 2. This was true across the range of WM span. However, there was no concomitant increase in performance on detail questions in experiment 2 to mirror the increase in performance by higher span subjects who performed extensive thematic processing in experiment 3. The likely explanation for these effects is that the increase in thematic processing observed in the topic absent condition of experiment 2 was due to the increased difficulty of constructing the thematic proposition. Thus, in the topic absent condition, there was no increase in *relational* thematic processing above that found in the topic present condition, so retention of details was not improved, and, in fact, performance on detail questions declined somewhat for low span subjects. For low span subjects the difficulty of performing two kinds of item-specific processes at once (constructing a thematic proposition while comprehending a specific detail) resulted in a kind of tradeoff in WM in which comprehension of details suffered.

That we obtained individual differences in WM management and performance on comprehension questions using texts that were relatively short and simple in structure has implications for an educational system in which the reading materials are usually longer, more complex, and more variable in organization than the texts used in these experiments. Consider the research on advanced organizers. Many investigators have tried to improve comprehension of text by providing advanced information on text organization as a way of improving what is learned from text (e.g., Reder, 1985). Studies on advanced organizers have produced a confusing, and sometimes conflicting, pattern of results. Although information about text organization can facilitate thematic processing (Mayer, 1979; Reder, 1985), there is disagreement over who is aided by such manipulations. Some investigators have reported more facilitation for poor readers (e.g., Mayer, 1980), while others have reported the opposite (e.g., Derry, 1984).

The claim that advanced organizers help poor readers more than good readers suggests that poor readers do not spontaneously perform thematic processing (e.g., Meyer, 1975), or at least do not perform it as effectively as good readers (e.g., Lorch, Lorch, & Mogan, 1987). However, WM span correlates highly with reading achievement (e.g., Turner & Engler, 1989), and we found that in some conditions low WM span readers performed thematic processing, even if it was at the expense of retaining detail information. In addition, roughly the same level of thematic processing was observed among lower span readers across experiments 2 and 3, even though in the latter experiment the subjects had no reason to expect that any topic questions would be asked. Of course, there could be many reasons for the conflicting results. For one, it is difficult to evaluate claims about the effects of procedures on "poor readers" in general. Kloster and Winne (1989) noted that the direction of many aptitude by treatment interactions in reading varies as a function of how aptitude is defined. So, what is true of poor readers who have low WM capacity may not be true of other groups of poor readers. In addition, the efficiency with which readers can use a WM management strategy and the particular strategy readers use may vary as a function of the difficulty of the text and the reading goals employed (cf., Lorch et al., 1987; Mannes & Kintsch, 1987).

Just how flexible readers are in adapting to context is not well understood. Some studies suggest that proficient readers are more likely than less proficient readers to alter their strategies to accommodate different types of materials and tasks (Lorch, et al., 1987; Just & Carpenter, 1992). This was demonstrated clearly in the present study by the higher span subjects who read the passages quite differently in experiments 2 and 3, depending on the type of comprehension questions that were expected. However, other studies suggest that low span readers sometimes compensate for their lower capacity by making appropriate adjustments to task demands (Lee-Sammons & Whitney 1991; Whitney et al., 1991). More research needs to be done to determine how individual differences and variations in criterial tasks and materials affect the WM management strategies used in comprehension. We believe that the general approach taken here holds considerable promise for elucidating individual differences in adjustment to contextual conditions. That is, by identifying those contexts in which, for example, higher and lower span subjects do *not* seem to differ (as in experiment 1 and the topic present condition of experiment 2) and systematically varying conditions until span differences are obtained, we may be able to identify those factors that induce readers to adopt particular strategies.

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Table 1

Sample Text of Passage with Topic and Detail Probe Questions

In a race to save animals after the Exxon Valdez oil spill, the problems of the clean-up workers were often overlooked.

T-0

During the first few weeks after the Exxon Valdez oil spill, clean-up workers received only an hour of training.

D-0

Protective clothing was often unavailable for the clean-up workers.

T-2

Clean-up workers worked for days at a stretch in the same oil-soaked clothes.

D-2

One reason for concern is that the highly toxic components in the oil take days to evaporate.

T-4

Necropsies on dead otters revealed severe emphysema --presumably from breathing the fumes from the freshly spilled oil.

D-4

No on knows for sure what types of serious long term health problems the clean-up workers might face.

Topic probe question: The problems of the clean-up workers were usually overlooked.

Detail probe question: Most of the clean-up workers received many hours of training.

---

Note: T-0, T-2, T-4, D-0, D-2, D-4 indicate the locations of the topic probe questions (T) and detail probe questions (D) at each of the distances.

Table 2

Mean Proportion of Correct Responses as a Function of Lag: Experiment 1

| | Lag | | | |
|---|---|---|---|---|
| | 0 | 2 | 4 | *M* |
| Probe Type: | | | | |
| Topic | .80 | .75 | .74 | .05 |
| Detail | .84 | .69 | .73 | .13 |

Note: *M*= mean of net lag effect for lag 2 and lag 4.

## Figure Captions

Figure 1. Means (and standard error bars) for performance on topic probe questions as a function of WM span in Experiment 1.

Figure 2. Means (and standard error bars) for performance on detail probe questions as a function of WM span in Experiment 1.

Figure 3. Reading times by sentence position for group data in Experiment 2. Standard errors of the means ranged from approximately 140 to 170 ms.

Figure 4. Reading times by sentence position for subjects at the highest and lowest third of WM span scores in Experiment 2. Circles denote the topic present condition, and triangles denote the topic absent condition.

Figure 5. Relation between thematic processing and WM span in experiment 2 for both the topic present and topic absent conditions.

Figure 6. Performance on topic comprehension questions in Experiment 2.

Figure 7. Performance on detail comprehension questions in Experiment 2

Figure 8. Reading times by sentence position for subjects at the upper and lower quartile of WM span scores in Experiment 3.

Figure 9. Relation between thematic processing and WM span in Experiment 3.

Figure 10. Performance on topic and detail comprehension questions as a function of WM span in Experiment 3.

Fig 1

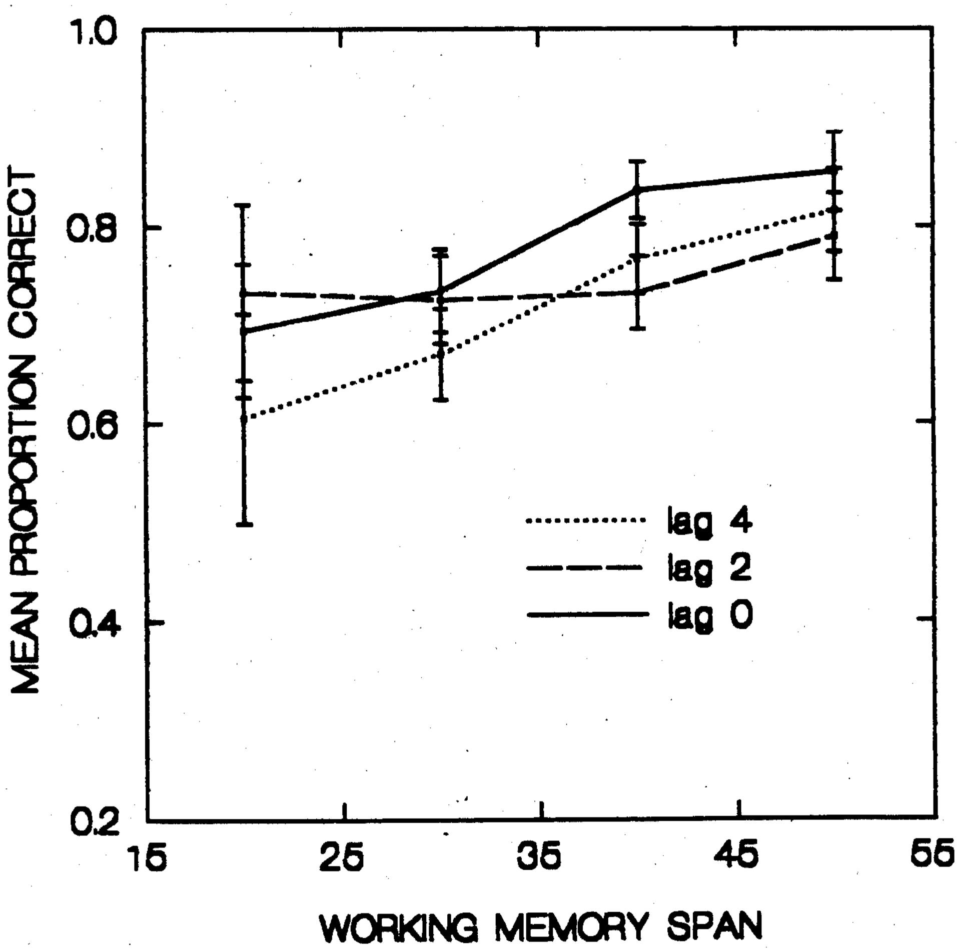
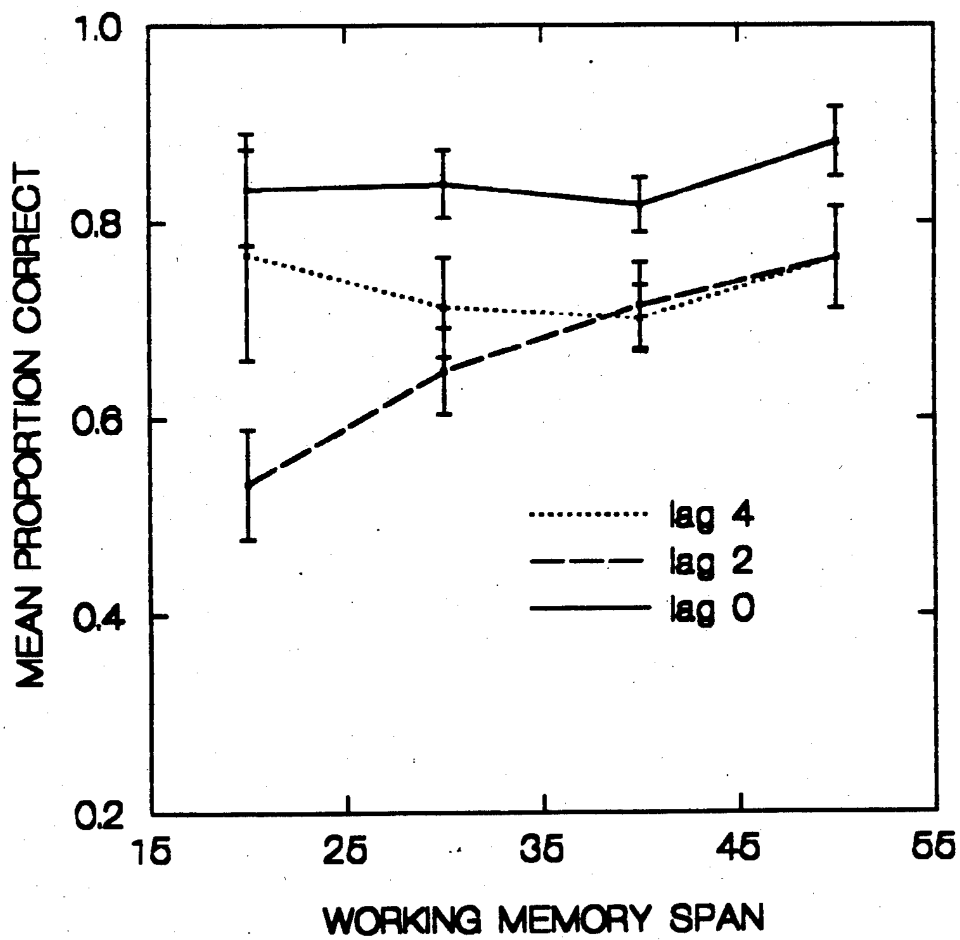

1.0
0.8
0.6
0.4
0.2
MEAN PROPORTION CORRECT
15
25
35
45
55
WORKING MEMORY SPAN
lag 4
lag 2
lag 0

Fig 2



MEAN PROPORTION CORRECT
1.0
0.8
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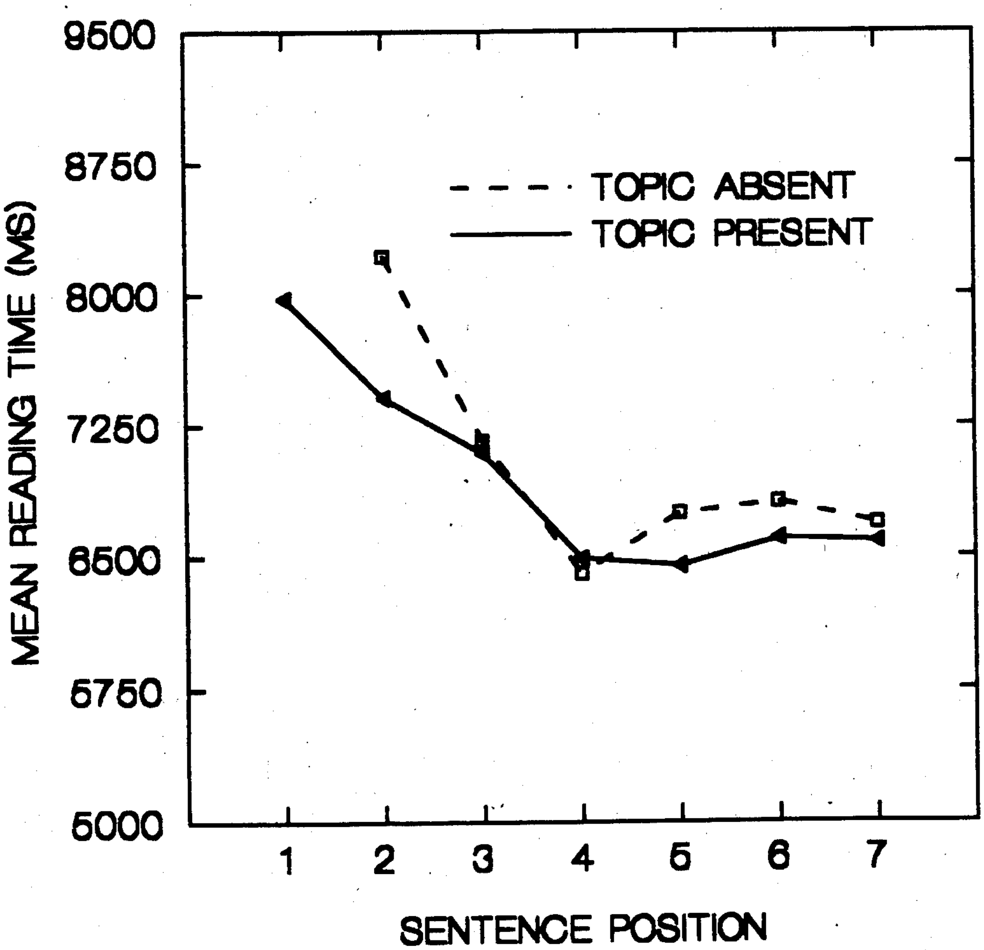
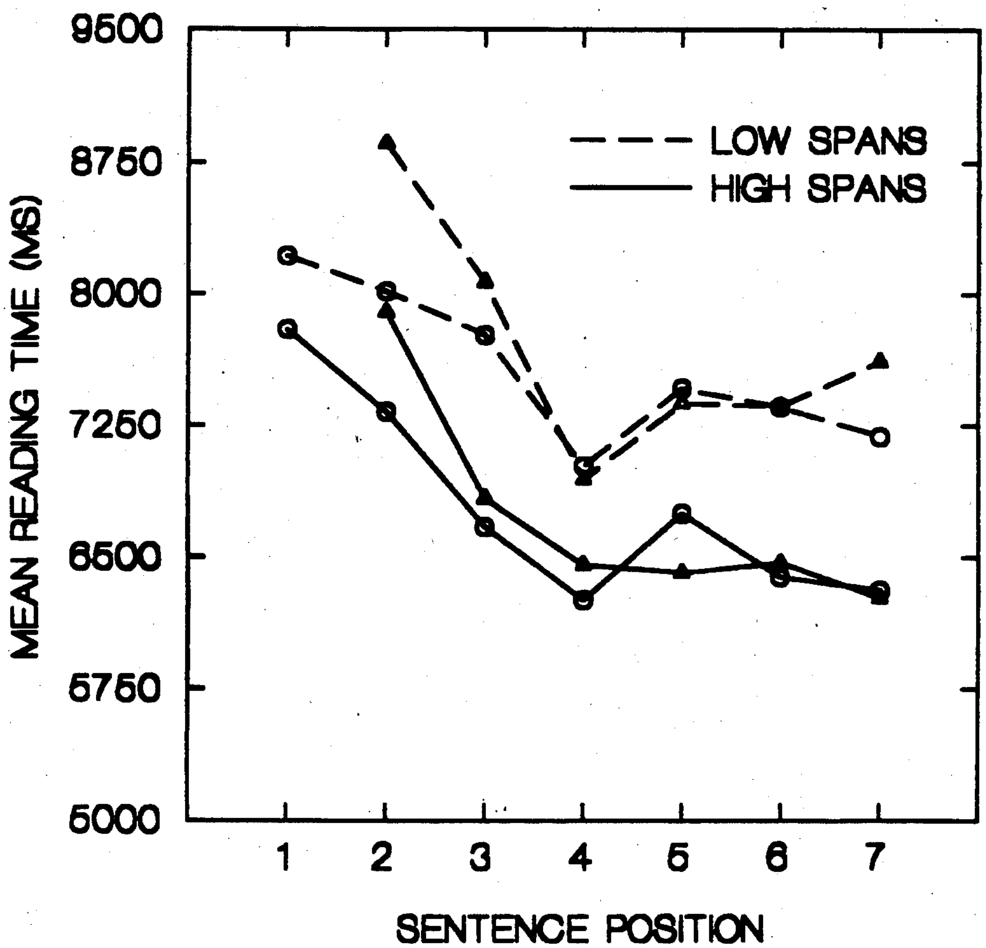
0.2
15
25
35
45
55
WORKING MEMORY SPAN
lag 4
lag 2
lag 0

Fig 3



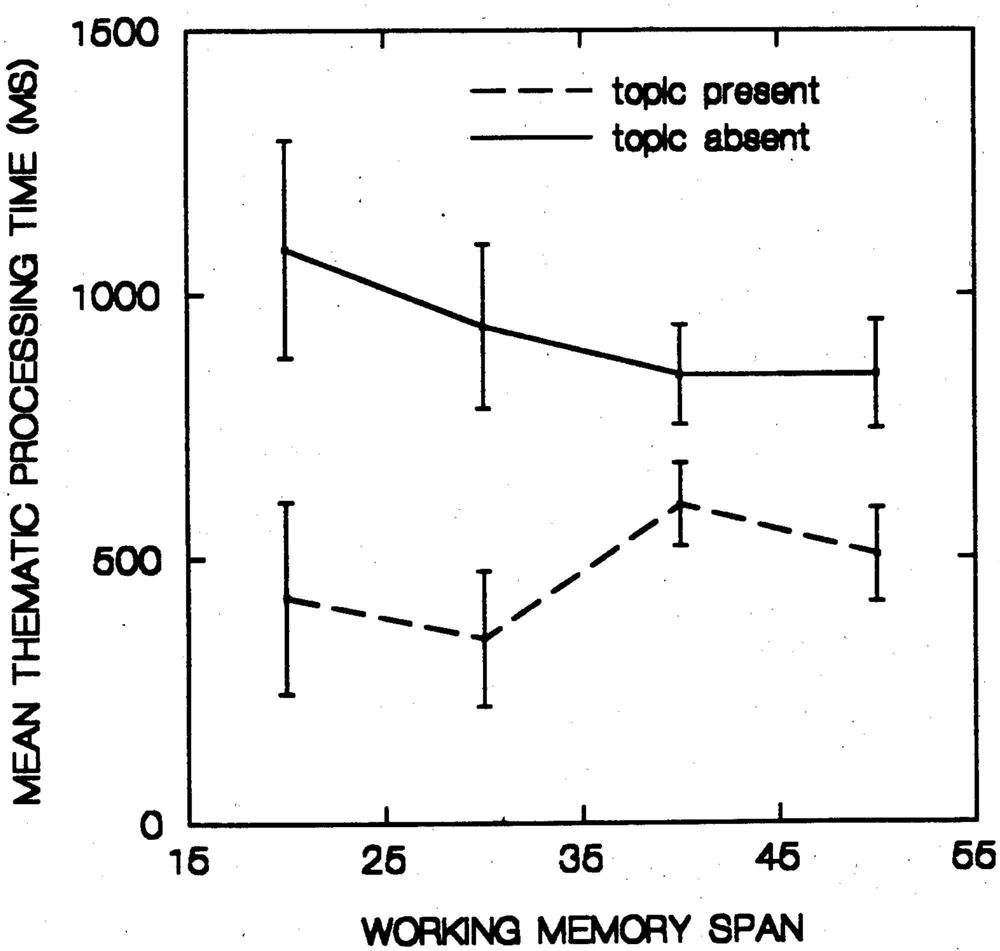
9500
8750
8000
7250
6500
5750
5000
MEAN READING TIME (MS)
TOPIC ABSENT
TOPIC PRESENT
1
2
3
4
5
6
7
SENTENCE POSITION

Fig 4



9500
8750
8000
7250
6500
5750
5000
MEAN READING TIME (MS)
LOW SPANS
HIGH SPANS
1
2
3
4
5
6
7
SENTENCE POSITION

Fig 5



1500
1000
500
0
15
25
35
45
55
topic present
topic absent
MEAN THEMATIC PROCESSING TIME (MS)
WORKING MEMORY SPAN

Fig 6

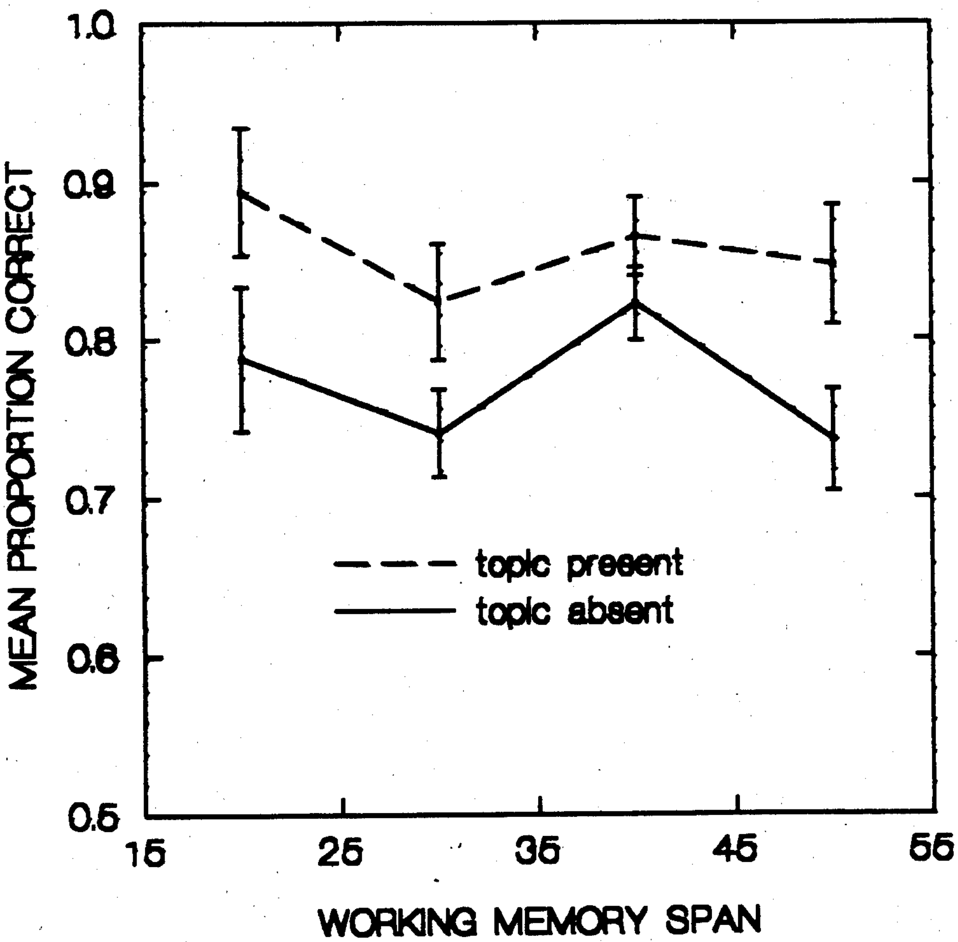
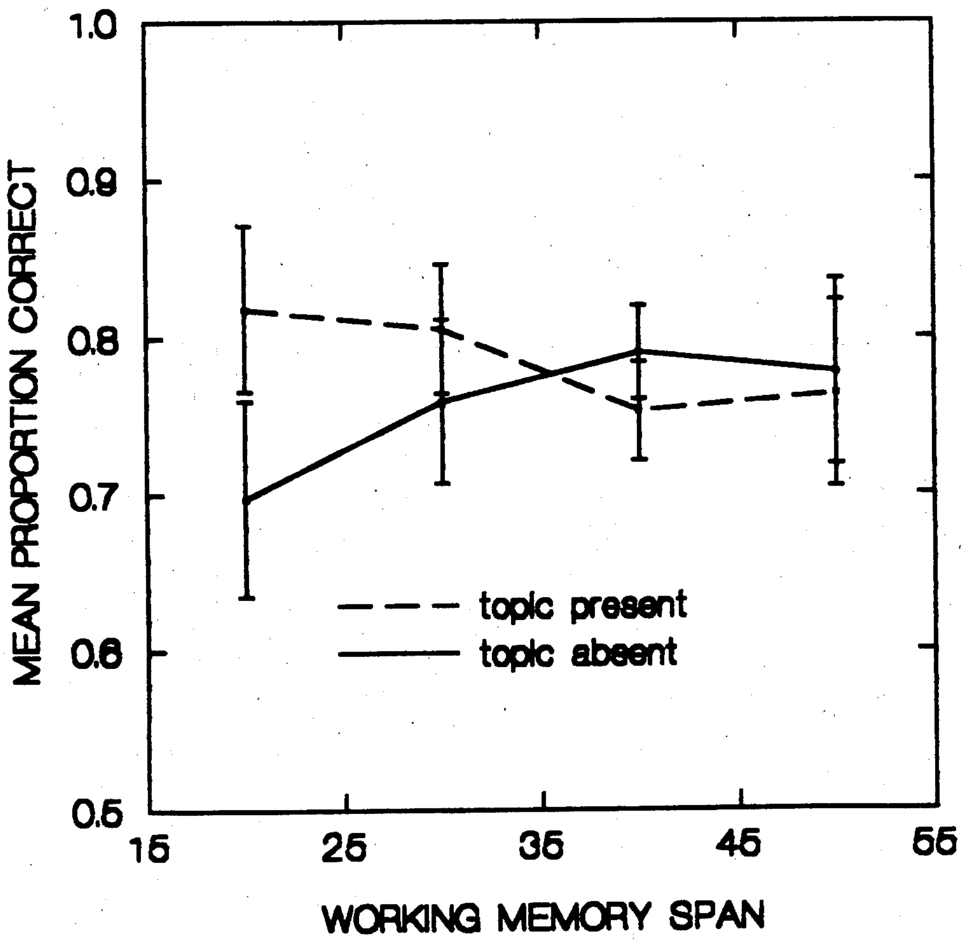
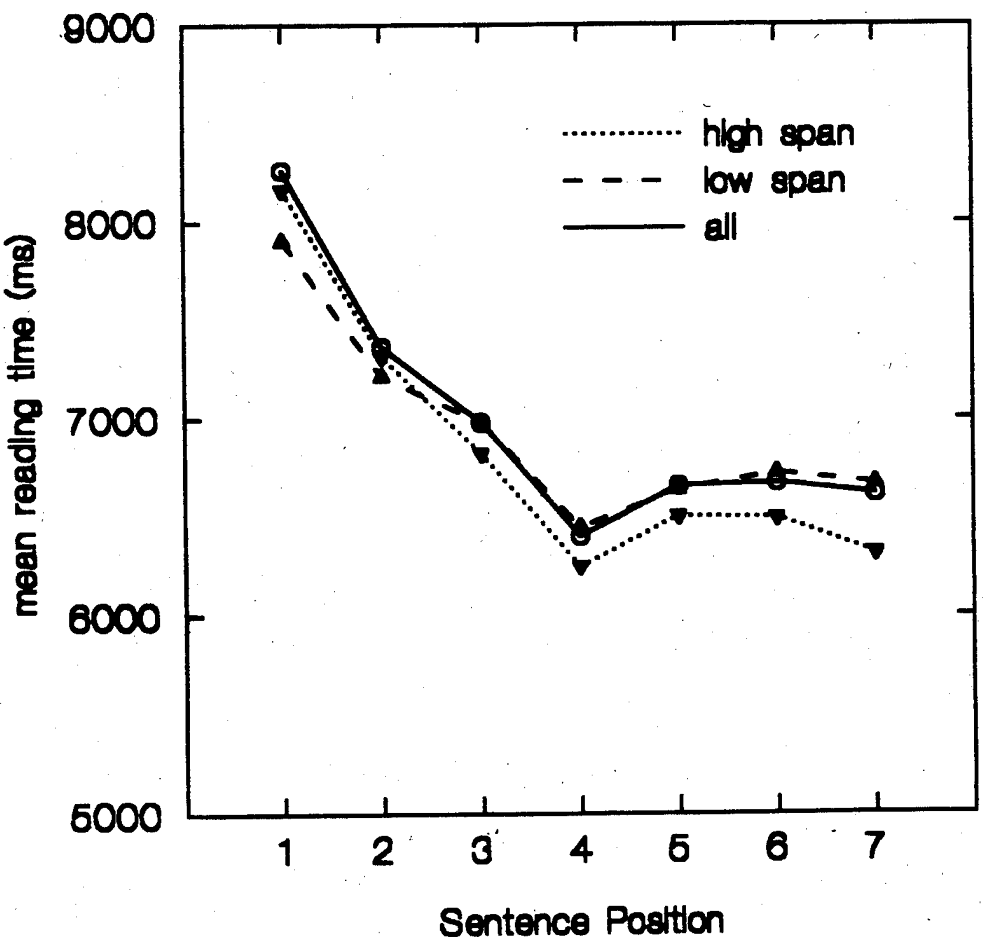

1.0
0.9
0.8
0.7
0.6
0.5
15
25
35
45
55
MEAN PROPORTION CORRECT
WORKING MEMORY SPAN
topic present
topic absent

Fig 7



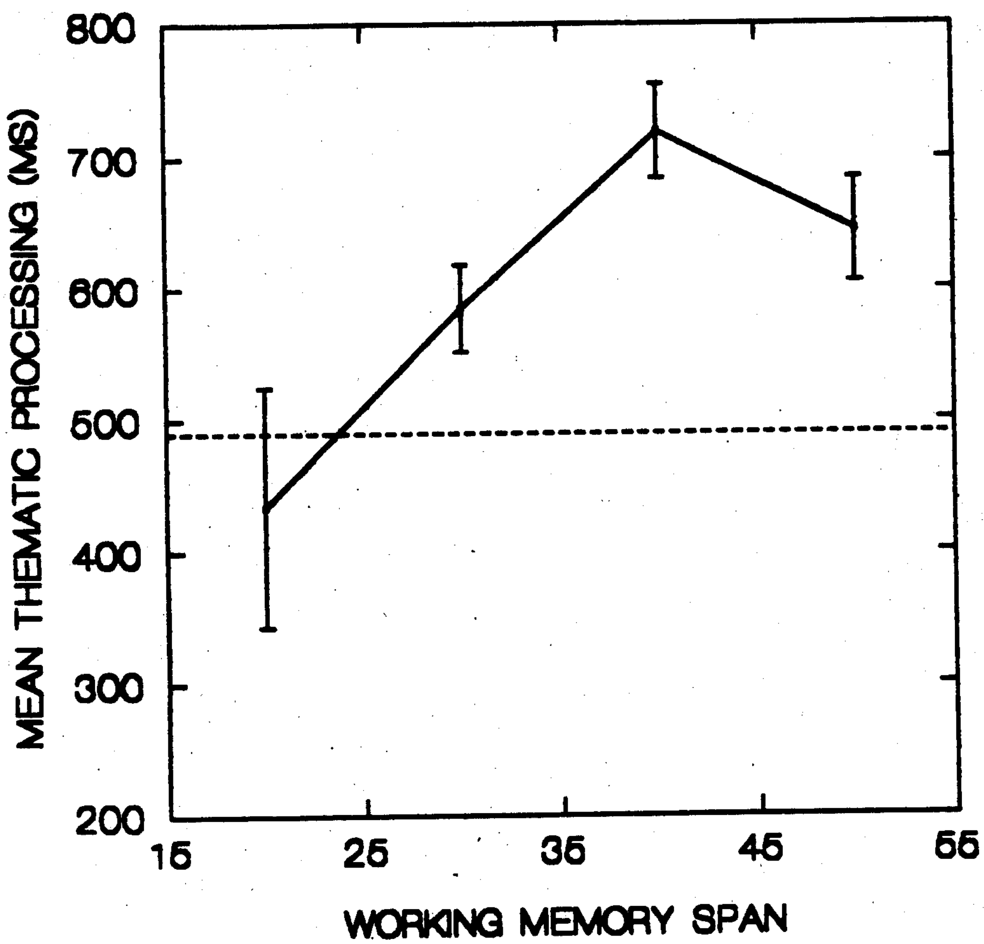
1.0
0.9
0.8
0.7
0.6
0.5
MEAN PROPORTION CORRECT
15
25
35
45
55
WORKING MEMORY SPAN
topic present
topic absent

Fig 8



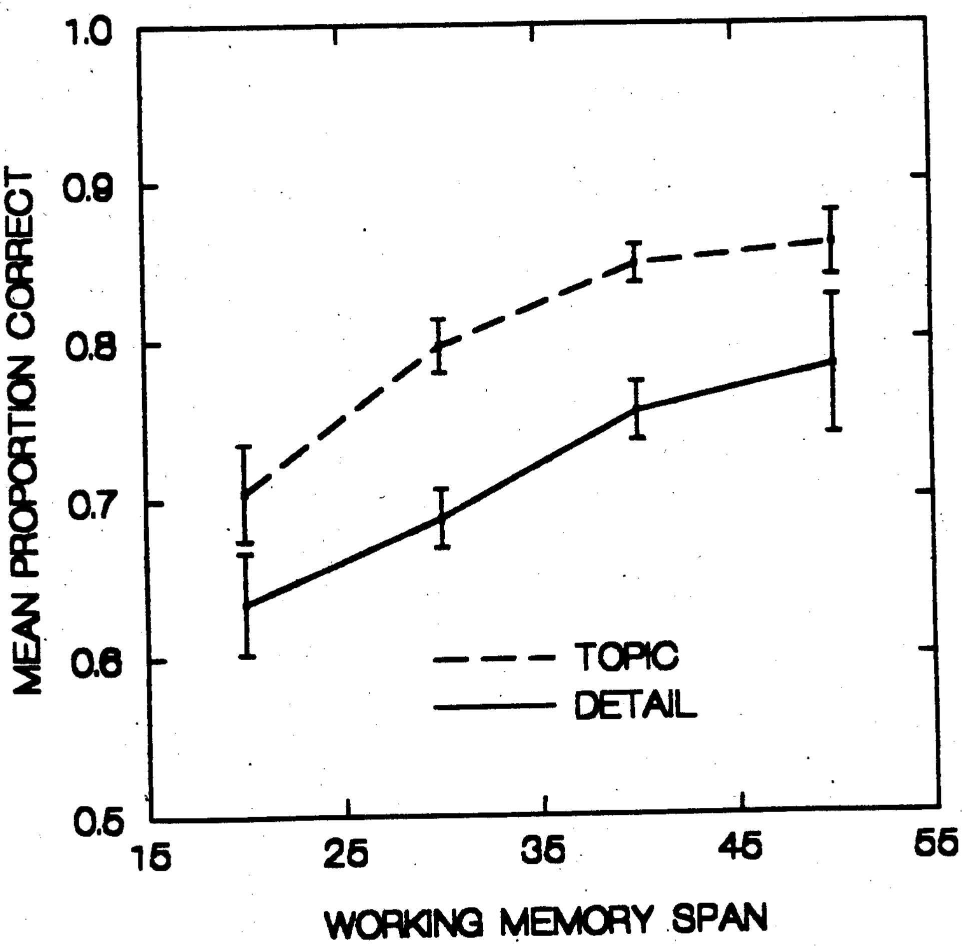
9000
8000
7000
6000
5000
mean reading time (ms)
high span
low span
all
1
2
3
4
5
6
7
Sentence Position

Fig 9



800
700
600
500
400
300
200
MEAN THEMATIC PROCESSING (MS)
15
25
35
45
55
WORKING MEMORY SPAN

Fig 10



1.0
0.9
0.8
0.7
0.6
0.5
MEAN PROPORTION CORRECT
15
25
35
45
55
WORKING MEMORY SPAN
TOPIC
DETAIL

Running Head: METAPHORIC FACILITATION

# Individual Differences in Metaphoric Facilitation of Comprehension

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# Individual Differences in Metaphoric Facilitation of Comprehension

Writer and reader are locked in a difficult relationship. A writer must anticipate what the intended reader knows and doesn't know. In addition, the writer must struggle to communicate what may be a very complex and essentially non-linear representation of ideas into a linear chain of sentences. The reader is trying to take this chain of sentences and recreate meaning. Often, the reader must also evaluate the meaning against experience. If the two partners are not in synchrony, the writer appears obtuse or the reader appears easily bored.

Metaphor is one instrument of communication that writers use to keep up their end of the bargain. Metaphor is often used to express ideas that are difficult to capture literally or to enliven prose that would otherwise be dull (e.g., Ortony, 1980; Pollio, this volume; Searle, 1979). In fact, at least for narrative writing, the tendency to use novel metaphors increases with the experience level of the writer (Williams-Whitney, Mio, & Whitney, 1992).

Despite the prevalence of metaphoric expressions in text, we are only beginning to understand how the use of metaphor affects the writer's partner in the linguistic relationship. Is the process of understanding metaphoric expressions different from the process of understanding literal expressions? How does the use of metaphor affect comprehension and memory? These are difficult questions, so it is not surprising that researchers often have simplified the issues by investigating the comprehension of isolated metaphoric sentences (e.g., Gildea & Glucksberg, 1983; Gregory & Mergler, 1990; Keysar, 1989). Studying the comprehension of metaphor using single sentence contexts is a reasonable approach, and we will draw on some of the data from such studies in the course of this chapter. However, our focus is on how metaphoric expressions affect the understanding of the larger discourse context in which they occur. In particular, we examine the utility of metaphor as an aid to the understanding of expository text.

## Understanding Expository Text

While narratives may sometimes be used to instruct by analogy or anecdote, we usually attempt to impart factual knowledge to a reader with an exposition. Expository text, such as the discourse used in textbooks, is usually quite different from narrative text. Unlike narratives, which tend to follow the same general plan--a setting, a problem, and a problem resolution--expositions are organized in a number of different ways (Graesser & Goodman, 1985; Meyer, 1975). In addition, except when experts are reading a text in the domain of their expertise, readers of narratives tend to have a much richer base of background knowledge that can be used to interpret the text (Graesser, 1981).

Given their less predictable organization and their less familiar content, expositions often present a special challenge to readers, particularly if the *connections* among the ideas are to be understood. Accordingly, researchers in psycholinguistics and educational psychology have experimented with ways of augmenting expository text in order to increase readers' understanding (e.g., Ausubel, 1968; Mayer, 1979). A number of "adjunct aids" have been developed to facilitate comprehension. These aids are presumed to facilitate comprehension by assisting in the selection of important information for further processing and by promoting the integration of information. In this chapter, we evaluate whether metaphoric statements can serve as adjunct aids to improve the comprehension of expository text. However, before turning to that research, we must consider some of the lessons learned from previous attempts to increase readers' understanding of expositions.

One important type of adjunct aid is known as signaling. Signaling does not add new content to a text. Instead, it gives emphasis to certain aspects of the content, or makes the organization of the text more clear (e.g., Meyer, 1975; Meyer, Brandt, & Bluth, 1980). Signaling thus makes explicit the nature of the relationship between items in the text. Without signals, such relations have to be inferred. For example, signals for comparison relations include the expressions *however* and *in contrast.* Expressions such as *therefore* and *as a result* are used to signal causal relationships.

Several studies that have manipulated the extent of signaling have shown a facilitative effect of signals on memory for text (e.g., Meyer, 1984; Spyridakis & Standal, 1987). However, the effects of signaling are qualified by several factors. One important mediating variable is the skill of the reader. Marshall and Glock (1979) showed that making logical connectives explicit facilitated text recall by less able readers, but such signaling had no effect on the performance of more able readers. Meyer (1975) found positive effects of signaling for poor and average readers, but no effect for good readers.

The effectiveness of specific signaling also depends on the type of criterial task used to assess comprehension and memory (Meyer, 1975; Loman & Mayer, 1983). For example, Loman & Mayer (1983) had two groups of subjects read expository passages. One group read passages with signaling and one read the same passages without signaling. The two groups did *not* differ in their ability to answer questions that assessed verbatim or factual knowledge of the texts. However, the group given signals recalled more information from the texts.

Finally, Spyridakis and Standal (1987) found that the effectiveness of signals depends on the length and difficulty of the text being read. Spyridakis and Standal (1987) manipulated the use of headings, previews, and logical connectives with texts of varying length and difficulty. They concluded that all three types of signals can enhance comprehension, but signalling appeared to be most effective with passages of moderate length and difficulty.

A similar pattern of effects can be seen in research on other types of adjunct aids. For example, adjunct questions can be inserted into a text to force rehearsal and integration of material. Whether such questions facilitate comprehension is dependent on several factors, including the skill of the reader and the difficulty of the text (e.g., Britton, Westbrook, & Holdredge, 1978).

Based on the research on adjunct aids, the simple question of "Do metaphors help people integrate text?" is the wrong question.

We should expect that whatever effects metaphors have on comprehension will be qualified by other factors. The focus of the present study is on whether any facilitative effects of metaphor are qualified by individual differences in reading ability. Before presenting our data, we first consider why metaphors might aid comprehension, and then we consider who should benefit most from metaphors as adjunct aids.

## Why Metaphors Might Aid Text Integration

Often when readers connect ideas from two literal expressions, they are able to rely on repetition of concepts or on pre-existing associations in memory as a bridge to link the expressions in memory (e.g. Kintsch & van Dijk, 1978; Sanford & Garrod, 1979). For example, because of our knowledge of conceptual categories, we can easily compute the coherence of the following sentences:

> *The Peterson's dog is the bane of the neighborhood. That animal never stops digging.*

A reader can determine easily that the "animal" in the second sentence refers to the same entity as the expression "the Peterson's dog" in the first sentence. In contrast, the connections between a *metaphorical expression* in one sentence and a literal expression in another sentence depend not so much on retrieving pre-existing associations in memory, but on computing similarities on-line during comprehension (cf., Camac & Glucksberg, 1984; Onishi & Murphy, 1993). For example, the reader must do more than retrieve a pre-existing association like *dog-animal* in order to understand:

> *The Peterson's dog is the bane of the neighborhood. That bulldozer never stops digging.*

Viewed in this context, understanding metaphoric references in text involves a kind of elaborative processing that "goes beyond the information given." Elaborations that form memorable connections between different text elements are one of the main factors that increase recall of text (Reder, 1980). Therefore, we might expect that metaphoric expressions function as a kind of adjunct aid that improves retention of prose material.

This hypothesis was tested in a study by Reynolds and Schwartz (1983). They gave subjects brief expository passages that ended with either a metaphorical summary statement or a literal paraphrase of the metaphor. For example, one of their passages was:

> The people of Nazi Germany were swayed by Hitler's rhetoric. Although he had committed his people to a course of war, he found it easy to persuade them of the virtue of his actions. Everyone in Europe at the time

was aware of the consequences of war, but the Germans had a blind belief in Hitler.

For each reader, the passage ended with one of the following:

(1) The sheep followed the leader over the cliff.

(2) The German people blindly accepted Hitler's dangerous ideas.

Note that the metaphoric summary, sentence (1), is a context dependent metaphor. That is, standing alone it could be literally true, but it is clearly metaphorical in the context of the passage. Using the first sentence of each passage as a retrieval cue, Reynolds and Schwartz (1983) found that passages with context dependent metaphors were better remembered.

Reynolds and Schwartz (1983) offered two possible explanations for metaphoric facilitation. First, metaphoric summaries might lead to greater elaborative processing of the text. At first blush, this would seem to contradict previous data that suggests that there is no difference in comprehension times for metaphorical versus literal statements (e.g., Ortony, Shallert, Reynolds, & Antos, 1978). However, reading times may only indicate initial comprehension and thus not reflect subsequent additional elaborative processing. Second, Reynolds and Schwartz (1983) noted that metaphoric summaries may have led to superior performance because the metaphoric statements themselves were more memorable. At retrieval they may have been more helpful in cuing the rest of the passage.

In reality, these two explanations depend on the same basic mechanism. If a metaphorical summary is to help in the recall of the whole passage, then it must be linked strongly in memory with the other statements in the passage (Reder, 1980). Thus, the Reynolds and Schwartz (1983) study suggests that metaphoric summary statements are more elaboratively processed in the sense that a more richly interconnected representation of the passage is obtained.

## A Study of Individual Differences in Metaphoric Facilitation

As noted above, general claims for the benefit of any adjunct comprehension aid must be viewed with caution. Accordingly, we attempted to replicate and extend the findings of Reynolds and Schwartz (1983) by testing for an aptitude X treatment interaction in metaphoric facilitation of comprehension. Aptitude was defined in terms of performance on the reading span test (Daneman & Carpenter, 1980). This test correlates highly with standardized tests of reading ability (e.g., Masson & Miller, 1983), but it is especially sensitive to individual differences in capacity for integration of different text propositions (e.g., Daneman & Carpenter, 1983).

Our purpose in testing for reading span differences in metaphoric processing was twofold. First, there is the practical question of who might benefit from the use of metaphors in text. Second, an interaction between reading span and type of summary could tell us something about why metaphors have a facilitative effect, and about the relative difficulty of processing metaphoric versus literal text.

The key theoretical question that ties together these issues--who benefits from metaphors and why--is whether the elaborative processing induced by metaphoric summaries consumes extra processing capacity. Depending on the nature of the elaborative processing that results in metaphoric facilitation, either of two forms of an aptitude X treatment interaction could be obtained. If the elaboration engendered by use of metaphors takes extra processing capacity, then low span readers will be less able to make the necessary connections to support metaphoric facilitation. This follows from the finding that low span readers have less capacity for integrating information during reading (e.g., Daneman & Carpenter, 1983; Whitney, Ritchie, & Clark, 1991). In this case, the aptitude X treatment interaction should take the form of increased benefit of metaphors as reading span increases. In contrast, if the compact and vivid nature of metaphors (Ortony, 1975) makes it easier to hold the summary in working memory and connect it to the rest of the passage, then low spans will be more likely to integrate the material with metaphoric summaries, but high spans will integrate the material regardless of whether metaphoric or literal summaries are used. In other words, the relative benefit of metaphoric summaries should be inversely related to reading span.

Subjects and Design

The subjects were 90 undergraduates enrolled in introductory psychology classes. They were divided into high, medium, and low reading span groups based on a tertile split of reading span scores (see below). Half of the subjects at each span level were randomly assigned to each type of passage ending (metaphoric or literal).

Reading Span Test

We used a version of the Daneman & Carpenter (1980) reading span test as modified by Masson & Miller (1983) to allow for group administration. Subjects were run in groups of 5-20. The stimulus materials were presented on an overhead projector. The test involved reading sets of unrelated sentences (12-17 words each) and then recalling the last word of each sentence. Each subject received three trials in which they read two sentences and then tried to recall the last word of each of the two sentences. Then we moved on to three trials with three sentences in each set. This procedure continued up to a set size of six. To insure the sentences were read, at the end of each trial subjects had to fill in a missing word from two of the sentences they had just read. The subjects were paced through the task by the experimenter, who read the sentences aloud as they were shown.

Subjects were divided into groups based on the highest set size at which they recalled all the final words on at least two of the three trials. A half point was added for getting one trial correct on a given set size. Thus, if a subject was correct on all three trials of set size three, and one trial of set size four, that subject's span score was 3.5. Using this procedure, we obtained a sample of 30 subjects each at a low span (score = 2.5 or less), medium span (score = 3.0-4.0), and a high span (score = 4.5 and above) level.

Passages and Procedures

We used the example passage provided by Reynolds and Schwartz (1983) that was given above, as well as six other passages adapted from ninth grade social studies texts. The passages contained from 39 to 66 words. A metaphorical summary sentence and a literal summary sentence was written for each passage. As in the Reynolds and Schwartz (1983) study, we used context-dependent metaphors so that all the summaries could be taken literally if presented out of context.

The passages and their summary sentences were pretested on a separate group of subjects. The pretest showed that the metaphoric and literal summaries were equally memorable out of context. When presented in the context of the passages, the two types of summaries were rated as equivalent in meaning.

The experiment was conducted in two sessions. The reading span test was given in one session and the subjects returned a week later to read the passages. The experiment was presented as a test of the suitability of some materials for use in later research. Subjects were given booklets with one passage per page. They were asked to read the passages at their own pace and rate each passage for readability and interest. Each subject read seven passages, but the first and last were used as buffers to avoid primacy and recency effects, so recall of these passages was not scored.

After reading and rating the passages, the subjects were given a five minute unrelated activity. They were then given a response booklet that provided the first sentence of each passage as a recall cue. Subjects were told to write everything they could remember for each passage. We tested incidental memory for the passages in order to get a more pure measure of the effect of the metaphors, uncontaminated by individual differences in deliberate learning strategies.

Analysis of the Experiment

The passages were divided into constituent idea units and two raters independently scored the recall protocols for the number of idea units correctly paraphrased. Interrater reliability was quite good ($r$ = .92). The mean proportion of idea units recalled in each condition are shown in Figure 1.

---

Insert Figure 1 about here

---

A 3 X 2 (Span X Summary Type) ANOVA was performed on arc sine transformations of the proportion of idea units recalled by each subject. The alpha level for all tests was .05. Collapsed across span levels, there was a significant advantage for metaphoric summaries over literal summaries, $F(1,84) = 5.93$, $MSe = .01$. Thus, ignoring individual differences, our results replicated those of Reynolds and Schwartz (1983). There was no main effect of span

($F < 1$). More importantly, there was a significant Span X Summary Type interaction, $\underline{F}(2,84) = 2.98$, $\underline{MSe} = .01$. Tests of the simple main effects showed that there was no metaphoric advantage for the high span readers, but both medium and low span readers performed better with the metaphoric summaries. Most surprisingly, as Figure 1 shows, the low span readers performed as well as the high span readers in the metaphoric condition.

## How Do Metaphors Facilitate Memory for Text?

From a practical standpoint, these data suggest that metaphors may increase the ability of poor to average readers to learn from text, without affecting the performance of better readers. Of course, this conclusion is only tentative, given the limited scope of the present study. From a theoretical standpoint, the results are in accord with the data that suggest that metaphoric processing does not involve an extra stage of processing, or at least not one that demands working memory capacity (e.g., Keysar, 1989; Shinjo & Myers, 1987). If processing metaphors required extra capacity, then the low span readers should have shown *less* benefit, or even poorer performance, with the metaphoric summaries. Nevertheless, the metaphoric summaries were somehow processed differently, so that they improved the performance of most of the subjects. This is similar to the conclusion by Onishi and Murphy (1993) that nonliteral expressions that refer back to information presented earlier "may qualitatively change the interpretation process" (p. 770).

The advantage in recall gained with metaphoric summaries may be related to the memorability of metaphoric statements themselves (Ortony, 1975; Mio, Thompson, & Givens 1993). The metaphoric concluding statements and their literal counterparts were constructed to be equivalent summaries of the passages. For example, in the passage about Hitler leading the German people into war, both *The sheep followed the leader over the cliff* and *The German people blindly accepted Hitler's dangerous ideas* contain two ideas: (1) the German people followed Hitler, and (2) Hitler's ideas were dangerous. Four of the five other sentences in the passage were related to one of these two ideas in the concluding sentence. If the concluding sentence is connected during comprehension with the other statements (a form of elaborative processing), then recall of the concluding sentence should assist recall of the rest of the passage (Reder, 1980). If the metaphoric summaries were more memorable when in the context of the passage, then they would be expected to lead to better recall performance than their literal counterparts (cf., Reynolds & Schwartz, 1983). Marschark and Hunt (1985) showed that metaphoric statements may be well remembered for several reasons, but particularly because of their imageability.

We are still left with the question of why the benefit from metaphoric summaries was qualified by working memory span. Some clues as to why metaphors may differentially affect the discourse comprehension of high and low span readers emerge from the materials appropriate processing (MAP) framework proposed by McDaniel and his colleagues (McDaniel, Einstein, Dunay, & Cobb, 1986; Hunt & McDaniel, 1993).According to the MAP framework, there are two basic types of elaborations: relational processing and proposition-specific processing. Relational processing results from the encoding of information that defines the relations between propositions in the text. Proposition-specific processing results from the encoding of information that defines syntactic and semantic relationships on an intrapropositional level. Optimal recall for textual information results when readers perform both proposition-specific processing and relational processing.

In addition, the elaborations that result from relational and proposition-specific processing are hypothesized to influence recall of text through different mechanisms (McDaniel et al., 1986; Hunt & McDaniel, 1993). Relational elaborations are employed at retrieval to generate and access important ideas contained in the text. Proposition-specific elaborations are used to reconstruct the text from general classes of information after the idea unit has been accessed. Therefore, good text recall depends mostly on the encoding of relational information, whereas proposition-specific processing is more important for tests of recognition.

The main thrust of the MAP framework is that the effectiveness of a particular encoding manipulation depends on the type of processing invited by the materials, the type of processing induced by the encoding task, and the interaction between the two. Both the encoding task and the stimulus materials "invite" particular degrees of relational and proposition-specific processing. Some technique designed to increase text retention will facilitate performance only to the extent it encourages additional elaborative processing of the type of information (relational or proposition-specific) not encoded in the absence of the technique.

Thus, in order to be helpful to text retention, an intervention must get the readers to do elaborative processing that they would not do naturally. This aspect of the MAP framework can be used to account for data on the effectiveness of adjunct aids (cf., Loman & Mayer, 1983; Meyer et al., 1980; Spyridakis & Standal, 1987). For instance, in the Meyer et al. (1980) study, recall protocols of good and poor readers in the unsignaled condition indicated that good readers inferred the implicit (unsignaled) relations in the passage, but poor readers did not. Thus, because good readers performed relational processing whether they had relational signals or not, the addition of signals produced mostly redundant relational processing and thus had no effect on recall. However, because poor readers were not already performing the relational processing that was encouraged by the signals, the addition of signals led to increased elaborative processing and thus increased recall.

If we extend this framework to research on metaphors, then the use of metaphor should increase recall when it results in elaborative processing that would not occur as a consequence of the reader's "normal" comprehension processes. This was apparently the case with our low and medium span subjects. However, metaphors should not increase recall if subjects already performed the relational processing encouraged by the addition of the metaphor. This was apparently the case for our high span subjects.

Because recall tests tap mainly relational processing, our interpretation of the present results could be tested in future research by comparing the effects of metaphor on recognition of proposition-specific information as well as recall of whole passages. If the metaphoric summaries are encouraging more relational processing by lower span readers, then the metaphoric advantage should be attenuated when testing depends on more proposition-specific information.

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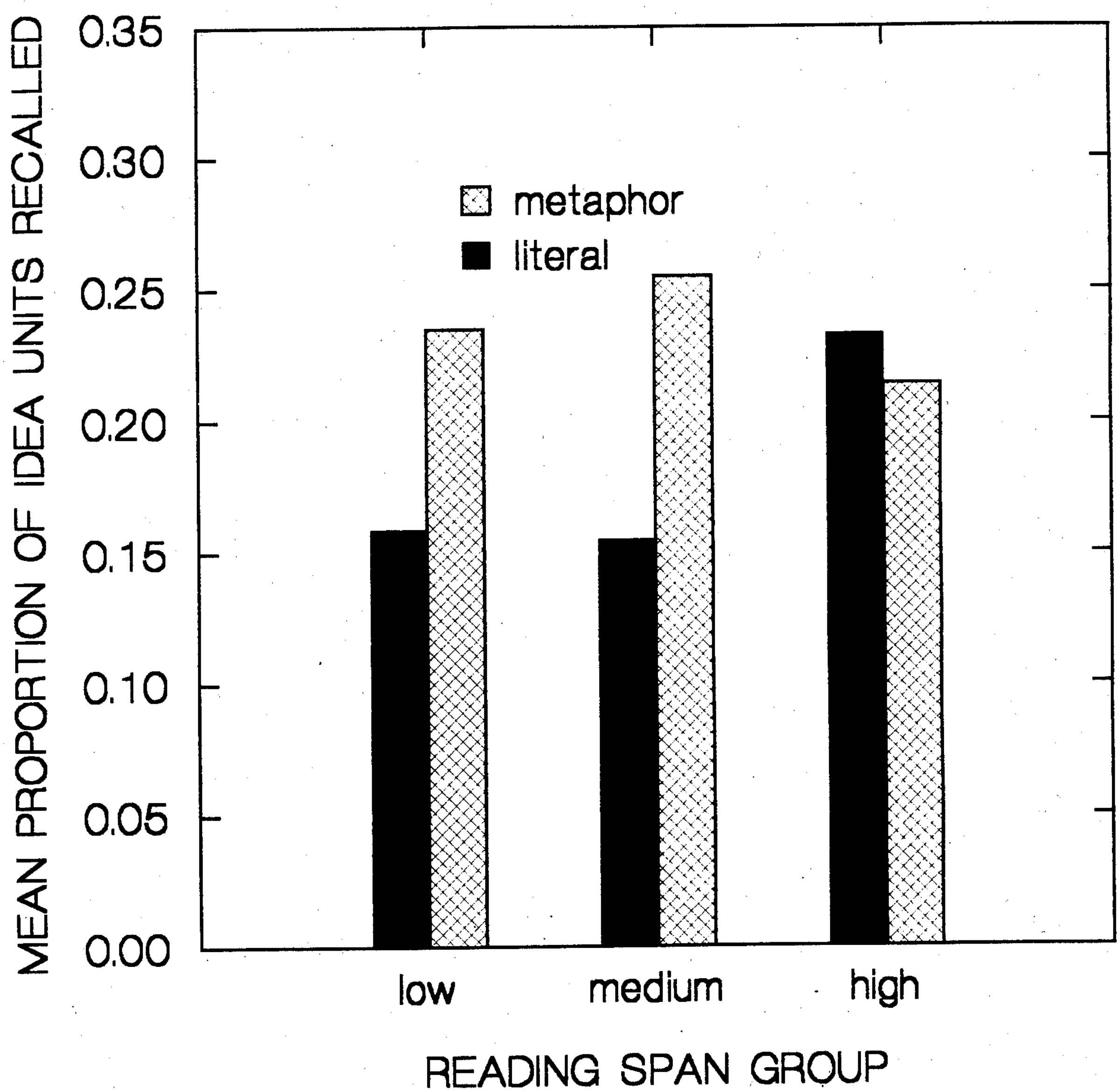
Figure Caption

*Figure 1.* Mean proportion of idea units recalled as a function of reading span and summary type (metaphorical or literal). The standard error for each mean is approximately .02.


MEAN PROPORTION OF IDEA UNITS RECALLED
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
metaphor
literal
low
medium
high
READING SPAN GROUP