Text Interruption and the Role of Working Memory in Discourse Processing

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ABSTRACT

Kerry Ledoux: Text Interruption and the Role of Working Memory in Discourse Processing
(Under the direction of Peter C. Gordon)

In this paper, I explore the role of working memory in discourse processing. Specifically, I am interested in describing the effects of text interruption (by another, unrelated text) on the construction and maintenance of a discourse representation in working memory. Working memory is required to bridge the span of such an interruption, and looking at reading behavior before and after an interruption by an unrelated text can help us to understand the function and contents of working memory during language processing. In this paper, I begin by introducing two alternative existing models of the role of working memory in discourse processing. I then describe two sets of experiments designed to differentiate between these two views. In the first set of three experiments, I used a self-paced reading paradigm to study the effects of text interruption on reading time. In the second set of four experiments, I used a probe-word paradigm to study the effects of interruption on verbatim text memory. In a final experiment, I measured performance on responses to memory probes and to comprehension questions following an interruption to reading. The results of these experiments support the memory representational view of the role of working memory in language processing.

To Evan,
who brightens every day,
whose smile is pure joy,
and who makes it all worth while.

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Text Interruption and the Role of Working Memory

in Discourse Processing

Readers perform many complex processes in their seemingly effortless ability to transform a printed code into a meaningful mental representation. Researchers have studied such diverse processes as word recognition (Coltheart, 1978; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; van Orden, 1987), pronoun resolution (Gernsbacher, 1989; Gordon & Hendrick, 1997; McKoon & Ratcliff, 1980), syntactic ambiguity resolution (Ferreira & Clifton, 1986; MacDonald, Just, & Carpenter, 1992; Waters & Caplan, 1996), and inference generation (Graesser, Singer, & Trabasso, 1994; Haviland & Clark, 1974; Singer, Andrusiak, Reisdorf & Black, 1992; Singer & Ferreira, 1983), all of which are among the many component processes said to play an important role in language comprehension. The experiments described in this paper represent an attempt to further understand language processing through an examination of another important cognitive construct, working memory, and its function in supporting the processes of reading comprehension. Specifically, the present research aims to characterize the type of information that is maintained and manipulated in working memory during discourse processing. How best might we describe the working memory representation that is necessary for language comprehension?

Current models of language processing present different characterizations of the information that is maintained and manipulated in working memory during reading, and of the structure of working memory itself. The traditional approach to working memory focuses on its cognitive architecture, specifying different working memory structures and the limitations imposed by their finite capacities. This approach is exemplified by the classic model of Baddeley and Hitch (1974), who proposed a system comprising three components, the central executive, the phonological loop, and the visuo-spatial sketchpad. Work in this tradition by Baddeley and his colleagues has described some of the many ways in which such a working memory system might be involved in language processing (Baddeley, 1986; Baddeley, 1997; Gathercole & Baddeley, 1993).

The work of Glanzer and his colleagues (Fischer & Glanzer, 1986; Glanzer, Dorfman, & Kaplan, 1981; Glanzer, Fischer, & Dorfman, 1984) provides a similar architectural approach to working memory and language comprehension, by positing that short-term storage during language comprehension consists of approximately two sentences of verbatim information that is used to help interpret subsequent information. This view of working memory was supported by a series of experiments using an interruption paradigm, in which the maintenance of sentences in memory was disrupted by imposing a distractor task (e.g., addition problems or the reading of unrelated sentences) between sentences in a paragraph. Reading times were longer for the sentence immediately after the interruption than when that same sentence occurred in a continuous paragraph; accuracy in answering comprehension questions about the paragraph was undiminished by the interruption. The effect of interruption was greater when the interpretation of the post-interruption sentence was dependent on the preceding material than when it was not (Fischer & Glanzer, 1986). Finally, because the interruption effect was not diminished by reinstatement of thematic information after the distractor task but *was* countered by reinstatement of the last one or two sentences that preceded the interruption, Fischer & Glanzer (1986) concluded that verbatim (not thematic) information is what must be maintained in memory for processing of the text. Thus, Glanzer's model is like Baddeley's in that it posits a short-term store of limited capacity that contains linguistic information at a relatively superficial level. In other words, according to this view of working memory, the information that is essential to comprehension of a discourse (and is thus maintained and manipulated in working memory) is verbatim or surface-level (in the classic terminology of van Dijk & Kintsch, 1983) information of a limited amount.

An alternative to these architectural views is one that emphasizes the role of memory representations in language processing. An example of such a view is Ericsson and Kintsch's (1995) notion of *long-term* working memory, which emphasizes the idea that people are very effective in creating elaborate, semantically-based structures in memory that can be accessed quickly and accurately when needed. This ability is particularly apparent in domains where people have expert skill, such as language comprehension. Since the knowledge is represented in long-term memory, it is maintained over long periods of time. This extension of working memory into long-term memory allows experts to circumvent the limited capacity of short-term memory, and can account for the ability of experts to be interrupted in a task and then resume it without difficulty.

The ability to resume language comprehension, after interruption with unrelated material, by relying on an elaborate semantic representation in long-term memory has also played an important theoretical role in computational linguistics. Grosz (1977; see also Grosz & Gordon, 1999) noted cases where pronominal reference was easily understood even though the referent appeared several sentences earlier, because the topic structure of a discourse was such that the discourse segment containing the appropriate referent could be easily retrieved. Other psycholinguistic work has also shown that referential expressions can sometimes be readily understood even without nearby referents if the text being understood facilitates effective memory retrieval (Greene, Gerrig, McKoon, & Ratcliff, 1994), a view of memory in language that also stresses general principles of retrieval from long-term memory.

Other psycholinguistic work has also described a role for an organized, semantic working memory representation in language processing. Gordon, Hendrick, & Johnson (2001) reported an effect of similarity of NP-type on the reading times of object- and subject-extracted relative clauses. Gordon, et al., suggest that this effect arose due to the memory interference caused by the similarity of the representations generated during reading. Gordon, Hendrick, & Levine (2002) found that memory loads composed of similar-type words to those in a following sentence exacerbated the effect of sentence complexity on reading times, again suggesting a role for similarity-based interference in language processing. Such interference is compatible with a representational account of the role of working memory in reading.

These two general approaches to working memory suggest different roles for working memory in language comprehension. The architectural account (Baddeley, 1986; Fischer & Glanzer, 1986; Glanzer, et al., 1981; Glanzer, et al., 1984) describes specific, limited stores for certain types of information, while the representational account emphasizes the efficient organization of semantic information in long-term memory (Ericsson & Kintsch, 1995). The distinction between the two models might be debated using concepts such as chunking, pointers to long-term memory, or other short-term structural mechanisms that interact with long-term memory representations. But such mechanisms ultimately depend on some kind of organized, semantic information, and thus are dependent on the ability to organize mental representations, a critical facet of the representational view. I wish here to distinguish between models that do suggest a role for an organized, semantic representation in memory (be it long-term working memory or not) and models that do not (such as that proposed by Glanzer, et al.), and that instead rely on relatively unprocessed, verbatim information from a text for language processing.

Which of these views more accurately characterizes the role of working memory in language processing? Does comprehension depend upon the availability of a limited amount of relatively unprocessed text information? Or does comprehension depend upon the creation and further accessibility of an elaborate, organized semantic representation in long-term memory? One way to attempt to further characterize working memory and its function during language comprehension, and to discriminate between these two views, is to attempt to assess its contents during discourse processing. One paradigm that is especially useful in this endeavor is one in which the reading of a discourse is interrupted by another, similar cognitive task (in this case, the reading of another, unrelated discourse). Because working memory is needed to bridge the time of this interruption, the resilience with which people can resume reading after an interruption can reveal some of the characteristics of the working memory representation that has been created and maintained, and about the nature of working memory itself. What information about a discourse is maintained in working memory across the span of an interruption in order to ensure comprehension?

This paper presents a series of experiments designed to examine the function of working memory in language processing. These experiments represent an attempt to understand some of the characteristics of the information that is maintained (and manipulated) in working memory during language processing by looking at the effect of interruption on comprehension. Presumably, working memory will function to maintain the information that is most essential to comprehension across the span of an interruption. In the first set of three experiments, I contrasted the two types of models of working memory described earlier (the architectural approach and the memory representational approach) through a series of self-paced reading experiments. Specifically, I looked at the reading of two interleaved passages that were stylistically similar (both narratives, or both expositions), or stylistically dissimilar (a narrative and an exposition). In another four experiments, I used a memory probe paradigm to further characterize the type of information that is maintained in working memory across the span of an interruption by unrelated distractor sentences. Finally, an eighth experiment looked at the effect of interruption on comprehensive reading using measures from both paradigms (self-paced reading and memory probe) with the same experimental items.

The two approaches to working memory generate different predictions about the effect of passage similarity and interruption on language comprehension. The architectural approach leads to a prediction that interruption should affect reading by means of occupying the mechanisms by which information from a text is remembered; in other words, interruption will disrupt reading if working memory capacity is taxed, regardless of the type of texts being processed. In contrast, the organizational approach leads to the prediction that interruption should affect reading comprehension to the degree that the interruption disrupts the efficient retrieval of information from organized long-term memory structures.

Effects of Interruption on Self-Paced Reading

Both of the types of models described earlier lead to the prediction that interruption will disrupt the process of comprehensive reading; however, the two models propose different explanations for any such disruption. The architectural approach leads to a prediction that interruption should affect reading by means of occupying the mechanisms by which information from a text is remembered; in other words, interruption will disrupt reading if working memory capacity is taxed, regardless of the type of texts being processed. In contrast, the organizational approach leads to the prediction that interruption should affect reading comprehension to the degree that the interruption disrupts the efficient retrieval of information from organized long-term memory structures.

If the two types of general models of the role of working memory in language processing both lead to the same prediction that interruption will disrupt reading, can we use an interruption paradigm to discriminate between these models? We can, if we design an interruption experiment that would address the underlying mechanisms proposed by each model for the occurrence of such a disruption. For example, an architectural account of working memory suggests that it should not matter what *type* of information is presented during an interruption to reading (what does matter is the *amount* of information to be maintained and processed). The representational account, on the other hand, suggests that the type of interrupting material *will* affect the magnitude of the disruption to reading. According to this account, representations in memory interfere with one another, and the magnitude of that interference is influenced by the similarity of the representations. Similar representations will cause more interference than dissimilar representations. Interleaving two similar texts, therefore, should cause more disruption than interleaving two dissimilar texts. If the long-term memory structures can be easily differentiated – as in the case of interrupting material that is in some way dissimilar – fast retrieval of information after an interruption should be facilitated relative to less easily differentiated memory structures.

In the first three experiments described herein, I asked participants to read four-sentence narrative and expository texts in a self-paced reading paradigm. Each text was paired on presentation with another text of the same style (for example, a narrative paired with a narrative) or of a different style (for example, a narrative paired with an exposition). These styles differ along such dimensions as word frequency, sentence length, and syntactic complexity (Dymock, 1999; Petros, Bentz, Hammes, & Zehr, 1990; Singer, Harkness, & Stewart, 1997; Weaver & Bryant, 1995), such that two passages of the same type are more similar to each other stylistically than passages of different types. The passage pairs were presented in a continuous format (in which a reader saw all four sentences of passage A, followed by the four sentences of passage B); or in an interleaved format (in which a reader saw sentence 1 of passage A, followed by sentence 1 of passage B, followed by sentence 2 of passage A, then sentence 2 of passage B, etc.) (see Appendix A for an example). Architectural models and representational models lead to the common prediction that the reading of a sentence will be slowed in the interleaved condition relative to the reading of that same sentence in the continuous condition. An architectural account would explain this effect as being due to the taxation of working memory capacity caused by the addition of the interrupting material. A representational account would explain this same effect as being due to the increased difficulty of maintaining and accessing multiple text representations in long-term memory.

Although both types of models predict an effect of interruption on reading, the representational view leads to an additional prediction about the effect of the similarity of the two passages in a pair. This view suggests that the construction and maintenance of a representation by working memory of two similar passages will be more difficult (relative to dissimilar passages) due to interference. I would thus expect, according to this view, an interaction between interruption and similarity; in other words, any detrimental effect that I see of interruption on reading should be exacerbated for pairs of passages that are similar (relative to those that are dissimilar). I expect to find this effect especially on the reading times of the first sentence of the second passage in an interleaved pair, as it is upon switching to the construction and maintenance of this representation that readers will experience interference. An architectural view of the role of working memory in language comprehension does not support such a prediction of an interaction between interruption and passage similarity; there is no role in such a model for the type of interrupting material.

Experiments 1, 2, and 3 were designed to differentiate between the architectural and representational accounts of the role of working memory in language processing. The designs of the three experiments were the same except for minor modifications from one experiment to the next. In Experiment 1, two passages were interleaved after every two sentences; in Experiments 2 and 3, interleaving occurred after each sentence. In Experiments 1 and 2, I provided participants with an explicit marker (a "+" at the beginning of each sentence of the second passage in a pair) to alert them to the switch from one passage to the other; in Experiment 3, I removed this marker. In Experiments 1 and 2, I encouraged processing of the texts for comprehension by asking one question at the end of each passage pair; in Experiment 3, I increased this demand by asking two comprehension questions about each pair. Based on these modifications, I expected the effects of interruption to be greater in the second and third experiments. Below, I present separate method and results sections for each of the three self-paced reading experiments; however, because of the similarity of the experiments, I discuss the results in one general discussion.

Experiment 1

Method

Participants

Sixty-four undergraduate students at the University of North Carolina served as participants in the experiment. They received course credit for an introductory psychology course for their participation.

Stimulus materials

Forty, four-sentence narrative passages and forty, four-sentence expository passages were constructed for the experiment. The narratives consisted of short stories about named characters and their actions. The expository passages were culled from a textbook on world history (Roberts, 1993), and briefly described some historical event or fact.

Four passages (two narratives and two expositions) were combined in pairs to form one complete set of experimental items. Each of the two passages in a pair could be either a narrative or an exposition; four stimulus pairs were created to be counterbalanced for first-passage type and second-passage type, with each combination of first and second appearing equally as often. Each participant saw the two mutually exclusive pairs from each set of four, for a total of forty pairs containing two unique passages each. The presentation of the items could be either blocked or interleaved, and each item was presented in each form an equal number of times. An example of the eight versions of one pair (based on a crossing of first-passage-type by second-passage-type by presentation) can be seen in Appendix A. The serial position of a passage in a pair (whether the passage appeared first or second) remained constant for that passage.

The sentences of the second passage in each pair (in both the continuous and the interleaved conditions) were marked with a "+" at the beginning to alert participants to the switch from the first to the second passage. In the interleaved condition, the presentation of the paragraphs alternated after every two sentences; the participant read two sentences from passage A, then two from the passage B, then the next two from passage A, etc., until all four sentences from both passages had been presented.

A true/false question was included for each item to ensure that participants would read the passages for comprehension. Half of the true/false questions referred to the first passage of the pair, and the other half referred to the second passage.

Design and procedure

An additional eight pairs (one of each experimental type) were constructed to form an initial warm-up block. The 40 experimental items were grouped into five subsequent experimental blocks of eight items each (one in each experimental condition). Four groupings of the experimental items were constructed so that a given participant read each experimental item once and read equal numbers of items in each of the eight conditions.

Participants read the passage pairs on a personal computer; they were told to read at a natural pace. Participants were informed about the presence of the "+" in some passages and about its function as an indicator of the switch to the second passage. Participants were also instructed that the presentation of the two texts in a pair might be interleaved, and that they should try to read both passages for comprehension. Sentences were presented one at a time and participants pressed the space bar after reading each sentence. After the passage was complete the true-false comprehension question was presented. Participants were instructed to press one key ("/") for true responses, and another ("z") for false.

Results

Reading time

Analyses of variance were conducted on the mean reading times per word. Previous research led to the expectation that the reading times of the first sentence of a passage would be substantially slower than those of the subsequent three sentences, a well-established finding that has been interpreted as representing the additional processing that is required to establish a discourse representation in working memory (Cirilo & Foss, 1980; Haberlandt, 1984; Haberlandt, Berian, & Sandson, 1980). Accordingly, I conducted separate analyses on the reading times per word for the first sentence and for the average of the second through fourth sentences.

First passage: Reading times and inferential statistics are shown in Tables 1 and 2. The presentation of the first sentence of the first passage of a pair was always the same, regardless of the experimental condition; it is therefore not surprising that I found no significant effect of interruption, similarity, or the interaction of the two variables on the reading times of this sentence. I also found no significant main effect of interruption or of similarity on the reading times of the subsequent three sentences of the first passage. There was, however, an interaction (marginal by subjects, significant by items) between interruption and similarity; the reading of the last three sentences of the first passage was slowed if that passage was interleaved with a similar passage (relative to a blocked pairing), $\underline{F}_1$ (1, 63) = 3.19, $\underline{p} < .079$, $\underline{F}_2$ (1, 19) = 5.75, $\underline{p} < .027$.

Table 1

Mean reading time per word (msec) at each sentential position for first and second passages (in both continuous and interleaved presentation forms) in Experiment 1.

		First Passage		**Second Passage**	
Similarity	**Presentation**	Sentence 1	Sentences 2-4	Sentence 1	Sentences 2-4
Same	Continuous	384	263	346	252
	Interleaved	394	271	344	257
Different	Continuous	391	270	324	252
	Interleaved	392	269	335	256

<u>Second passage</u>: There was no significant main effect of interruption on the reading times of the first sentence of the second passage. There was a significant main effect of similarity; the first sentence of the second passage was read more slowly when that passage was paired with a similar first passage, relative to when it was paired with a dissimilar passage, $\underline{F}_1$ (1, 63) = 7.71, $\underline{p} = .007$, $\underline{F}_2$ (1, 19) = 7.15, $\underline{p} = .015$. The interaction of interruption and similarity was not significant in the reading times of the first sentence. There was no (main or interaction) effect of the experimental manipulations on the reading

times of the subsequent three sentences of the second passage in a pair. (See Table 2 for the results of the inferential statistics.)

Table 2

Inferential results for first and second passages in Experiment 1.

		Passage 1		**Passage 2**	
Effect		Sentence 1	Sentence 2-4	Sentence 1	Sentence 2-4
Interruption	Subjects	$F_1\,(1,63) < 1$	$F_1\,(1,63) = 1.88$ $p = .176$	$F_1\,(1,63) = 1.10$ $p = .299$	$F_1\,(1,63) = 2.76$ $p < .102$
	Items	$F_2\,(1,19) < 1$	$F_2\,(1,19) < 1$	$F_2\,(1,19) < 1$	$F_2\,(1,19) < 1$
Similarity	Subjects	$F_1\,(1,63) < 1$	$F_1\,(1,63) < 1$	$F_1\,(1,63) = 7.71$ $p = .007$	$F_1\,(1,63) < 1$
	Items	$F_2\,(1,19) < 1$	$F_2\,(1,19) < 1$	$F_2\,(1,19) = 7.15$ $p = .015$	$F_2\,(1,19) < 1$
Interruption x Similarity	Subjects	$F_1\,(1,63) < 1$	$F_1\,(1,63) = 3.19$ $p = .079$	$F_1\,(1,63) = 2.02$ $p = .160$	$F_1\,(1,63) < 1$
	Items	$F_2\,(1,19) < 1$	$F_2\,(1,19) = 5.75$ $p = .027$	$F_2\,(1,19) < 1$	$F_2\,(1,19) < 1$

Comprehension question accuracy:

Participants did not show a significant difference in their ability to answer questions that referred to the first or second passage of each pair, F_1 and $F_2 < 1$; I therefore present analyses of comprehension accuracy collapsed across this variable. The mean accuracy on the comprehension questions for similar and dissimilar passages in both continuous and interleaved presentation forms in Experiment 1 is presented in Table 3.

Table 3

Mean comprehension question accuracy (percent correct) for questions about similar and dissimilar passage pairs in continuous and interleaved presentation forms in Experiment 1.

	Continuous	**Interleaved**
Same	85%	82%
Different	85%	85%

Interruption did not have a significant effect on participants' question-answering accuracy, $\underline{F}_1$ and $\underline{F}_2 < 1$, nor was there a significant effect of match-of-passage-type on question accuracy, $\underline{F}_1\ (1, 63) = 1.61$, $\underline{p} = .209$, $\underline{F}_2\ (1, 19) = 1.38$, $\underline{p} = .255$. The interaction of the experimental factors was not significant, $\underline{F}_1$ and $\underline{F}_2 < 1$.

In the next experiment, I sought to further explore the effect of interruption on the construction of a discourse representation in working memory by modifying the experimental materials. In Experiment 1, reading was not significantly disrupted by the interleaving (after every two sentences) of two passages in a pair, although there were some trends in the reading times in that direction. In Experiment 2, the interleaving of two passages in the interruption condition was done after every sentence; I thought that this manipulation would increase the demands on working memory, and might allow a clearer understanding of the effects of interruption on discourse processing.

Experiment 2

Method

Participants.

Sixty-four undergraduate students from the same population as the previous study participated in the experiment.

Stimulus materials.

The same forty passage pairs from Experiment 1 were used, with one modification. In Experiment 2, the interleaving of the two passages in each pair occurred after one sentence, so that a participant read one sentence from passage A, then one from passage B, then the second sentence of passage A, etc. (see Appendix A). Otherwise, the materials for Experiment 2 were the same as those used in Experiment 1.

Design and procedure.

The same additional eight items as in Experiment 1 were used as an initial warm-up block. The 40 experimental items were grouped into five subsequent experimental blocks of eight items each (one in each experimental condition). Four groupings of the experimental items were constructed so that a given participant read each experimental item once and read equal numbers of items in each of the eight conditions.

Participants read the passages on a personal computer; they were told to read for comprehension at a natural pace. Sentences were presented one at a time and participants pressed the space bar after reading each sentence. After the passage was complete the true-false comprehension question were presented on the screen.

Results

Analyses were performed in the same manner as the preceding experiment.

Reading time:

First passage: Reading times and inferential statistics are shown in Tables 4 and 5. The presentation of the first sentence of the first passage of a pair was again always the same, regardless of the experimental condition; it is therefore not surprising that I found no significant effect of interruption, similarity, or the interaction of the two variables on the reading times of this sentence. I also found no significant effect of interruption, similarity, or the interaction of the two on the reading times of the subsequent three sentences of the first passage.

Table 4

Mean reading time per word (msec) at each sentential position for first and second passages (in both continuous and interleaved presentation forms) in Experiment 2.

		First Passage		**Second Passage**	
Similarity	**Presentation**	Sentence 1	Sentences 2-4	Sentence 1	Sentences 2-4
Same	Continuous	393	271	337	248
	Interleaved	406	272	381	268
Different	Continuous	408	269	336	248
	Interleaved	413	272	353	274

Table 5

Inferential results for first and second passages in Experiment 2.

		Passage 1		**Passage 2**	
Effect		Sentence 1	Sentence 2-4	Sentence 1	Sentence 2-4
Interruption	Subjects	F_1 (1,63) = 1.74 p =.192	F_1 (1,63) < 1	F_1 (1,63) = 21.43 p < .001	F_1 (1,63) = 48.11 p < .001
	Items	F_2 (1,19) = 1.04 p =.321	F_2 (1,19) < 1	F_2 (1,19) = 32.93 p < .001	F_2 (1,19) = 19.43 p < .001
Similarity	Subjects	F_1 (1,63) = 3.61 p =.062	F_1 (1,63) < 1	F_1 (1,63) = 4.92 p =.030	F_1 (1,63) = 1.22 p =.274
	Items	F_2 (1,19) = 2.63 p =.122	F_2 (1,19) < 1	F_2 (1,19) = 5.86 p =.026	F_2 (1,19) < 1
Interruption x Similarity	Subjects	F_1 (1,63) < 1	F_1 (1,63) < 1	F_1 (1,63) = 7.74 p =.007	F_1 (1,63) < 1
	Items	F_2 (1,19) < 1	F_2 (1,19) < 1	F_2 (1,19) = 6.15 p =.023	F_2 (1,19) < 1

Second passage: Figure 1 depicts the mean reading times per word for the critical first sentence of the second passage. There was a main effect of interruption on the reading times of this sentence, F_1 (1, 63) = 21.43, $p < .001$, F_2 (1, 19) = 32.93, $p < .001$; as well as a main effect of similarity, F_1 (1, 63) = 4.92, $p = .03$, F_2 (1, 19) = 5.86, $p = .026$. These main effects were moderated by a significant interruption x similarity interaction; the disruptive effect of interruption on the reading of the first sentence of the second passage was greater when that second passage was paired with a first passage of a similar type (relative to a different-type pairing), F_1 (1, 63) = 7.74, $p = .007$, F_2 (1, 19) = 6.15, $p = .023$. Table 6 shows that readers continue to experience a disruptive effect of interruption [F_1 (1, 63) = 48.11, $p < .001$, F_2 (1, 19) = 19.43, $p < .001$], but recover from the moderating effect of similarity on interruption (F_1 and $F_2 < 1$), when reading the subsequent three sentences of the second passage in a pair (see Table 5 for results of the ANOVAs).

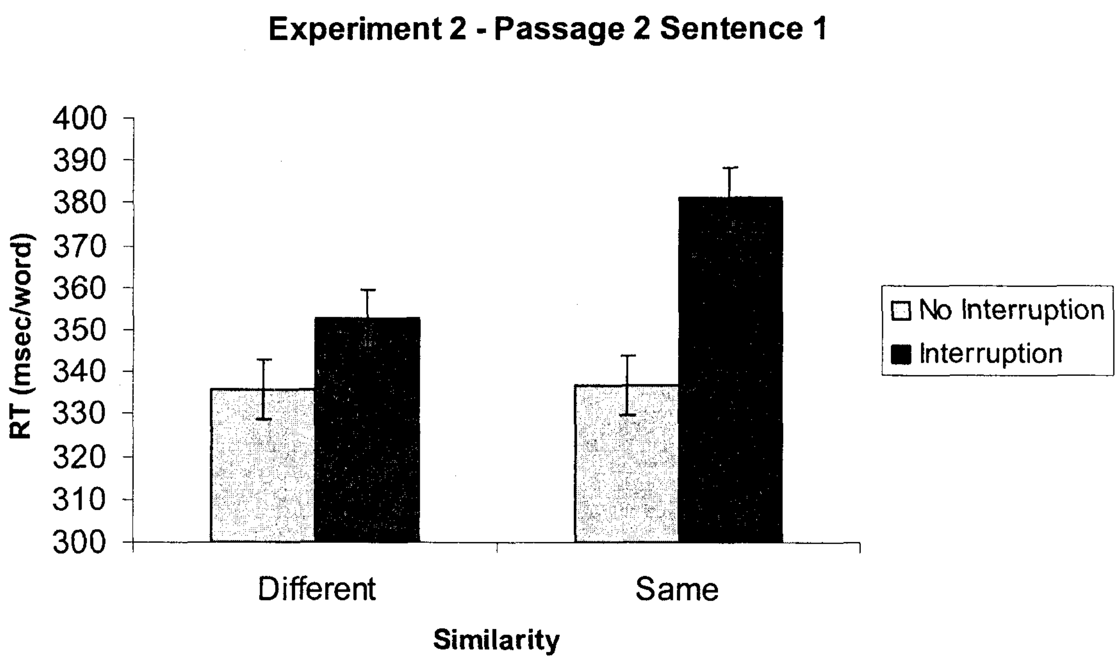

Figure 1. Mean reading time per word (msec) for the first sentence of the second passages in both continuous and interleaved presentation forms in Experiment 2.

Comprehension question accuracy:

Participants did not show a significant difference in their ability to answer questions that referred to the first or second passage of each pair, F_1 and $F_2 < 1$; I therefore present analyses of comprehension accuracy collapsed across this variable. The mean accuracy on the comprehension questions for similar and dissimilar passages in both continuous and interleaved presentation forms in Experiment 2 is presented in Table 6.

Table 6

Mean comprehension question accuracy (percent correct) for questions about similar and dissimilar passage pairs in continuous and interleaved presentation forms in Experiment 2.

	Continuous	**Interleaved**
Same	81%	80%
Different	84%	82%

Interruption did not have a significant effect on participants' question-answering accuracy, $\underline{F}_1$ (1,63) = 1.74, p = .191, $\underline{F}_2 < 1$, nor was there a significant effect of match-of-passage-type on question accuracy, $\underline{F}_1$ (1, 63) = 2.68, $\underline{p}$ = .107, $\underline{F}_2$ (1, 19) = 3.37, $\underline{p}$ = .884. The interaction of the experimental factors was not significant, $\underline{F}_1$ and $\underline{F}_2 < 1$.

In Experiment 3, I further modified the experimental materials in another attempt to exacerbate the effect of interruption.

Experiment 3

Method

Participants.

Sixty-four undergraduate students from the same population as the previous studies served as participants in the experiment.

Stimulus materials.

The same forty passage pairs from Experiment 2 were used, with two additional modifications. First, the "+" at the beginning of the sentences of the second passage in the pair was removed throughout the experiment, so that participants had to track the passages themselves, without an overt marker. Second, an additional comprehension question was created for each passage pair. Each participant was presented with two comprehension questions for each item, one referring to the first passage and one referring to the second (see Appendix A for an example). The order of the questions was counterbalanced, such that on half of the trials, participants answered a question about the first passage first, and on the other half they answered a question about the second passage first. Otherwise, the materials for Experiment 3 were the same as those used in Experiment 2.

Design and procedure.

Again, an additional eight items (one of each experimental type) were used in an initial warm-up block. The 40 experimental items were grouped into five subsequent experimental blocks of eight items each (one in each experimental condition). Four groupings of the experimental items were constructed so that a given participant read each experimental passage pair once and read equal numbers of items in each of the eight conditions.

Participants read the passages on a personal computer; they were told to read for comprehension at a natural pace. Sentences were presented one at a time and participants pressed the space bar after reading each sentence. After the passage was complete the two true-false comprehension questions were presented, one at a time, on the screen.

Results

Reading time:

First Passage: Reading time results and supporting statistics are shown in Tables 7 and 8. As in Experiments 1 and 2, the presentation of the first sentence of the first passage of a pair was always the same, regardless of the experimental condition, and again I found no significant effect of interruption, similarity, or interaction of the two variables on the reading times of this sentence. In this third experiment, in which I strengthened the manipulation of interruption, I found a main effect of this variable on the reading times of the second, third and fourth sentences of the first passage; participants read these sentences more slowly when they were interleaved with the sentences of the second passage in the pair (relative to the reading of these sentences in the continuous condition), F_1 (1, 63) = 6.19, p = .016, F_2 (1, 19) = 8.12, p = .01. The main effect of similarity, and the interaction of similarity and interruption, were not significant for these sentences (all F_1 and F_2 < 1).

Table 7

Mean reading time per word (msec) at each sentential position for first and second passages (in both continuous and interleaved presentation forms) in Experiment 3.

		First Passage		**Second Passage**	
Similarity	**Presentation**	Sentence 1	Sentences 2-4	Sentence 1	Sentences 2-4
Same	Continuous	421	269	330	256
	Interleaved	426	284	382	275
Different	Continuous	415	272	346	257
	Interleaved	431	287	364	281

Table 8

Inferential results for first and second passages in Experiment 3.

		Passage 1		Passage 2	
Effect		Sentence 1	Sentence 2-4	Sentence 1	Sentence 2-4
Interruption	Subjects	F_1 (1,63) = 2.66 p =.108	F_1 (1,63) = 6.19 p =.016	F_1 (1,63) = 23.13 p < .001	F_1 (1,63) = 20.79 p < .001
	Items	F_2 (1,19) = 2.19 p =.156	F_2 (1,19) = 8.12 p =.010	F_2 (1,19) = 25.24 p < .001	F_2 (1,19) = 26.07 p < .001
Similarity	Subjects	F_1 (1,63) < 1	F_1 (1,63) < 1	F_1 (1,63) < 1	F_1 (1,63) < 1
	Items	F_2 (1,19) < 1	F_2 (1,19) < 1	F_2 (1,19) < 1	F_2 (1,19) < 1
Interruption x Similarity	Subjects	F_1 (1,63) < 1	F_1 (1,63) < 1	F_1 (1,63) = 8.69 p =.004	F_1 (1,63) < 1
	Items	F_2 (1,19) < 1	F_2 (1,19) < 1	F_2 (1,19) = 3.56 p =.075	F_2 (1,19) < 1

Second passage: Figure 2 depicts the mean reading times per word for the critical first sentence of the second passage. As in Experiment 2, there was a main effect of interruption on the reading times of this sentence, F_1 (1, 63) = 23.13, p < .001, F_2 (1, 19) = 25.24, p < .001. There was no main effect of similarity (F_1 and F_2 < 1). The main effect of interruption was again moderated by a significant interruption x similarity interaction; the disruptive effect of interruption on the reading of the first sentence of the second passage was greater when that second passage was paired with a first passage of a similar type (relative to a different-type pairing), F_1 (1, 63) = 8.69, p = .004, F_2 (1, 19) = 3.56, p = .075. Table 8 shows that readers continue to experience a disruptive effect of interruption [F_1 (1, 63) =

20.79, $p < .001$, F_2 (1, 19) = 26.07, $p < .001$], but recover from the moderating effect of similarity on interruption (F_1 and $F_2 < 1$), when reading the subsequent three sentences of the second passage in a pair.

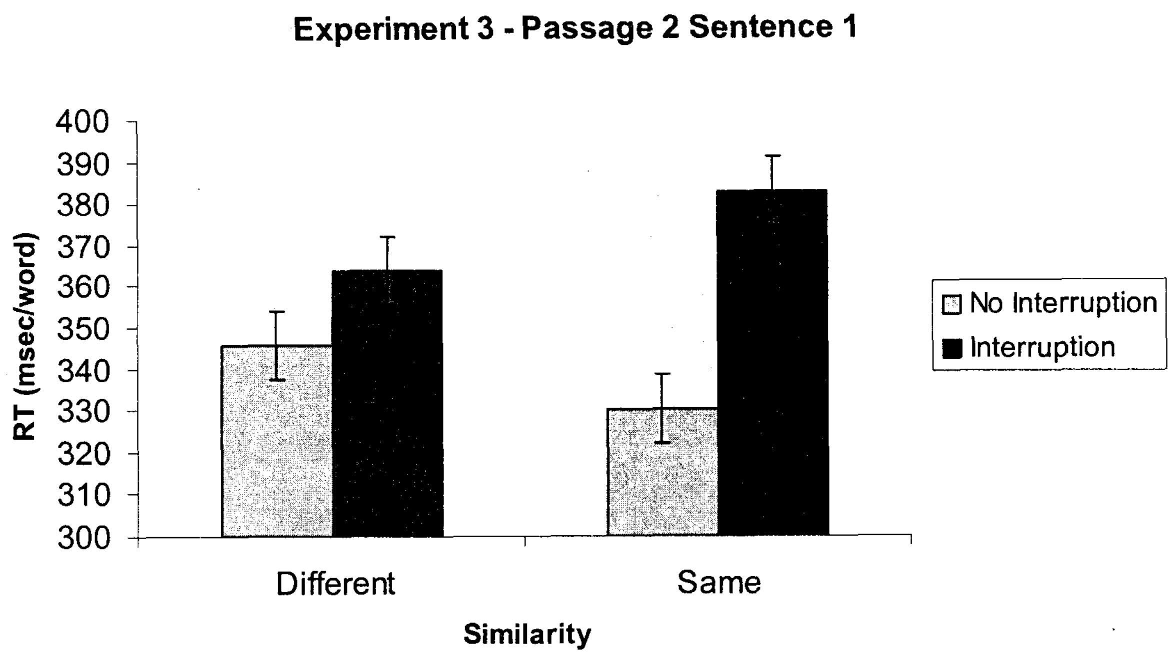

Figure 2. Mean reading time per word (msec) for the first sentence of the second passages in both continuous and interleaved presentation forms in Experiment 3.

Comprehension question accuracy:

In Experiment 3, two comprehension questions were asked on each trial, one referring to the first passage in the pair, and one referring to the second passage. I analyzed the responses to these comprehension questions separately.

Analysis of variance revealed that participants were significantly more accurate at answering the first comprehension question when it referred to the second passage (on half of the trials) than when it referred to the first passage (on the other half of the trials) (by subjects, F_1 (1, 63) = 3.92, $p = .052$; this difference was not significant by items, $F_2 < 1$); however, because this factor did not interact with any other experimental variables, I present analyses of comprehension accuracy on the first question collapsed across this variable. The mean accuracy on the first comprehension questions for similar and dissimilar passages in both continuous and interleaved presentation forms in Experiment 3 is presented in Table 9.

Table 9

Mean comprehension question accuracy (percent correct) for first questions about similar and dissimilar passage pairs in continuous and interleaved presentation forms in Experiment 3.

	Continuous	**Interleaved**
Same	84%	78%
Different	83%	82%

Participants were more accurate at answering the first comprehension question after reading passages in the continuous condition relative to the interleaved condition, F_1 (1, 63) = 6.86, $p = .011$, F_2 (1, 19) = 9.05, $p = .007$. There was no significant effect of similarity on first-question accuracy, F_1 and $F_2 < 1$. The interaction of the experimental factors was not significant, F_1 (1, 63) = 2.33, $p = .132$, F_2 (1, 19) = 2.70, $p = .117$.

Participants did not show a significant difference in their ability to answer second questions that referred to the first (on half of the trials) or second (on the other half of the trials) passage of each pair, F_1 and $F_2 < 1$; I therefore analyzed comprehension accuracy collapsed across this variable. The mean accuracy on the comprehension questions for similar and dissimilar passages in both continuous and interleaved presentation forms in

Experiment 3 is presented in Table 10. There was no significant difference in participants' ability to answer this question based on experimental condition (for interruption: F_1 and $F_2 < 1$; for similarity: F_1 and $F_2 < 1$; for the interaction: F_1 (1, 63) = 2.28, $p = .136$, F_2 (1, 19) = 3.38, $p = .082$).

Table 10

Mean comprehension question accuracy (percent correct) for second questions about similar and dissimilar passage pairs in continuous and interleaved presentation forms in Experiment 3.

	Continuous	**Interleaved**
Same	85%	82%
Different	83%	84%

Discussion of Self-Paced Reading Experiments

I began by introducing two contrasting views of the role of working memory in language comprehension. The architectural approach (Baddeley, 1986; Baddeley, 1997; Gathercole & Baddeley, 1993; Fischer & Glanzer, 1986; Glanzer, et al., 1981; Glanzer, et al., 1984), describes working memory as a set of structures of limited storage capacity for particular kinds of (relatively superficial) information about a text. The memory organizational approach (Ericsson & Kintsch, 1995) describes working memory as an efficiently organized semantic representation of a text in long-term memory that supports rapid and accurate retrieval of information needed for comprehension; while there may be some limits to the capacity of short-term memory, this approach characterizes the ability to organize memory representations as the fundamental memory constraint on language comprehension. These two approaches led to different predictions about the effect of interruption on reading. The first approach suggests that interruption will disrupt reading if the interruption causes working memory's capacity to be reached or exceeded; this approach does not predict an effect of the type of material that is being read. The second approach, on the other hand, predicts that interruption will affect reading if the interrupting material disrupts the efficient organization of semantic information in long-term memory. This view, then, describes a moderating function for the type of material being read; material that makes this semantic organization in long-term memory more difficult will exacerbate the disrupting effects of interruption on reading. This representational view thus generates the additional prediction (beyond that of an effect of interruption on reading, suggested by both models) that the similarity of the interrupting material to the text being read will influence the extent of the resulting disruption.

To explore this question, I conducted three self-paced reading experiments using the same narrative and expository passages in the same types of experimental items. Passages were presented in continuous or interleaved pairs that varied in their similarity; participants read pairs of the same types of passages (two narratives or two expositions), or pairs of different types of passages (a narrative and an exposition). In the first experiment, passages of a pair were interleaved after every two sentences; in Experiments 2 and 3, the passages of a pair were interleaved after a single sentence. In Experiments 1 and 2, participants were provided with an overt cue (the presence of a "+" sign) to help them to differentiate between the first and second passage of a pair; in Experiment 3, this cue was removed. Additionally, in Experiments 1 and 2, participants answered only one comprehension question (referring to either the first or the second passage in a pair), whereas in Experiment 3, I presented participants with two comprehension questions, one about each passage in the pair.

The results provide evidence that the representational processes described by the organizational view of working memory play a very important role in reading comprehension. Although there was no effect of interruption on reading in the first experiment, by strengthening the interruption manipulation, I was able to demonstrate a main effect of interruption on reading in the next two experiments (and on comprehension question accuracy in the third experiment). This supports the notion that the maintenance of text information in working memory is affected by interruption. Second, I found that the initial reading of the second passage in a pair is disrupted more if the first passage in the pair is of a similar type than if it is of a dissimilar type. Again, the architectural approach would not predict any effect of similarity on the magnitude of the effect of interruption; the organizational approach would, as more similar texts make efficient organization of the two in memory more difficult (due to interference). The fact that this similarity effect fades also seems consistent with the organizational approach; the similarity of the two passages initially makes it difficult to differentiate their two representations in memory, but once this has occurred, the similarity of the two has less impact. Accordingly, these results support the organizational/representational approach toward characterizing the critical aspects of working memory during higher-level language comprehension. Of course, it is possible that an architectural approach to working memory could be elaborated so as to account for these findings, but current architectural characterizations do not predict these results while the representational accounts do.

The results of Experiments 1 – 3 show very consistent effects of interruption on self-paced reading. In the next four experiments, I tested participants in a different, but also commonly used, language processing paradigm, one in which participants are asked at various points during text processing to report whether they've seen a certain word (the probe word) in the text they've read. Participants responded to a probe word from a passage before or after an interruption by non-passage sentences.

Effects of Interruption on Memory Probe Responses

In this section, I will describe four experiments that were conducted using a probe word paradigm, in which participants were asked to report whether they had seen a given word in the text they had read thus far. Experiments 1 – 3 supported the presence of an elaborate, semantic representation of a text in memory; however, I wondered if any evidence could be found of the type of verbatim, structural representation described by the architectural model of working memory. The probe method seems especially likely to access a verbatim representation (if one exists), in that participants must rely upon an exact recall of the verbatim elements of a sentence to respond accurately to a probe. I wondered if participants would be as able to respond to a probe following an interruption by unrelated text material as they were able to respond to that same probe before such an interruption; their ability to do so would provide evidence that working memory was indeed maintaining an accurate verbatim representation across the span of the interruption. If performance on a probe task was instead adversely affected by interrupting text, we might conclude that such a verbatim representation was not maintained across the span of the interruption. Experiments 4 - 7 represent an attempt to answer this question.

The first two of these experiments established a basic pattern of results: that interruption significantly diminishes memory probe performance. In Experiment 4, I examined the effect of interruption on the maintenance of a surface-level representation of the text in working memory by measuring response time to a probe name from the first sentence of the passage both immediately before and immediately after the presentation of interrupting distractor sentences. In Experiment 5, I measured reaction time to a probe word from the first sentence of the discourse immediately after two discourse sentences, immediately after two interrupting sentences, and after a short resumption of the reading of the discourse following the interruption.

These two experiments examined the effect of interruption on the time to respond to a probe name from the first sentence from the passage, as seen Examples 1 and 2 below (where **p1**, **p2**, and **p3** indicate the possible positions of the probe word).

Experiment 4

Method

Participants

Twelve undergraduates from the same population as the previous studies served in the experiment.

Stimulus materials

Forty, four-sentence narrative passages and forty, two-sentence expository interruptions (of the same type used in Experiments 1, 2, and 3) were used to construct the materials for the experiment. An sample passage is shown in Example 1.

Example 1:

Susan wanted to buy Tom a puppy as a Christmas present.
She told him about the idea in advance. **p1**
+Some 10,000 years ago, the New Stone Age began in the Near East.
+What we call civilization arose 5,000 years ago in Mesopotamia and Egypt. **p2**

Probe word = SUSAN

The first sentence of each passage introduced two characters by name, one of which was in the position of grammatical subject of the sentence. Because reading of the passage was terminated following the presentation of the probe word, participants saw only the first two sentences of the narrative passage (and, in the interruption condition, the two distractor sentences following the two sentences from the passage). Accordingly, there was no comprehension question for the experimental passages. Probes consisted of either the first name introduced as the subject in the first sentence of the passage (for positive responses) or a name of similar length and gender that had not appeared in the passage (for negative responses). One-half of the experimental trials seen by each participant contained distractor sentences, and one-half of the trials required a negative response to the probe word.

A set of 96 filler passages was also used. The filler passages were always of one theme throughout the four sentences. Twenty of the filler passages (half of which were interrupted for each participant) required a response to a probe word; these passages were similar to the experimental passages in every way except that both the positive and negative probes consisted of content words (not names) that either were or were not in the first passage sentence. Half of the remaining filler passages contained an interruption by distractor sentences after the first two passage sentences. These passages did not require a response to a probe word, and continued after the interruption (as in Experiments 1, 2, & 3). These passages were followed by a comprehension question.

Design and procedure

The design and procedure were the same as those described for Experiments 1 - 3, except for the introduction of the probe word. On probe trials, the participant read through the passage sentences (and the distractor sentences, when applicable) at their own pace. Immediately after they pressed the space bar indicating that they had finished reading the last sentence, they were presented with a probe word at the top of the screen in all capital letters. They were instructed to respond as quickly as possible whether or not they had seen this word in the passage so far. Participants used the same key ("/") to respond "yes" (for memory probes) and to respond "true" (for comprehension questions); they also used the same key ("z") for "no" and for "false." Participants were given feedback about incorrect responses to the probe word (experimental trials) and to the comprehension question (filler trials).

Results

Table 11 shows the mean response time for positive and negative probes to which participants responded correctly for each condition.

Table 11

Mean reaction times (ms) to positive and negative probes in each of the two conditions in Experiment 4.

	No Interruption	Interruption	Average
Positive probe	1335	1757	1546
Negative probe	1793	2251	2022
Average	1564	2004	

Analysis of variance of the response times showed that responses to the probe word were faster when it appeared before the interruption than when it appeared after the interruption $\underline{F}_1(1,11) = 21.74$, $\underline{p} = .001$, $\underline{F}_2(1,39) = 40.28$, $\underline{p} < .001$. Participants responded significantly more quickly to positive than to negative probes (a replication of a well-established finding in the memory probe literature), $F_1(1,11) = 17.31$, $p = .002$, $F_2(1,39) = 43.05$, $p < .001$. The interaction of interruption and probe type (positive or negative) was not significant $F_1(1,11) <1$, $F_2(1,39) = 1.71$, $p = .199$.

Table 12 shows the mean percent correct for positive and negative probes in each condition.

Table 12

Mean percent correct responses to positive and negative probes in each of the two conditions in Experiment 4.

	No Interruption	Interruption	Average
Positive probe	99%	79%	89%
Negative probe	88%	75%	82%
Average	93%	77%	

Accuracy was higher when probes were presented before the distractor sentences than after them; $F_1(1,11) = 21.17$, $p < .001$, $F_2(1,39) = 21.34$, $p < .001$. The interaction of accuracy and probe type (positive or negative) was not significant $F_1(1,11) <1$, $F_2(1,39) = 1.00$.

Clearly, the distractor sentences caused a substantial elevation of response times and error rates to the probe words. This suggests that the distractor task produced a significant disruption of the lexical representations in working memory. I wondered if this effect might be countered by a resumption of the passage following the interruption. In other words, might a resumption of the reading of the passage following the interruption (and the concurrent attempt to fully comprehend the passage) lead to a reinstatement of the verbatim representation in working memory? I explored this question in Experiment 5.

Experiment 5

Method

Participants

Twenty-four undergraduates from the same population as the previous studies served in the experiment.

Stimulus materials

The materials from Experiment 4 were modified slightly for Experiment 5. First, a short, adjunct phrase (one that made sense with the rest of the sentence, but that contained relatively little semantic information about the passage) was added to the third sentence of each (experimental) narrative passage. Then, each sentence in the experimental passages was segmented into short phrases at logical points in the text, as seen in Example 2 (where a "*" indicates a point of segmentation).

Example 2:

Susan wanted*to buy Tom*a puppy*as a Christmas present.*
She told him*about the idea*in advance.* **p1**
+Some 10,000 years ago,*the New Stone Age*began in the Near East.*
+What we call civilization*arose 5000 years ago*in Mesopotamia and Egypt.* **p2**
Soon after, she* **p3** went to the pet store.*
The Dalmatian puppies*were the cutest.*

Probe word = SUSAN

The first segment of the third sentence of each experimental narrative (which followed the interruption when it was present) always consisted of the fronted adjunct phrase described above, plus the original first word of the sentence, which was always a pronoun. In this way, the passages could be presented a phrase at a time, and probe responses could be obtained immediately before the interruption (after the last phrase of the second sentence of the narrative), immediately after the interruption, and after the resumption (the first phrase) of the first post-interruption sentence. Probes again consisted of either the first name introduced as the subject in the first sentence of the passage (for positive responses) or a name of similar length and gender that had not appeared in the passage (for negative responses). The probe position (before the interruption, immediately after the interruption, or after the passage resumption) was counterbalanced across items and participants.

In Experiment 5, the presentation of the stimuli did not terminate with the probe response. Participants were presented with the rest of the passage after they made their response. (When the probe appeared in the first position, immediately after the second sentence of the passage, the interrupting sentences were omitted, and participants read only the four sentences of the passage itself.) At the end of the passage, they were presented with a true/false comprehension question.

The 96 filler passages from Experiment 4 were also modified for use in Experiment 5. All of the filler passages were segmented into phrases at logical points in the text, like the experimental passages. Twenty-eight of the filler passages resembled the format of the experimental passages, in that they contained (in this case, content-word) probes at one of three positions (before the interruption, after the interruption, or after the fronted-adjunct-resumption, counterbalanced across items and participants). The remaining 68 filler passages (half of which contained an interruption) did not require a response to a probe. All of the filler passages, like the experimental passages, were followed by a comprehension question, presented all at once on the computer screen.

Design and procedure

An initial warm-up block was constructed of 16 fillers, half of which contained probes. The subsequent five experimental blocks contained 24 stimuli each, eight of which were experimental items, and 16 of which were fillers. Four of the fillers in each experimental block contained a probe (the position of which was counterbalanced across subjects and items); the other 12 fillers did not.

Participants read the passages on a personal computer. The passages were presented a phrase at a time at a pace controlled by the computer (600 ms per word plus 32 ms per character). (Computer pacing was employed to eliminate the button pressing used to advance the screen in the self-paced paradigm; the phrase-at-a-time presentation would have required frequent and rapid button presses.) After the passage was complete the true-false comprehension question was presented (all at once) on the screen, and participants were asked to make a response. Participants were given feedback about incorrect responses to the probe word and the comprehension question.

Results

Table 13 shows the mean response time for positive and negative probes to which participants responded correctly for each condition.

Table 13

Mean reaction times (ms) to positive and negative probes in Experiment 5.

	Before Interruption	After Interruption	After Resumption	Average
Positive probe	1337	1691	1649	1559
Negative probe	1632	1819	1717	1723
Average	1485	1755	1683	

Analysis of variance of the response times showed that responses to the probe word differed significantly among the three conditions, $\underline{F}_1(2, 46) = 12.31$, $\underline{p} < .001$, $\underline{F}_2(2, 78) = 10.40$, $\underline{p} < .001$. Responses to the probe word were significantly faster before the interruption than after ($\underline{t}_1(23) = 4.94$, $\underline{p} < .001$; $\underline{t}_2(39) = 4.22$, $\underline{p} < .001$); however, responses to the probe were not facilitated by the resumption of the passage following the interruption ($\underline{t}_1(23) = 1.291$, $\underline{p} < .10$; $\underline{t}_2(39) = 1.1026$, $\underline{p} < .10$). Participants responded significantly more quickly to positive than to negative probes, $\underline{F}_1(1, 23) = 6.93$, $\underline{p} = .015$, $\underline{F}_2(1, 39) = 6.71$, $\underline{p} < .013$. These effects were mediated by a significant interaction of interruption and probe type (positive or negative), $\underline{F}_1(2, 46) = 3.57$, $\underline{p} = .036$, $\underline{F}_2(2, 78) = 3.23$, $\underline{p} = .045$.

Table 14 shows the mean percent correct for positive and negative probes in each condition.

Table 14

Mean percent correct responses to positive and negative probes in each of the three conditions in Experiment 5.

	Before Interruption	After Interruption	After Resumption	Average
Positive probe	89%	80%	81%	83%
Negative probe	93%	80%	79%	84%
Average	91%	80%	80%	

Analysis of variance showed that accuracy in responding to the probe word differed significantly among the three conditions, F_1 (2, 46) = 7.59, $p < .001$, F_2 (2, 78) = 7.65, $p < .001$. Participants were more accurate at responding to the probe word when it was presented before an interruption than when it was presented following an interruption, $t_1(23) = 3.34$, $p < .001$; $t_2(39) = 3.34$, $p < .001$. The resumption of the passage following the interruption, however, did not significantly increase participants' accuracy, $t_1(23) = 0.11$; $t_2(39) = 0.11$. The main effect of probe type (positive or negative) on accuracy was not significant (F_1 (1, 23) <1, F_2 (1, 39) < 1), nor was the interaction of accuracy and probe type (F_1 (2, 46) <1, F_2 (2, 78) < 1).

As in Experiment 4, the distractor sentences in Experiment 5 caused a substantial elevation of response times and error rates to the probe words. This effect persisted even when participants were forced to resume reading of the narrative passage after the interruption.

Discussion of Experiments 4 and 5

Experiments 4 and 5 employed a probe methodology in an attempt to access the verbatim representation of a discourse in working memory. The results of both experiments suggest that such a representation was greatly diminished by an interruption to reading in the form of the presentation of two, unrelated distractor sentences. It would seem, then, that the maintenance of a verbatim representation in working memory is disrupted by an interruption to language processing.

However, the experiments conducted thus far are not truly inconsistent with either view of working memory as described earlier. Glanzer's (Fischer & Glanzer, 1986; Glanzer, Dorfman, & Kaplan, 1981; Glanzer, Fischer, & Dorfman, 1984) architectural view describes working memory as capable of the maintenance of two sentences verbatim. According to this view, then, in our preliminary probe experiments, the two distractor sentences disrupted the maintenance of the two passage sentences because they exceeded the limited capacity of working memory. This view therefore predicts an increase in reaction time and a decrease in accuracy to a probe presented after the two distractor sentences because the information about the passage has been forced out of working memory by the information from the two interrupting sentences. This prediction remains unchanged when the reading of the passage is resumed after the interruption.

The memory organizational view of working memory can also accommodate these probe experiment results. According to this view, working memory maintains an elaborated semantic representation (not necessarily verbatim information) across the span of the interruption. Therefore, participants will have difficulty with a probe following an interruption because they will have to reconstruct their knowledge of the surface structure of a sentence from their semantic representation. This reconstruction takes time (longer reaction times to the probe) and is not always accurate (decreased accuracy of responses).

The probe experiments presented so far are thus unable to differentiate between the view of working memory as a repository of a limited amount of relatively unprocessed information and the view of working memory as a creator and manager of elaborate, semantically-based retrieval structures about a discourse in long-term memory. The third probe experiment was designed to differentiate between these two views.

Experiment 6

This experiment was designed to further contrast the two views of the function of working memory in language processing. The probe word paradigm of Experiments 4 and 5 was again used; however, the materials of this experiment were designed to elicit different predictions from each of the two models.

This experiment used passages similar to those used in Experiments 4 and 5. The passages were modified so that participants were presented with one passage sentence before an interruption by one or two distractor sentences, as seen in Example 3 (where "p*" indicates a possible probe position).

Example 3

a.) Passage only condition:
Susan wanted to buy Tom a puppy as a Christmas present. **p***
Probe word = SUSAN

b.) Passage + one distractor condition:
Susan wanted to buy Tom a puppy as a Christmas present.
+Some 10,000 years ago, the New Stone Age began in the Near East. **p***
Probe word = SUSAN

c.) Passage + two distractors condition:
Susan wanted to buy Tom a puppy as a Christmas present.
+Some 10,000 years ago, the New Stone Age began in the Near East.
+What we call civilization arose 5000 years ago in Mesopotamia and Egypt.
p*
Probe word = SUSAN

The two views of working memory discussed above offer different predictions about the responses to the probe words in this experiment. According to the architectural view, working memory should have the capacity to maintain the relatively unprocessed, verbatim information of two sentences. The reading of one passage sentence and one distractor sentence (as in Example 3b) should not tax the limited capacity of working memory, and therefore a verbatim representation of both the passage sentence and the interrupting distractor sentence should be maintained. According to this view, then, responses to the probe should be similar before and after the one-sentence interruption. A two-sentence interruption (as in Example 3c), however, would disrupt the maintenance in working memory of a verbatim representation of the first passage sentence, because working memory can only maintain a representation of the two most recently processed sentences. Therefore, according to the architectural view, responses should be similar when the probe is presented before the interruption (Example 3a) and when it is presented after one distractor sentence (Example 3b), but performance will diminish when the probe is presented after two distractor sentences (Example 3c).

The memory organizational view of working memory leads to a different prediction. According to this view, verbatim information is not maintained across the span of an interruption (instead, an organized, elaborated, semantic representation is). This is true regardless of the amount of interrupting material. According to this view, then, I would expect similar results to those of Experiments 4 and 5 in both the passage + one distractor (Example 3b) and passage + two distractor (Example 3c) conditions: a lengthening of reaction times and a decrease in accuracy when responding to a probe after an interruption (of either one unrelated sentence or two) relative to one before.

Method

Participants.

Thirty undergraduates from the same population as the previous studies served in the experiment.

Stimulus materials.

The materials from Experiment 4 were modified for Experiment 6 (see Example 3). In Experiment 6, each experimental item consisted of the first sentence of each of the forty narrative passages used in Experiment 4. An additional twenty narrative sentences were created (to be of the same form as those in Experiment 4), for a total of sixty experimental items. In the "passage only" condition, participants read only this narrative sentence, after which they were immediately presented with the memory probe. [Probes again consisted of either the first name introduced as the subject of the sentence (positive probes) or a name of similar length and gender that had not appeared in the passage (negative probes).] In the "passage + 1 distractor" condition, participants read the narrative sentence and one expository distractor sentence (the same distractors used in Experiments 4 and 5, marked by a "+" sign) before responding to the (positive or negative) name probe. In the "passage + 2 distractors" condition, participants read the narrative sentence and two distractor sentences (as in Experiments 4 and 5) before responding to the probe. One-half of the experimental trials seen by each participant included a negative probe. Reading of the experimental items was terminated following the presentation of the probe word; there were no comprehension questions for these items.

A set of 120 filler passages was also used. Thirty of the filler items (twenty modified from those used in Experiment 4 and ten new items) required a response to a probe word. These items were similar to the experimental items in every way except that both the positive and negative probes consisted of content words (not names) that either were or were not in the first narrative sentence; I will thus refer to these as "pseudo-experimental" fillers. Each participant saw ten such fillers that contained one narrative passage sentence; ten that contained one narrative sentence plus one distractor sentence; and ten that contained one narrative sentence plus two distractor sentences. (These fillers were counterbalanced so that different participants saw a given item in each of the three conditions, and each participant saw equal amounts of passages in each of the three conditions.)

An additional 90 "question" filler passages were seen by each participant. These passages were composed of four narrative sentences of the same type and form (including named characters) as the experimental items in the previous experiments. Thirty of these fillers were read continuously without interruption. Another thirty included an interruption by one non-related distractor sentence (expository sentences marked by a "+" sign of the same type and form used throughout the previous experiments) after the presentation of the first narrative passage sentence. Finally, another thirty included an interruption by two distractor sentences after the first narrative sentence. These filler passages did not require response to a probe word, and reading of the fillers continued after the interruption (as in Experiments 1, 2, & 3). These passages were followed by a comprehension question. The fillers required equal numbers of true and false responses, and one-third of the comprehension questions referred to the distractor sentences.

Design and procedure.

An additional 24 fillers were used to construct an initial practice block. Six of these fillers were of the same form as the experimental items; two contained no interruption, two contained one distractor sentence, and two contained two distractor sentences. Half required positive and half negative responses to the name probes. Another six practice fillers were of the same form (and followed the same patterns of interruption) as the pseudo-experimental fillers; these required positive (on half of the trials) and negative (on half of the trials) responses to content-word probes. The other 12 practice fillers were question fillers (to which the answer was true on half of the trials and false on half of the trials); there were four of each of the interruption conditions.

Five subsequent experimental blocks contained 36 trials each, 12 of which were experimental items and 24 of which were fillers (six pseudo-experimental fillers and 18 question fillers). The experimental items were counterbalanced for interruption position and for probe response (positive or negative); six groupings of the experimental items were constructed so that a given participant read each experimental item once and read equal numbers of items in each of the six (interruption position x positive/negative probe response) conditions.

Participants read the passages on a personal computer at their own pace. Sentences were presented one a time and participants pressed the space bar after reading each sentence. On probe trials, immediately after they had pressed the space bar to indicate that they had finished reading the last sentence, participants were presented with a probe word at the top of the screen in all capital letters. They were instructed to respond as quickly as possible whether or not they had seen this word in the passage so far. Participants were given feedback about incorrect responses to the probe word. On question trials, the comprehension question was presented (all at once) on the screen after participants had pressed the space bar after having read the last sentence of the passage. Participants were asked to respond whether the statement presented was true or false, and were given feedback about incorrect responses.

Results and Discussion

Table 15 shows the mean response time for positive and negative probes to which participants responded correctly for each condition.

Table 15

Mean reaction times (ms) to positive and negative probes in each of the three conditions in Experiment 6.

	Passage Only	Passage + 1 Distractor	Passage + 2 Distractors	Average
Positive probe	1052	1123	1153	1109
Negative probe	1280	1335	1394	1336
Average	1166	1229	1274	

Analysis of variance of the response times showed that responses to the probe word differed significantly (by subjects) among the three interruption conditions, $F_1(2, 57) = 6.83$, $p = .002$, $F_2(2, 118) = 1.10$, $p = .336$. Responses to the probe word were significantly slower after interruption by one distractor sentence ($t_1(57) = -3.417$, $p < .001$), and after interruption by two distractor sentences ($t_1(57) = -5.818$, $p < .001$), relative to the speed of responses to probes presented immediately after the passage sentence. Responses to the probe word were significantly slower after a two-sentence interruption than after a one-sentence interruption, $t_1(57) = -2.426$, $p < .01$. Participants responded significantly more quickly to positive than to negative probes, $F_1(1, 29) = 36.90$, $p < .001$, $F_2(1, 59) = 113.72$, $p < .001$. The interaction of interruption condition and probe response type was not significant, F_1 and $F_2 < 1$.

Table 16 shows the mean percent correct for positive and negative probes in each condition.

Table 16

Mean percent correct responses to positive and negative probes in each of the three conditions in Experiment 6.

	Passage Only	Passage + 1 Distractor	Passage + 2 Distractors	Average
Positive probe	89%	85%	81%	85%
Negative probe	87%	82%	78%	82%
Average	88%	84%	79%	

Analysis of variance showed that accuracy in responding to the probe word differed significantly among the three conditions, $F_1(2, 58) = 11.24$, $p < .001$, $F_2(2, 118) = 7.19$, $p = .001$. Participants were less accurate at responding to the probe word when it was presented after an interruption by one distractor sentence ($t_1(58) = 2.374$, $p < .02$; $t_2(118) = 1.938$, $p < .05$), and when it was presented after an interruption by two distractor sentences ($t_1(58) = 4.747$, $p < .001$; $t_2(118) = 3.876$, $p < .001$), than when it was presented immediately after the passage sentence. Responses to the probe word were significantly less accurate after a two-sentence interruption than after a one-sentence interruption, $t_1(58) = 2.373$, $p < .02$; $t_2(118) = 1.938$, $p < .05$. The main effect of probe type (positive or negative) on accuracy was not significant (F_1 (1, 29) <1, F_2 (1, 59) = 2.10, p = .153), nor was the interaction of accuracy and probe type (F_1 and F_2 < 1).

In Experiment 6, I varied the length of the interrupting material in order to generate different predictions from the architectural and representational views about the effect of the interruption on responses to a memory probe. The architectural view would suggest that because working memory can maintain verbatim information from two (but not three) text sentences (Glanzer, et al.), response time and accuracy to a probe requiring verbatim memory of text information from a sentence should decline if such a probe is presented when a participant has read two distractor sentences after a the critical text sentence, relative to cases in which the probe is presented immediately after the critical sentence. An interruption by one distractor sentence should not have the same effect, as working memory resources for verbatim text information will not be taxed. The representational view, on the other hand, suggests that verbatim information is in fact not maintained in working memory across the span of an interruption (an organized semantic representation is). Responses that require the use of verbatim information (such as those made to a memory probe) rely on working memory's ability to regenerate such information as needed from the organized semantic representation in long-term memory. Interrupting material makes more difficult the maintenance of and access to that semantic information (as, presumably, the interrupting material is also represented, which requires working memory resources). Thus, any interruption (regardless of its length) will lead to a detriment in probe performance (relative to performance when no interruption is present).

The results of Experiment 6 were consistent with the predictions of the memory representational view. Probe performance (in terms of reaction time and response accuracy) was worse in both post-interruption conditions; in other words, participants had more difficulty responding to the probe after an interruption, regardless of the length of that interruption. These results do not suggest that participants are able to maintain and equally access verbatim information about two sentences in working memory, as suggested by Glanzer and colleagues; if that had been the case, participants should have been equally good at responding to a probe after one interrupting sentence as they were at responding immediately after the narrative sentence. The fact that probe performance was worse in the "passage + 2 distractors" condition than in the "passage + 1 condition" also seems consistent with the representational view; a reader must devote more working memory resources to the maintenance of a semantic representation of a passage sentence plus two distractor sentences than to the maintenance of such a representation of a passage sentence plus only one distractor sentence. There is also more possibility for interference with the additional representation. Both of these factors could make the reconstruction of verbatim information from a text more difficult when there are two (instead of one) distractor sentences.

One explanation for the probe results in Experiments 4, 5 and 6 (relative to the reading time results in Experiments 1 – 3) is that the verbatim representation of a discourse in working memory is not maintained across the span of an interruption because it is not essential to comprehension (while an organized, semantic representation is). A somewhat simpler, alternative explanation for these results exists: that the responses to the probe after an interruption are slowed and less accurate because the distance between the presentation of the probe word and its referent is larger. In other words, it is possible that the probe results I obtained in Experiments 4, 5, and 6 are due to the length of the intervening material, and not to a disruption of the contents of working memory by the presentation of a semantically-unrelated interruption.

Perhaps the strongest evidence we could find against the architectural view of working memory in discourse processing would come from interruption effects on reading or comprehension processes that are due to the *type* of interrupting material. To this point, additional material that participants have had to read after the initial passage sentence but before a probe has always been interrupting material that is unrelated to the passage (and the referent of the probe) itself. I cannot yet conclude, however, that the detrimental effects of interruption on probe performance are due to the fact that a reader is presented with *unrelated* material, because this factor has always been confounded with the insertion of additional material. Perhaps probe responses are affected because there are more items in a verbatim memory representation that must be searched before making a response (if one assumes this search to be serial). Perhaps a verbatim representation is maintained in working memory across the span of additional text, and is serially searched for a match to the probe; as more text is read, there are more items to be searched for a match in this representation, which will take more time. I want to eliminate this possibility if I am to reject the view of working memory suggested by the architectural models. This was the motivation for Experiment 7.

Experiment 7

I designed a similar probe experiment to those described previously. In this experiment, readers responded to a memory probe about a word from a passage sentence immediately after having read that sentence, or after having read an additional two sentences.

These two sentences were of one of two types, as can be seen in Example 4 (where "*" indicates a possible probe position).

Example 4

a.) Passage only condition:
Scott was invited to Wendy's dinner party. *
Probe word = SCOTT

b.) Passage + passage condition:
Scott was invited to Wendy's dinner party.
The party was being held to celebrate a close friend's recent promotion at work.
It's considered good manners to bring the hostess a small gift, like a bottle of wine. *
Probe word = SCOTT

c.) Passage + interruption condition:
Scott was invited to Wendy's dinner party.
+In 1570 BC the Egyptians drove out the Hyksos and embarked upon empire building.
+In 586 BC the Kingdom of Judah fell to the Chaldeans, and the temple was destroyed. *
Probe word = SCOTT

In these stimuli, the distance between the probe and its referent (in terms of number of words) was the same; what differed was the relatedness of the second sentence to the first. In the passage + passage condition (Example 4b), the additional sentences were related to the first, and were thus not seen as an interruption to the reading of the passage. In the passage + interruption condition (Example 4c), the additional sentences were unrelated to the first, and were therefore read as interrupting distractors. If the previous probe results of Experiments 4, 5, and 6 were due only to the decreased proximity of the probe to its referent (and not to the lack of continued maintenance of a verbatim representation across the span of an interruption), I expected to see a similar lengthening of response times and decrease in accuracy to the probe after the additional sentences in both conditions. If, however, the probe results of the previous experiments were due to a disruption of the contents of working memory by an interruption by unrelated information, then I would expect to see lengthened response times and decreased accuracy to the probe after the additional sentences only in the passage + interruption condition. Again, the architectural view of working memory suggests no role for the type of intervening material, only for its length; the memory representational view, however, suggests that the type of intervening material does matter, as having to access one organized, semantic representation of a text in long-term memory (as in the passage + passage condition) will be quicker and more accurate than having to access two (as in the passage + interruption condition).

Method

Participants.

Forty-eight undergraduates from the same population as the previous studies served in the experiment.

Stimulus materials.

The materials from Experiment 6 were modified for Experiment 7 (see Example 4). As in Experiment 6, each experimental item consisted of the first sentence of each of sixty narrative passages. In the "passage only" condition, participants read only this narrative sentence, after which they were immediately presented with the positive or negative memory probe. In the "passage + passage" condition, participants read the narrative sentence plus two additional passage sentences (that continued the theme of the first sentence but did not refer to any previously-mentioned or new named characters) before responding to the same (positive or negative) name probes as in the "passage only" condition. In the "passage + interruption" condition, participants read the narrative sentence plus two distractor sentences (that referred to unrelated material about world history and that were marked with a "+" sign, as in the previous probe experiments) before responding to the same probe. One-half of the experimental trials seen by each participant included a negative probe. Reading of the experimental items was terminated following the presentation of the probe word; there were no comprehension questions for these items.

Table 17 includes information about the length of the additional material in the passage + passage and passage + interruption conditions (where "second sentence" and "third sentence" refer to the first and second additional sentences after the passage sentence itself).

Table 17

Word and character counts for the additional sentences in the passage + passage and passage + interruption conditions.

	Passage + Passage		Passage + Interruption	
	Words	Characters	Words	Characters
Entire passage	39.73	235.32	39.73	238.03
Second sentence	14.58	87.5	14.58	88.32
Third sentence	15.23	94.7	15.23	96.4

The two additional sentences that followed the passage sentence in the continuous and interruption conditions were matched for word length on a passage-by-passage basis, so that for a given passage, the number of words in the additional material in each of the conditions was exactly the same. I also tried to ensure that the number of characters in these sentences (which includes spaces and punctuation) was similar for the two conditions;

although these were not completely matched, the mean number of characters in these sentences was nearly the same for the two conditions.

The same set of 120 filler passages from Experiment 6 was also used. The thirty pseudo-experimental items (which presented content word probes instead of name probes) were presented in each of the three conditions (passage only, passage + passage, and passage + interruption) equally as often and were counterbalanced for condition across participants. The additional sentences used in the pseudo-experimental items were also matched for length in a manner similar to that used for the experimental items. Half of the 90 question filler passages seen by each participant were read continuously without interruption; half included an interruption by two non-related distractor sentences.

Design and procedure.

The same additional 24 fillers from Experiment 6 were used to construct an initial practice block. Six of these fillers were of the same form as the experimental items (two in each condition); another six practice fillers were of the same form (and followed the same patterns of interruption) as the pseudo-experimental fillers; and the other 12 practice fillers were question fillers.

Five subsequent experimental blocks contained 36 trials each, 12 of which were experimental items and 24 of which were fillers (six pseudo-experimental fillers and 18 question fillers). The experimental items were counterbalanced for interruption position and for probe response (positive or negative); six groupings of the experimental items were constructed so that a given participant read each experimental item once and read equal numbers of items in each of the six (interruption position x positive/negative probe response) conditions.

Participants again read the passages on a personal computer at their own pace. Sentences were presented one a time and participants pressed the space bar after reading each sentence. On probe trials, immediately after they had pressed the space bar to indicate that they had finished reading the last sentence, participants were presented with a probe word at the top of the screen in all capital letters. They were instructed to respond as quickly as possible whether or not they had seen this word in the passage so far. Participants were given feedback about incorrect responses to the probe word. On question trials, the comprehension question was presented (all at once) on the screen after participants had pressed the space bar after having read the last sentence of the passage. Participants were asked to respond whether the statement presented was true or false, and were given feedback about incorrect responses.

Results and Discussion

Table 18 shows the mean response time for positive and negative probes to which participants responded correctly for each condition.

Table 18

Mean reaction times (ms) to positive and negative probes in each of the three conditions in Experiment 7.

	Passage Only	Passage + Passage	Passage + Interruption	Average
Positive probe	1109	1148	1239	1165
Negative probe	1394	1452	1543	1463
Average	1251	1300	1391	

Analysis of variance of the response times showed that responses to the probe word differed significantly among the three experimental conditions, $F_1(2, 94) = 17.44$, $p < .001$, $F_2(2, 118) = 5.69$, $p = .004$. Responses to the probe word were significantly slower after reading an additional two passage sentences ($t_1(94) = -2.8665$, $p < .005$, $t_2(118) = -1.1209$, $p < .10$), and reading an additional two distractor sentences ($t_1(94) = -8.3205$, $p < .001$, $t_2(118) = -4.5762$, $p < .001$), relative to the speed of responses to probes presented immediately after the first passage sentence. Critically, responses to the probe word were significantly slower after reading two distractor sentences than after reading two additional passage sentences, $t_1(94) = -5.4538$, $p < .001$, $t_2(118) = 3.4553$, $p < .001$. Participants again responded significantly more quickly to positive than to negative probes, $F_1(1, 47) = 34.92$, $p < .001$, $F_2(1, 59) = 194.15$, $p < .001$. The interaction of interruption condition and probe response type was not significant, F_1 and $F_2 < 1$.

Table 19 shows the mean percent correct for positive and negative probes in each condition.

Table 19

Mean percent correct responses to positive and negative probes in each of the three conditions in Experiment 7.

	Passage Only	Passage + Passage	Passage + Interruption	Average
Positive probe	92%	86%	78%	85%
Negative probe	88%	82%	79%	83%
Average	90%	84%	79%	

Analysis of variance showed that accuracy in responding to the probe word differed significantly among the three conditions, F_1 (2, 94) = 31.59, $p < .001$, F_2 (2, 118) = 21.31, $p = .001$. Participants were significantly less accurate at responding to the probe word when it was presented after an additional two passage sentences ($t_1(94) = 5.894$, $p < .001$; $t_2(118) = 4.6681$, $p < .001$), and when it was presented after an additional two distractor sentences ($t_1(94) = 11.2779$, $p < .001$; $t_2(118) = 8.9679$, $p < .001$), than when it was presented immediately after the passage sentence. Responses to the probe word were significantly less accurate after a two-sentence interruption than after a two-sentence passage continuation, $t_1(94) = 5.383$, $p < .001$; $t_2(118) = 4.30$, $p < .001$. The main effect of probe type (positive or negative) on accuracy was not significant (F_1 (1, 47) <1, F_2 (1, 59) = 1.80, $p = .185$), nor was the interaction of interruption type and probe type (F_1 (2, 94) = 2.07, $p = .132$, F_2 (1, 118) = 2.06, $p = .132$).

The results of Experiment 7 suggest that while the length of intervening material between the probe and its referent does have an effect on probe performance, there is an additional, greater detrimental effect if that intervening material is a true interruption (i.e., is of a different style and theme than what has previously been read). Participants were slower and less accurate when responding to memory probes when there were two additional sentences between the probe and the sentence containing the probe's referent. It does seem that having additional information in working memory at the time of responding to the probe makes the search for the probe's referent more difficult. However, a critical result from this experiment was the finding that responses are not affected equally for additional sentences of different types. Instead, performance is impaired (in both speed and accuracy) if the additional intervening material is of a different style and theme than the original sentence, relative to responses made when the additional intervening material is of the same semantic theme (and when the sentences of each are matched to be of the same length). In other words, in Experiment 7, I found some effect due to the length of the intervening material; but there is an additional effect of *interrupting* material, a finding that is not well accounted for by the architectural view of working memory (which again suggests no role for the *type* of interrupting material). This result is better explained by the memory representational view, which suggests that information of one theme can be maintained in one organized, semantic representation. When there is more information to be captured by this representation (as when there is more intervening stylistically-continuous material between a probe and its referent), it will be more difficult to reconstruct the necessary information to respond to a memory probe. But above and beyond that, according to the memory representational view, probe performance will be more adversely affected when such reconstruction has to be done from more than one representation, as will be the case when the intervening material is of a different style.

Discussion of Probe Experiments

In Experiments 4 – 7, I examined the effect of interruption on reading using a different methodology, the probe word paradigm. In the probe task, readers are presented with a word (the probe) at various points during their reading of a passage, and are asked to respond whether they have seen that word in what they have read of the passage thus far or not. In these experiments, I assessed probe performance at points during reading that came before and after an interruption by unrelated material.

The probe paradigm would seem to rely on verbatim information from a text, and might encourage readers to maintain a strong verbatim representation during reading. The type of working memory representation described by Glanzer and colleagues (Fischer & Glanzer, 1986; Glanzer, et al., 1981; Glanzer, et al., 1984), one in which a small amount of relatively unprocessed information about a text is maintained for use in further processing, would be especially useful to readers in the probe task, as such a representation would keep active in working memory the exact form of words read in the text. These words could be searched upon the presentation of a probe for a match, facilitating response to the probe.

These experiments suggest that readers do *not* maintain such a representation across the span of an interruption, at least not to the same extent that it is present immediately after the processing of a sentence. Probe performance is negatively affected by interrupting material; in Experiment 4, I found longer latencies and decreased accuracy to probes of passage information presented after two interrupting sentences, relative to presentation of the same probes immediately after the passage sentence. In Experiment 5, I found that this decrement in performance was not countered by reinstatement of the passage, so that even when participants were forced to return to the reading of a passage after an interruption, their ability to respond to the probes was negatively affected. In Experiment 6, I modified the experimental materials to keep them within the working memory capacity limit for verbatim information described by Glanzer and colleagues, and found that participants were still unable to respond to probes following an interruption as well as they were able to respond when that interruption was not present. In Experiment 7, I showed that the length of the intervening material alone is not enough to account for the effects on probe responses in the previous three experiments. The type of intervening material also plays a significant role, another result that is not accommodated by the architectural view of working memory.

Can these results be accommodated by the memory representational view of memory? That view proposes that readers do not maintain a verbatim representation of a text in working memory; instead, the role of working memory is to create and maintain access to an organized, semantic representation of a text in long-term memory. That representation can be drawn upon efficiently and rapidly during subsequent processing as needed. Factors that affect retrieval from long-term memory (such as the similarity of texts, as seen in Experiments 1 – 3) will affect reading.

Because verbatim information is not maintained in working memory, according to this view, surface-level information about a text (such as that required for a response to a memory probe) must be re-generated from the semantic representation in long-term memory. Again, factors that affect retrieval from long-term memory (list-length, similarity, interference, etc.) will affect a reader's ability to re-generate this surface-level information.

The probe results in Experiments 4 – 7 seem consistent with this view of working memory. When presented with interrupting material during reading, participants are forced to switch from the construction and maintenance of one representation (for the main text) to the construction and maintenance of another (for the distractor text). Having to maintain and subsequently access both representations in an attempt to reconstruct the necessary surface-level information to respond to a memory probe will result in longer latencies and decreased accuracy to probes following an interruption (Experiments 4 and 5). This will be true whether the interruption is one sentence or two sentences long (Experiment 6).

In Experiment 7, participants were tested with probes after a continuation of the passage or after a disruption by distractor sentences. Probe performance was worse in both of these conditions than it was when the probe was presented immediately after the first passage sentence. But, importantly, performance was *still* worse in the interruption condition than in the passage continuation condition. According to the memory representational view of working memory, in the passage continuation condition, readers are able to maintain one semantic representation of the single text in working memory. This representation will be "larger" than the representation for just the first sentence from the text, and thus reconstruction of surface-level information may take longer; thus the decrement in probe performance in the passage continuation condition. But what is really difficult for readers is to construct and maintain two separate semantic representations in working memory, and to subsequently use both representations to re-generate surface-level information. This leads to the decreased performance in the interruption condition relative to the continuation condition.

The results of the memory probe experiments, like the reading time experiments before them, thus seem more consistent with the memory representational view of working memory. In one final experiment, I wanted to look at the effect of interruption on reading comprehension and probe memory using one design.

Effects of Interruption on Reading Comprehension and Probe Memory

This final experiment was designed to directly examine the effects of interruption on comprehension performance and on probe performance in one experiment. This experiment was meant to establish that even when verbatim information is lost or severely diminished across the span of an interruption (as measured through probe performance), participants are still able to answer comprehension questions accurately because working memory is functioning to create and maintain an elaborated semantic representation (on the basis of which the questions are answered).

This experiment included four conditions, as seen in Example 5.

Example 5

a.) Continuous probe condition:
Mark received a chain letter from Amy yesterday. **p1**
Probe word = MARK

b.) Interrupted probe condition:
Interruption Condition:
Mark received a chain letter from Amy yesterday.
+One reason for the growth of empires was the migration of Indo-Europeans . **p2**
Probe word = MARK

c.) Continuous comprehension condition:
Mark received a chain letter from Amy yesterday.
A lot of people have very superstitious beliefs about chain letters.
T or F: Mark sent Amy a letter.

d.) Interrupted comprehension condition:
Mark received a chain letter from Amy yesterday.
+One reason for the growth of empires was the migration of Indo-Europeans .
A lot of people have very superstitious beliefs about chain letters.
+In the ninth century BC, empire building resumed with the Assyrians.
T or F: Mark sent Amy a letter.

On probe trials (Examples 5a and 5b), I used materials similar to those used in Experiment 6, in which participants were probed after one passage sentence (Example 5a) and after one passage sentence plus one distractor sentence (Example 5b). Based on the results of the previous probe experiments, I expected to find poorer performance (longer reaction times and decreased response accuracy) on the memory probes presented after an interruption (the interrupted probe condition) relative to performance on the same memory probes presented after the passage sentence alone (the continuous probe condition).

On comprehension question trials, (Example 5c and d), I used the same first passage sentences as used for the probe trials. The continuous comprehension condition (Example 5c) extended the materials to contain another passage sentence, so that readers read a two-sentence narrative passage (without interruption). The presentation of these passages was followed by a comprehension question that referred to the first sentence of the passage. The interrupted comprehension condition (Example 5d) used the same two-sentence narrative passages as the continuous comprehension condition. In this condition, however, the reading of the passages was interrupted by the presentation of two distractor sentences, one after each passage sentence. These passages were followed by the same comprehension questions used in the continuous comprehension condition. I expected to find that participants were able to answer the comprehension question equally well in the two comprehension conditions; in other words, although I expected to find (through examination of the probe results) that the verbatim representation of the first passage sentence is diminished following an interruption, I expected participants to be as able to answer a comprehension question about that sentence following an interruption (the interrupted comprehension condition) as they are when there was no interruption (the continuous comprehension condition). Such a result would demonstrate that readers rely on an organized, semantic representation to answer the comprehension questions (and thus to read comprehensively), one that is maintained in working memory across the span of an interruption even when verbatim information is lost.

Experiment 8

Method

Participants.

Forty-eight undergraduates from the same population as the previous studies served in the experiment.

Stimulus materials.

The 60 experimental items from Experiment 6 were modified for Experiment 8. Each experimental item was constructed to appear in each of the four experimental conditions (in equal numbers across subjects). In the continuous probe condition (Example 5a), participants read the narrative passage sentence, after which they were immediately presented with the (positive or negative) name probe. In the interrupted probe condition (Example 5b), participants read the same narrative sentence, followed by one distractor sentence (an expository sentence about world history, marked with a "+" sign), before being presented with the same memory probe. In the continuous comprehension condition (Example 5c), participants read the same first narrative passage sentence as in the probe conditions; this sentence was followed by another narrative sentence that continued the theme of the passage but that did not refer to previously-mentioned or new named characters. After having read these two passage sentences, participants were presented with a comprehension question that referred to (one or both of) the named character(s) of the first narrative sentence. Finally, in the interrupted comprehension condition (Example 5d), participants read the same two narrative passage sentences and answered the same comprehension questions as in the continuous comprehension condition; however, the two passage sentences were interleaved with two unrelated distractor sentences. (The first distractor sentence of the two was the same as that used for a given item in the interrupted probe condition.) One-half of the probe trials seen by each participant required a negative response; one-half of the comprehension questions were false.

One-hundred and ten of the 120 filler passages from Experiment 6 were used. Fifteen of the filler items for a given participant were pseudo-probe items; these were similar to the experimental probe items in every way except that both the positive and negative probes consisted of content words (not names) that either were or were not in the first narrative sentence. Half of these contained an interruption by one distractor sentence that appeared after the narrative sentence. Fifteen of the filler items for a given participant were pseudo-question items; these were similar to the experimental question items in every way except that the comprehension questions referred to the second sentence of the narrative passage. Half of these contained an interruption by two distractor sentences that appeared, one each, after each narrative sentence.

An additional 80 filler passages were seen by each participant. Twenty of these fillers included a memory probe that was presented immediately after one narrative sentence (as in the continuous probe condition); ten of these fillers required a response to a name probe, and ten to a content word probe. Another twenty fillers included one narrative sentence, one distractor sentence, and a memory probe (as in the interrupted probe condition); half of these probes were names, and half were content words. Of these forty probe fillers, half required a negative response. Forty fillers contained two narrative sentences followed by a comprehension question; half of these also contained an interruption (as in the interrupted comprehension condition), and half did not (as in the continuous comprehension condition). Half of the answers to the questions for these forty fillers were false.

Design and procedure.

An additional 20 fillers were used to construct an initial practice block. Half of these fillers were probe items; half of the probe items contained an interruption. Six of these ten used name probes; four used content probes; and half were positive, half negative. The remaining ten warm-up items were question items; half of the question items contained an interruption, and half of the answers to the questions was false.

Five subsequent experimental blocks contained 34 trials each, 12 of which were experimental items and 22 of which were fillers (six pseudo-experimental fillers and 16 other fillers). The experimental items were counterbalanced for task (probe or question) and for interruption. Probe items were counterbalanced for positive and negative responses. Eight groupings of the experimental items were constructed so that a given participant read each experimental item once and read equal numbers of items in each of the eight (task x interruption x positive/negative probe response) conditions.

Participants read the passages on a personal computer at their own pace. Sentences were presented one a time and participants pressed the space bar after reading each sentence. On probe trials, immediately after they had pressed the space bar to indicate that they had finished reading the last sentence, participants were presented with a probe word at the top of the screen in all capital letters. They were instructed to respond as quickly as possible whether or not they had seen this word in the passage so far. Participants were given feedback about incorrect responses to the probe word. On question trials, the comprehension question was presented (all at once) on the screen once participants had pressed the space bar after having read the last sentence of the passage. Participants were asked to respond whether the statement presented was true or false, and were given feedback about incorrect responses.

Results and Discussion

Continuous vs. Interrupted Probes:

Table 20 shows the mean response time for positive and negative probes to which participants responded correctly for each condition.

Table 20

Mean reaction times (ms) to positive and negative probes in each of the two conditions in Experiment 8.

	Continuous Probe	Interrupted Probe	Average
Positive probe	1046	1133	1090
Negative probe	1181	1421	1301
Average	1114	1277	

Analysis of variance of the response times showed that responses to the probe word were significantly slower in the interrupted condition than in the continuous condition, $F_1(1, 47) = 11.92$, $p = .001$, $F_2(1, 59) = 15.77$, $p < .001$. Participants again responded significantly more quickly to positive than to negative probes, $F_1(1, 47) = 24.06$, $p < .001$, $F_2(1, 59) = 67.51$, $p < .001$. The interaction of interruption condition and probe response type was significant by items, $F_2(1, 59) = 8.10$, $p = .006$, but not by subjects, $F_1(1, 47) = 1.45$, $p = .235$.

Table 21 shows the mean percent correct for positive and negative probes in each condition.

Table 21

Mean percent correct responses to positive and negative probes in each of the two conditions in Experiment 8.

	Continuous Probe	Interrupted Probe	Average
Positive probe	94%	89%	92%
Negative probe	95%	82%	89%
Average	95%	86%	

Analysis of variance showed that participants were significantly less accurate at responding to the probe word in the interrupted probe condition than in the continuous probe condition, $F_1 (1, 47) = 11.01$, $p = .002$, $F_2 (1, 59) = 21.82$, $p < .001$. The main effect of probe type (positive or negative) on accuracy was not significant ($F_1 (1, 47) <1$, $F_2 (1, 59) = 1.33$, $p = .253$), nor was the interaction of interruption and probe type (F_1 and $F_2 < 1$).

Continuous vs. Interrupted Questions:

The mean accuracy for comprehension questions about a passage in the continuous question condition was 92%. The mean accuracy for comprehension questions about a passage in the interrupted question condition was 90%. A t-test showed no significant effect of interruption on participants' ability to answer comprehension questions, t_1 (94) = 1.120, p = .266, t_2 (117) = 1.528, p = .129.

As expected, participants in this experiment were slower and less accurate at responding to a memory probe that was presented after an interruption by unrelated material, relative to a probe that was presented immediately after the sentence containing its referent. This would seem to indicate the degradation of a verbatim representation across the span of the interruption. In other words, interrupting material appears to diminish the verbatim representation of the text in working memory. On the other hand, participants did not show a decrement in their ability to answer comprehension questions after a similar interruption; they were equally able to answer comprehension questions about a passage when their reading of that passage was interrupted (by the presentation of unrelated distractor sentences) as they were when there was no such interruption. Readers are still able to access and rely upon an organized, semantic representation in long-term memory in order to answer the comprehension questions; this representation does not seem to be detrimentally affected by interruption. Interruption, in this experiment, does not have the same affect on verbatim and semantic representations.

General Discussion

In this paper, I have described the results of eight experiments that were designed to examine the representation of a text in working memory during discourse processing. This paper has contrasted two views of text representation in working memory, which I've labeled the architectural view and the memory representational view. The architectural view (Baddeley, 1986; Baddeley, 1997; Gathercole & Baddeley, 1993; Fischer & Glanzer, 1986; Glanzer, et al., 1981; Glanzer, et al., 1984) describes working memory (as it relates to memory) as a structure that is capable of the maintenance of a limited amount of relatively unprocessed, surface-level text information. A reader will comprehend a text to the extent that he is able to integrate newly read information with this surface-level representation. The memory representational view (Ericsson & Kintsch, 1995) depicts the function of working memory in text processing as involving the creation of an elaborate, semantic representation of text information in long-term memory. Working memory is also involved in the maintenance of elaborate retrieval structures that allow rapid and efficient access to this representation as needed during further text processing. According to this view, then, a reader will comprehend a text to the extent that he is able to create and maintain this representation and its associated retrieval structures.

The eight experiments described herein attempted to differentiate between the predictions generated by these two views of working memory through the use of an interruption paradigm in reading. The interruption of reading by the presentation of unrelated distractor sentences was predicted to disrupt comprehensive reading by affecting the text representation in working memory. The two views offered different explanations for this effect, in terms of a taxing of the capacity of working memory in maintaining verbatim information about a text (the architectural view), or in terms of a decline in the efficient retrieval of information from organized long-term memory structures (the memory organizational view).

The two approaches make very different predictions about the effect of the *type* of interrupting material on reading. Within the architectural framework, there is no place for such an effect; this view emphasizes limitations to comprehensive reading that derive from the amount of material working memory can process, but does not address differences that may arise due to varying types of interrupting material. The memory organizational view, on the other hand, suggests that anything that disrupts the creation of an organized, elaborate semantic representation in long-term memory or that disrupts the subsequent efficient retrieval of this information will disrupt reading. According to this view, then, the *type* of interrupting material may indeed matter. Some interrupting material might make reading easier (to the extent that it makes these working memory processes more effective); other material might make reading more difficult (to the extent that it makes these working memory processes less effective).

In these eight experiments, I looked at one dimension along which the type of interrupting material might vary: stylistic similarity (in relation to the text itself). I used texts of one style (narrative, in the probe experiments, and narrative or expository, in the reading time experiments) and interrupted participants' reading of the texts with the presentation of sentences of a different style. What I found, across the course of these experiments, was that the type of interrupting material did indeed matter; the effects of interruption on reading were different, depending on the similarity of the disrupting material to the text.

In the first three reading time experiments, I found consistent effects of interruption (especially in Experiments 2 and 3, after I had strengthened the interruption manipulation). Additionally, and importantly, I found a moderating effect of similarity; the effect of interruption on reading was greater when the distractor sentences were of the same type as the text sentences (relative to an interruption by distractor sentences of a different type). This finding suggests that different interrupting material will affect the working memory representation differently.

In the four probe experiments, I found that non-related interrupting material inserted between a memory probe and its referent disrupted performance on that probe. This was true even when the amount of interrupting material was within the limit suggested by work within an architectural framework (Fischer & Glanzer, 1986; Glanzer, et al., 1981; Glanzer, et al., 1984), and was true relative to the disrupting effect caused by the insertion of thematically related (and stylistically similar) sentences of the same length.

These results seem incompatible with the architectural view of working memory for several reasons. First, I have seen little evidence to support the idea that verbatim information about text sentences is necessarily and accurately maintained across the span of an interruption, as one would expect based on the architectural view. A reader's response to a memory probe would rely on verbatim information about the text. Our results suggest that this representation is greatly diminished by an interruption by unrelated material, as responses to the probe are slower and less accurate following an interruption. But, as seen in Experiment 8, despite this loss or decay of verbatim information by an interruption, readers are able to comprehend the text as well when it is interrupted as when it is not. This suggests that readers are not, in fact, relying on such a representation in comprehensive reading.

Our finding of an interaction of interruption and similarity is also problematic for this view of working memory, in which there is no role for the type of interrupting material (only for its length). I have demonstrated that the type of interrupting material does moderate the effect of interruption on reading. Reading times (in the self-paced reading experiments) were slowed more by an interruption by similar material. Probe responses were affected more by the insertion of interrupting (stylistically dissimilar) sentences than by the insertion of stylistically similar sentences. Again, these results seem incompatible with the architectural view of working memory as it is described in language processing.

On the other hand, these results are compatible with the view of working memory as a system that is responsible for the establishment of elaborate retrieval structures that access an organized, semantic representation of a text in long-term memory. According to this view, the similarity of interrupting material to the text will disrupt the efficiency of this process, and will make text processing more difficult. It also seems, from the results of the final experiment, that even when verbatim information is compromised by an interruption, readers are able to answer comprehension questions about what they have read by relying on their semantic representation. Readers are able to do this even when they must maintain representations for more than one text. These results suggest, therefore, that comprehensive reading may rely on an organized, semantic representation of a text in working memory.

Although the results described herein lend greater support to a memory representational view of the role of working memory in language processing, I certainly do not wish to claim that a verbatim representation of a text plays no role in language comprehension. Indeed, while the probe experiments described here suggest that the verbatim representation maintained by readers is diminished across the span of an interruption, it would be unwarranted to claim that this representation does not exist or that it is eliminated completely from working memory by interruption. Instead, it seems that some verbatim information does exist in working memory, and might be accessible to readers when the task demands its use. It does not seem, however, that this information is as essential to reading comprehension as is an organized, semantic representation. In future research, I would like to study the extent to which this verbatim information is maintained (how much is available, for how long, etc.) and the extent to which its maintenance is task-specific.

I also would like to examine the effects of other types of passage/interrupter similarity. In these experiments, I found that the stylistic similarity of the interrupting material to the discourse being read moderated the effect on reading of interleaving two passages. I could instead define similarity in terms of the overlap of content between the two passages, and determine whether this type of similarity had a similar moderating effect on interruption. I would also like to look at other factors that might affect the efficient establishment of and retrieval from organized, semantic representational structures in long-term memory to further validate the role of such structures in language processing.

In summary, these eight experiments used interleaved texts to examine the effect of interruption on reading. The results support the view of the role of working memory in language processing as a system whose function comprises the creation and maintenance of an elaborate, semantic representation of a text and the efficient retrieval of this representation from long-term memory.

Appendix A

Appendix A: A sample stimulus set, created by combinations of a first and second narrative and a first and second exposition in continuous and interleaved forms. In Experiment 1, the passages were interleaved after every other sentence; in Experiments 2 and 3, the passages were interleaved after every sentence as shown here. The plus signs (explicit markers of the second passage) were present in Experiments 1 and 2, but not in Experiment 3. The second comprehension question was included in Experiment 3 (but not in Experiments 1 and 2).

Narrative followed by narrative (continuous presentation)

Susan wanted to buy Tom a puppy as a Christmas present.
She told him about the idea in advance.
She went to the pet store last weekend.
The Dalmatian puppies were the cutest.
[+]Chris picked Laura for the track team even though they hate each other.
[+]He really wants to win the next meet.
[+]He runs the 100 meter and the 500 meter events.
[+]It takes a lot of dedicated practice to succeed at racing.
T or F: Susan wanted to buy Tom a kitten.
[T or F: Laura is Chris's best friend.]

Narrative interrupted by narrative (interleaved presentation)

Susan wanted to buy Tom a puppy as a Christmas present.
[+]Chris picked Laura for the track team even though they hate each other.
She told him about the idea in advance.
[+]He really wants to win the next meet.
She went to the pet store last weekend.
[+]He runs the 100 meter and the 500 meter events.
The Dalmatian puppies were the cutest.
[+]It takes a lot of dedicated practice to succeed at racing.
T or F: Susan wanted to buy Tom a kitten.
[T or F: Laura is Chris's best friend.]

Exposition followed by exposition

Neanderthal men walked erect and had big brains.
Though they were in other ways more primitive than Homo sapiens, they represent a great evolutionary stride.
One striking example is their use of technology to overcome the environment.
For instance, we know from evidence that Neanderthal men wore clothes.
[+]The peak of Minoan civilization came about 1600 BC.
[+]A century or so later, the Minoan palaces were mysteriously destroyed.
[+]Historians have speculated that a great eruption may have occurred on the island of Thera at a suitable time.
[+]This could have been accompanied by tidal waves and earthquakes that led to destruction in Crete.
T or F: Neanderthal man was more advanced than Homo sapiens.
[T or F: The Minoan civilization was at its peak around 2500 BC.]

Exposition interrupted by exposition	Neanderthal men walked erect and had big brains. [+]The peak of Minoan civilization came about 1600 BC. Though they were in other ways more primitive than Homo sapiens, they represent a great evolutionary stride. [+]A century or so later, the Minoan palaces were mysteriously destroyed. One striking example is their use of technology to overcome the environment. [+]Historians have speculated that a great eruption may have occurred on the island of Thera at a suitable time. For instance, we know from evidence that Neanderthal men wore clothes. [+]This could have been accompanied by tidal waves and earthquakes that led to destruction in Crete. T or F: Neanderthal man was more advanced than Homo sapiens. [T or F: The Minoan civilization was at its peak around 2500 BC.]
Narrative followed by exposition	Susan wanted to buy Tom a puppy as a Christmas present. She told him about the idea in advance. She went to the pet store last weekend. The Dalmatian puppies were the cutest. [+]The peak of Minoan civilization came about 1600 BC. [+]A century or so later, the Minoan palaces were mysteriously destroyed. [+]Historians have speculated that a great eruption may have occurred on the island of Thera at a suitable time. [+]This could have been accompanied by tidal waves and earthquakes that led to destruction in Crete. T or F: Susan wanted to buy Tom a kitten. [T or F: The Minoan civilization was at its peak around 2500 BC.]
Narrative interrupted by exposition	Susan wanted to buy Tom a puppy as a Christmas present. [+]The peak of Minoan civilization came about 1600 BC. She told him about the idea in advance. [+]A century or so later, the Minoan palaces were mysteriously destroyed. She went to the pet store last weekend. [+]Historians have speculated that a great eruption may have occurred on the island of Thera at a suitable time. The Dalmatian puppies were the cutest. [+]This could have been accompanied by tidal waves and earthquakes that led to destruction in Crete. T or F: Susan wanted to buy Tom a kitten. [T or F: The Minoan civilization was at its peak around 2500 BC.]

Exposition followed by narrative	Neanderthal men walked erect and had big brains. Though they were in other ways more primitive than Homo sapiens, they represent a great evolutionary stride. One striking example is their use of technology to overcome the environment. For instance, we know from evidence that Neanderthal men wore clothes. [+]Chris picked Laura for the track team even though they hate each other. [+]He really wants to win the next meet. [+]He runs the 100 meter and the 500 meter events. [+]It takes a lot of dedicated practice to succeed at racing. T or F: Neanderthal man was more advanced than Homo sapiens. [T or F: Laura is Chris's best friend.]
Exposition interrupted by narrative	Neanderthal men walked erect and had big brains. [+]Chris picked Laura for the track team even though they hate each other. Though they were in other ways more primitive than Homo sapiens, they represent a great evolutionary stride. [+]He really wants to win the next meet. One striking example is their use of technology to overcome the environment. [+]He runs the 100 meter and the 500 meter events. For instance, we know from evidence that Neanderthal men wore clothes. [+]It takes a lot of dedicated practice to succeed at racing. T or F: Neanderthal man was more advanced than Homo sapiens. [T or F: Laura is Chris's best friend.]

Note: Each participant was presented with two passages from this set, the two mutually-exclusive passages of the same presentation type (a. and c., or b. and d., for example).

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