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Interruption-similarity effects during discourse processing

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Abstract

We examined the effect of interruption on reading to determine if discourse processing is susceptible to similarity-based interference. Participants read pairs of passages, either one before the other (in the continuous condition) or with the sentences of the two passages interleaved (in the interruption condition). In addition, the similarity of the types of passages (narrative or expository) in a pair was manipulated. Performance was measured with self-paced reading time of the sentences and with accuracy in answering comprehension questions. In two experiments, interruption slowed the reading of text sentences; this effect of interruption was greatest when the interrupting text was of the same style as the primary text (an interruption-similarity effect). We discuss these results with respect to current models of the role of working memory in discourse processing.

Current memory models offer differing character-isations of the information that is maintained and manipulated in working memory during cognitive tasks, and of the structure of working memory itself. Our interest in this paper is in the nature of working memory underlying language comprehension, particularly as it handles interruption during reading. Different views of working memory in language processing lead to different predictions about how interruption should affect the process of reading comprehension.

A great deal of research on text memory has demonstrated that some elements of a text (such as the semantic relationships among entities, or situational aspects) are remembered better (with more accuracy and over greater periods of time) than other elements (such as the exact wording of a particular sentence; Bransford & Franks, 1971; Sachs, 1967). This suggests that different types of information from a text are represented and organised differently in memory. Several researchers have described the processes by which text representations are created and maintained (Frederiksen, 1975; Graesser, 1981; Jarvella, 1979; Meyer, 1975). Kintsch and his colleagues (Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983; see also Kintsch, 1985, 1994; Kintsch, Welsch, Schmalhofer, & Zimny, 1990) have described three ways in which linguistic information is represented. The surface representation captures several aspects of the text (including lexical and syntactic information) verbatim, and is thus an exact mental representation of the text. The propositional or semantic representation captures the meaning of a text at both a local and a global level. Finally, the situational representation is further removed from the given text than the other two, and represents those aspects of prior knowledge that are triggered by the reading of the text; it is thus a representation based on schematic knowledge. The construction-integration model of discourse processing (Kintsch, 1988; see also Goldman & Varma, 1995; Kintsch, Britton, Fletcher, Kintsch, Mannes, & Nathan, 1993;

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Kintsch & Welsch, 1991) and its predecessors (Kintsch, 1985; Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983) were developed to describe the processes by which these representations, at their different levels, are created during comprehensive reading.

Other models offer mechanisms by which similar processes could occur across general cognitive domains, including (but not limited to) text processing (Anderson & Lebiere, 1998; Ericsson & Kintsch, 1995; Gernsbacher, 1990). Models developed from fuzzy-trace theory (Brainerd & Reyna, 2004; Reyna, 1995; Reyna & Brainerd, 1995; Reyna & Kiernan, 1994), for example, differentiate between verbatim memory (an item-specific or integrated representation of surface form) and gist memory (an elaborated, semantic, relational representation about an item), both of which are formed and stored simultaneously (in parallel) for any given item or event. Verbatim and gist traces can be dissociated at retrieval, as demonstrated in experiments with conditions that provide surface-level retrieval cues (and thus encourage reliance on verbatim traces) or semantic retrieval cues (encouraging reliance on gist traces). However, because verbatim traces are not maintained as well as gist traces over time, there may come a point where the type of retrieval cue matters little. These principles of fuzzy-trace theory could be applied to explain some of the existing research on memory for text, in which a reader's goal is to extract a semantic representation from a surface-level one (Reyna & Kiernan, 1994).

Certain general features that are fundamental to discourse processing are captured within all of these models. As text is processed, new information is integrated with representations of information derived from previous text at the level of the sentence and the discourse. Without this integration, reading has no coherence. During this process, some parts of a text may be maintained in memory, while other parts may be lost, or incorporated into a new level of representation. The reader's prior knowledge will influence the types of representations that are formed and the types of processing that are undertaken. These models imply or directly stipulate a role for working memory in this process of integration; previously processed information must be *maintained* in some form, and is available for further *manipulation* once new text is encountered.

To the extent that working memory is essential to the process of discourse integration, preventing the operation of working memory should interfere with reading comprehension. Because of its limited capacity, one way in which the operation of working memory during reading might be disrupted is by the presentation of extraneous information that is not directly related to the text itself, but that demands processing of some kind; in other words, by interrupting the processing of the text with some additional task. Further, the relationship between the text and the interrupting material might be informative about the representational contents of working memory at the time of the interruption.

Glanzer, Dorfman, and Kaplan (1981) introduced the reading interruption paradigm, in which they attempted to disrupt the maintenance of sentences in memory by imposing a distractor task (in two experiments using addition problems and in two experiments using a counting task) between sentences in a paragraph. In a self-paced reading paradigm, participants who read interrupted paragraphs showed longer reading times of the critical sentence after the interruption than did participants who read the same sentence in a continuous paragraph; however, their ability to answer comprehension questions about the paragraph was undiminished by the interruption. In subsequent experiments, Glanzer, Fischer, and Dorfman (1984) used several different types of interruption tasks: addition problems (one experiment), the reading of unrelated sentences (one experiment), or the reading of two passages interleaved with each other (three experiments). They showed that these effects were not due primarily to a shift in cognitive operations (from a reading to an arithmetic task and back), but were due instead to the effect of the disruption on the contents of working memory. Furthermore, the interruption effect was not diminished by reinstatement of thematic information after the distractor sentences but *was* countered by reinstatement of the last one or two sentences that preceded the interruption. These results, then, supported the claim that verbatim (not thematic) information is what must be maintained in memory for coherent processing of the text.

In another four experiments (using the reading of unrelated sentences, digit recall, and addition problems as distractors), Fischer and Glanzer (1986) continued research with the interruption paradigm with a manipulation of dependency. They argued that the surface form of information is needed in memory for resolution of reference between expressions before and after the distractors. They operationalised dependency as the use of sentences containing reference and conjunction within a discourse, and found that while dependent passages were read more quickly than independent ones in the continuous condition, this pattern was reversed in the interrupted condition. Although additional evidence suggested that working memory might also contain some kind of thematic representation, Fischer and Glanzer (1986) concluded that it is best characterised as the repository of a surface representation of the text.

In summary, Glanzer and colleagues took their results to support a model in which the role played by working memory in text processing is one of maintaining surface-level structural information. Discourse integration is hindered by the loss of this verbatim information that occurs during the processing of unrelated material, but it is not prevented entirely; comprehension (as indexed by question accuracy) still occurs, but with greater effort of processing (as indexed by reading times).

Ericsson and Kintsch (1995) offered a different interpretation of Glanzer et al.'s results within the framework of their model of long-term working memory (LT-WM). This model was developed, in part, as a way of understanding the extraordinary memory performance of experts for large amounts of information related to their specific domain of expertise, even over extended periods of time (Chase & Ericsson, 1981, 1982; Chase & Simon, 1973a,b; Ericsson & Polson, 1988; Ericsson & Staszewski, 1989; Simon & Chase, 1973). According to the LT-WM model, experts in a given domain create elaborate retrieval structures in long-term memory. Current information that is relevant to their domain of expertise can be maintained in these retrieval structures, and can be accessed quickly and accurately via retrieval cues that are stored in short-term working memory (ST-WM). Because this representation of knowledge is within long-term memory, it can be maintained over long periods of time. This extension of working memory into long-term memory depends on the satisfaction of several conditions. First, in order to rapidly store information in retrieval structures in long-term memory, a person must have a large body of knowledge relevant to the information to be stored; in other words, he or she must have expertise in the domain of the information. Second, the conditions in which the new information will be used must be very familiar to the person (to allow the anticipation of future retrieval demands). Third, reliable and appropriate retrieval cues must be formed (so that on retrieval, the cue reinstates some of the conditions of encoding and thus assists with retrieval). The use of these rapidly formed, rapidly accessed retrieval structures in long-term memory (along with their associated retrieval cues) allows experts to circumvent the limited capacity of STWM, and can account for the skilled memory effect. This use of LT-WM by experts does not eliminate the use of ST-WM for the maintenance of some aspects of domain-specific information; indeed, ST-WM is implicated in the maintenance of the associated retrieval cues, or in their manipulation upon reinstatement if they are not maintained.

Language comprehension is one type of processing in which LT-WM could play a role. Ericsson and Kintsch (1995) suggest that skilled readers have expertise in the domain of reading, and that, combined with the organisation of text, allows the creation and use of organised retrieval structures in long-term memory. Different types of information might be represented and organised differently in ST-WM and in LT-WM. For instance, skilled readers might represent some surface-level or structural information about a text in ST-WM in the traditional, temporary way; this would allow access to this information for enough time to process it fully and to represent its propositional and situational features. Readers might then represent this semantic and situational information about a text in organised retrieval structures in LT-WM, where it will enjoy the extended accessibility necessary for its integration with other parts of a discourse. Retrieval cues (encountered in subsequent text) would allow the rapid and accurate retrieval of these semantic and situational representations from LT-WM whenever they are needed for further discourse integration.

Ericsson and Kintsch (1995) described interruption as one way of evaluating their model of long-term working memory. Interruption disrupts the contents of short-term working memory, but should not affect the maintenance of information in long-term working memory, which should be accessible after an interruption if the proper retrieval cues are reinstated in short-term working memory. Ericsson and Kintsch interpreted Glanzer et al.'s (Fischer & Glanzer, 1986; Glanzer et al., 1981, 1984) results from the interruption paradigm as being consistent with the long-term working memory model. They equated the Glanzer model of working memory as a system that maintains verbatim information, with their structure of short-term working memory; the propositional or situational representation of a text would be maintained in their additional structure of long-term working memory. The longer reading times following an interruption in Glanzer et al.'s data were interpreted as reflecting the time needed to access the pre-interruption text information from a LT-WM retrieval structure after the reinstatement of retrieval cues in short-term memory that occurs when reading of the passage is resumed. They attribute the lack of an effect of interruption on comprehension to the fact that the semantic information about the passage is still accessible in long-term working memory and is not itself disrupted in any way. Accordingly, this interpretation posits that a structural representation of the text in short-term working memory should be disrupted by interruption by unrelated material, but a semantic and situational representation of the text in long-term working memory should not be so affected.

Elaborating on these ideas, McNamara and Kintsch (1996) described circumstances under which the disruption of reading would be exacerbated. Text comprehension depends on the integration of newly processed information with that maintained in LT-WM from earlier parts of a text, accessed by means of retrieval cues in ST-WM. Reading will thus be hindered to the extent that (a) there are no retrieval structures in LT-WM; or (b) there are no retrieval cues in ST-WM. McNamara and Kintsch tested this prediction by manipulating two factors in a reading-interruption experiment that they believed would prevent or at least interfere with the creation and maintenance of retrieval structures in LT-WM. First, they included a mid-sentence interruption condition, under the assumption that a full retrieval structure would not have been constructed by that point during reading. Second, they used difficult texts from domains that were unfamiliar to the readers, so that readers would be unable to rely on background knowledge to assist in the creation of retrieval structures. They reasoned that if retrieval structures are not available in LT-WM, the retrieval cues in ST-WM (encountered during the reinstatement of the text following the interruption) will not quickly and efficiently access previously read information; instead, more elaborate, complex, and time-consuming retrieval operations would have to be undertaken, with costs to reading time and/or comprehension.

Their results supported this interpretation. When interruptions (in the form of unrelated sentences or arithmetic problems) were presented between sentences, they found a slowing of reading times of approximately 400 ms upon resumption of the passage, replicating Glanzer et al.'s findings. In addition, they reported an interaction of interruption position and text difficulty, such that when difficult texts were interrupted mid-sentence, reading times following the interruption were slowed by approximately 1.5 seconds, a result that is taken to reflect the engagement in this condition of more effortful retrieval operations by readers due to the lack of an organised retrieval structure in LT-WM. In all cases, comprehension, as assessed by a text recall measure, was unaffected by interruption.

The current experiments manipulated text similarity, a factor that should also lead to difficulty in creating, maintaining, and accessing retrieval structures for texts in LT-WM. Participants were asked to read four-sentence narrative and expository texts in a self-paced reading paradigm. Each text was paired on presentation with another text, either 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 differed along such dimensions as word frequency (with similar log frequency for the two types of passages but greater variability within the expositions; narratives: $M = 298.0$, $SD = 35.0$; expositions: $M = 305.0$, $SD = 56.0$); passage length (narratives: $M = 34.53$ words, $SD = 4.45$; expositions: $M = 51.80$ words, $SD = 7.85$); and syntactic complexity. Thus, two passages of the same type were more similar to each other stylistically than passages of different types (Dymock, 1999; Petros, Bentz, Hammes, & Zehr, 1990; Singer, Harkness, & Stewart, 1997; Weaver & Bryant, 1995); in other words, they differed at the representational level of the text genre (Biber, 1988; Graesser, Millis, & Zwaan, 1997). Further, latent semantic analysis (LSA; Landauer & Dumais, 1997) was used to establish that genre similarity was associated with semantic similarity. The passage pairs were presented in a continuous format (in which the reader saw all four sentences of the primary passage, followed by the four sentences of the secondary passage) or in an interleaved format (in which the reader saw sentence 1 of the primary passage, followed by sentence 1 of the secondary passage, followed by sentence 2 of the primary passage, then sentence 2 of the secondary passage, etc.; see Table 1 for an example).[1]

If text retrieval structures of the type proposed by Ericsson and Kintsch (1995) are created and maintained in LT-WM, we might expect them to be subject to some of the same influences that have been demonstrated to affect long-term memory performance. Memory researchers have clearly and reliably demonstrated that memory for items is impaired by the subsequent presentation of similar items (Baddeley, 1966; Shulman, 1970; Waugh & Norman, 1965; Wickelgren, 1965); most accounts of this difficulty attribute this effect to interference among similar items (Dempster & Brainerd, 1995). We expected that similarity would make the creation and maintenance of text retrieval structures (or their reinstatement following an interruption) more difficult, resulting in extended reading times after an interruption by a similar text.

Experiments 1 and 2 were designed to test this prediction. The experiments were the same except for two changes in the second experiment that were designed to exacerbate the effects of interruption (see below). All other aspects of the design of the experiments were the same; because of the similarities between the two experiments, they are presented with a single method section.

EXPERIMENTS 1 AND 2

Method

Participants—A total of 64 undergraduate students at the University of North Carolina served as participants in each of the two experiments, for a total of 128 participants. They received credit for an introductory psychology course for their participation.

Stimulus materials—A total of 40 four-sentence narrative passages and 40 four-sentence expository passages were constructed for the experiments. The narratives consisted of short

[1]We use the terms “primary” and “secondary” here for the sake of exposition; these terms refer only to the order of presentation of the two passages on a given trial.

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. Table 1 presents an example of the passages.

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 counterbalanced stimulus pairs were created by varying primary-passage type and secondary-passage type, with each combination appearing equally often. Each participant saw the two mutually exclusive pairs from each set of four, for a total of 40 pairs containing two unique passages each. The presentation of the items could be either continuous or interleaved, and each item was presented in each form an equal number of times. An example of the eight versions of one set (based on a crossing of primary-passage-type by secondary-passage-type by presentation) can be seen in Table 1. The serial position of a passage in the various pairs (whether the passage appeared first or second) remained constant for that passage.

In Experiment 1, 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. 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. These explicit cues were removed in Experiment 2 to see if the effect of interruption would be exacerbated in their absence. In both experiments, participants were 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. In both experiments, in the interleaved condition, the presentation of the paragraphs alternated after each sentence; the participant read the first sentence from the primary passage, then the first sentence from the secondary passage, then the second sentence from the primary passage, etc., until all four sentences from both passages had been presented.

In Experiment 1, a single 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 primary passage of the pair, and the other half referred to the secondary passage. In Experiment 2, each trial included two comprehension questions for each item, one referring to the primary passage and one referring to the secondary passage (see Table 1). The order of the questions in Experiment 2 was counterbalanced, such that on half of the trials, participants answered a question about the primary passage first, and on the other half they answered a question about the secondary passage first.

LSA analysis—As is apparent from the examples in Table 1, there are substantial semantic and stylistic differences between the narratives and expositions that were used as stimuli. In order to provide an objective, quantified measure of these differences, the similarity in meaning between narratives and expositions was analysed using Latent Semantic Analysis or LSA (Landauer & Dumais, 1997). LSA is a computational technique for automatically extracting the meanings of words based on patterns of lexical co-occurrence in a corpus. It represents word meaning as a vector in a high-dimensional space. The meaning of a sentence is a vector created by summing the vectors of the words that the sentence contains. The similarity in meaning between a pair of sentences is given by the cosine of the angle between the two sentence vectors. This scale ranges from 1 to −1, with 1 representing maximum similarity and 0 representing no similarity. We used LSA to estimate semantic similarity between successive sentences in experimental passages as a function of genre, thereby providing an assessment of whether passages of a given type are more similar than passages of a different type. This analysis was done using the LSA corpus called "General Reading up to First-Year College", using the default value of 300 dimensions. Continuous and interleaved passages were analysed separately.

Table 2 shows the internal similarities between successive sentences for narratives and for expositions occurring as the first and the second passages in non-interleaved conditions. Passage-internal similarity did not differ significantly between narratives and expositions for either first passages, $F(1, 38) = 2.94$, $p = .094$, or second passages, $F(1, 38) < 1$. The results for interleaved passages are shown in Table 3, which presents the similarities between the second, third, and fourth sentences in each passage to the sentence from the other passage that immediately preceded it in the experimental stimuli. Overall, these similarities between sentences of different passages are, as expected, notably smaller than the similarities observed within passages. The crucial issue is whether the similarities are higher in the matched condition than the non-matched condition. They were for both the first passage, $F(1, 38) = 40.7$, $p < .001$, and the second passage, $F(1, 38) = 24.3$, $p < .001$.

In summary, there were highly reliable effects showing that similarity between the sentences of two different narratives or two different expositions was greater than between the sentences of a narrative and an exposition. While it is doubtful to us that LSA captures all of the meaning in a text, the results of this objective, quantitative analysis are consistent with the impressions created by examining the experimental materials.

Design and procedure—Both experiments involved a 2 ×2 ×2 factorial design, with the three independent variables (interruption, similarity, and type of primary passage) manipulated within subjects.

An additional eight pairs of passages (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 and 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(s) appeared on the screen and remained until the participant had entered a response using labelled keys.

Results: Experiment 1

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, we have done separate analyses on the reading times per word for the first sentence and for the average of the second through fourth sentences. Preliminary analyses that included text genre as a factor found a main effect of genre (narratives were read more quickly than expositions); however, because this factor did not interact with the variables of interest, we present analyses collapsed across this factor. We thus included interruption, similarity, and the interaction of these variables in our analyses.

Primary passage—Reading times are shown in Table 4. The presentation to the reader of the first sentence of the primary passage of a pair was always the same, regardless of the experimental condition; it is therefore not surprising that we found no significant effect of interruption, similarity, or the interaction of the two variables on the reading times of this sentence. We 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 primary passage.

Secondary passage—Figure 1 depicts the mean reading times per word for the first sentence of the secondary passage. There was a main effect of interruption on the reading times of this sentence, $F_1(1, 63) = 21.43$, $p < .001$ (by subjects), $F_2(1, 19) = 32.93$, $p < .001$ (by items); 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 by similarity interaction; the disruptive effect of interruption on the reading of the first sentence of the secondary passage was greater when that secondary passage was paired with a primary 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 4 shows that when reading the subsequent three sentences of the secondary passage, readers continued to experience a disruptive effect of interruption, $F_1(1, 63) = 48.11$, $p < .001$, $F_2(1, 19) = 19.43$, $p < .001$, but recovered from the moderating effect of similarity on interruption (F_1 and F_2 <1).

Comprehension question accuracy—Participants did not show a significant difference in their ability to answer questions that referred to the primary or secondary passage of each pair, F_1 and F_2 <1; we 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 5.

Interruption did not have a significant effect on participants' question-answering accuracy, $F_1(1, 63) = 1.74$, $p = .191$, F_2 <1, nor was there a significant effect of match of passage type on question accuracy, $F_1(1, 63) = 2.68$, $p = .107$, $F_2(1, 19) = 3.37$, $p = .088$. No interactions of the experimental factors were significant.

Results: Experiment 2

Reading time—Analyses were performed in the same manner as in the preceding experiment.

Primary passage—Reading time results are shown in Table 6. As in Experiment 1, the presentation to the reader of the first sentence of the primary passage of a pair was always the same, regardless of the experimental condition, and again we found no significant effect of interruption, similarity, or the interaction of the two variables on the reading times of this sentence. In this second experiment, in which we strengthened our manipulation of interruption, we found a main effect of this variable on the reading times of the second, third, and fourth sentences of the primary passage; participants read these sentences more slowly when they were interleaved with the sentences of the secondary 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).

Secondary passage—Figure 2 depicts the mean reading times per word for the first sentence of the secondary passage. As in Experiment 1, 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 by similarity interaction; the disruptive effect of interruption on the reading of the first sentence of the secondary passage was greater when that second passage was paired with a primary 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 6 shows that readers continued to experience a disruptive effect of interruption, $F_1(1, 63) = 20.79$, $p < .001$, $F_2(1, 19) = 26.07$, $p < .001$, but recovered from the moderating effect of similarity on interruption (F_1 and F_2 <1), when reading the subsequent three sentences of the secondary passage in a pair.

Comprehension question accuracy—In Experiment 2, two comprehension questions were asked on each trial, one referring to the primary passage in the pair, and one referring to the secondary passage. The order in which these were asked was counterbalanced, such that half the time the first comprehension question referred to the primary passage, and half the time it referred to the secondary passage. When we analysed the responses to these comprehension questions separately, we found that participants did not show a significant difference in their ability to answer second questions that referred to the primary (on half of the trials) or secondary (on the other half of the trials) passage of each pair, F_1 and F_2 <1. We therefore analysed 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 7. 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. No interactions of the experimental factors were significant. There was no significant difference in participants' ability to answer the second comprehension question based on experimental condition.

Discussion

We investigated the prediction from the long-term working memory model (Ericsson & Kintsch, 1995) that factors that influence the creation and maintenance of, and access to, semantically organised retrieval structures in LT-WM will affect reading times during the processing of text. Interruption by semantically and stylistically similar text was predicted to be such a factor, based on previous research that demonstrates an effect of similarity on memory performance. We conducted two 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 both experiments, the passages of a pair were interleaved after a single sentence. In Experiment 1, 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 2, this cue was removed. Additionally, in Experiment 1, participants answered only one comprehension question (referring to either the first or the second passage in a pair), whereas in Experiment 2 we presented participants with two comprehension questions, one about each passage in the pair.

Our results show that the similarity between the text and the interrupting material does affect ease of comprehension as measured by reading times. We found a main effect of interruption on reading times in both experiments, replicating previous results using this paradigm (Fischer & Glanzer, 1986; Glanzer et al., 1981, 1984; McNamara & Kintsch, 1996), and supporting the notion that the maintenance of text information in memory is affected by interruption. Importantly, we found that the initial reading of the second passage in a pair was disrupted more if the first passage in the pair was of a similar type than if it was of a dissimilar type. This effect is not easily reconciled with the view proposed by Glanzer and colleagues that what is crucial in working memory to text processing is the maintenance of verbatim information. Such an account does not predict any effect of similarity on the magnitude of the effect of interruption; it is difficult to see a role for the influence of semantic similarity within a framework describing the maintenance of surface-level information by readers in working memory. Within such a framework, the magnitude of the effect of interruption might be influenced by the *amount* of extraneous material presented (in that representing larger amounts of verbatim information will tax working memory resources, at least within a capacityconstrained model). It is unclear, however, how such a model would account for the influence of the *type* of intervening material.

On the other hand, this effect is consistent with the predictions of the long-term working memory model, which suggests that the construction and maintenance of separate retrieval structures for the two texts in LT-WM will be made more difficult by similarity, a source of interference. This view, then, proposes a moderating function for the type of material being read, in that material that makes semantic organisation in long-term memory more difficult will exacerbate the disrupting effects of interruption on reading. According to the LT-WM model, the semantic similarity of two passages of the same genre leads to interference in long-term memory, and hinders the creation and maintenance of organised text retrieval structures, or the access to such structures following an interruption.

In both experiments, this similarity-by-interruption interaction was localised to the reading of the first sentence of the second passage, suggesting that the difficulty due to similarity arose during the establishment of the retrieval structure of the second passage (or the laying of the discourse foundation; Gernsbacher, 1990). Readers were subsequently equally able to access this retrieval structure, once established, in the matched and non-matched conditions, once retrieval cues were reinstated. It seems, then, that during text processing, interference by a similar passage leads to difficulty in establishing a new memory trace for incoming material. This finding adds to the results described by McNamara and Kintsch (1996) by suggesting a third mechanism by which reading might be hindered by interruption: not only can reading be slowed by a lack of retrieval structures, or by a lack of available retrieval cues, it can also be affected by the ease or difficulty of creating retrieval structures in the first place. All three mechanisms are consistent with the LT-WM account, in demonstrating the importance of elaborate semantic retrieval structures in reading.

Our results are also consistent with more general cognitive models that have been used to account for memory for text. Within fuzzy-trace theory, for example, one would expect the formation of both verbatim and gist memory traces during text processing. Previous research (Brainerd & Reyna, 1993, 2004) has shown that manipulations of task will dictate reliance on one memory trace or another at any given time. Our use of comprehension questions (that did not necessarily preserve the surface form of the text, and which often demanded integration across different sentences of a passage for a correct response) probably encouraged a reliance on gist. The relatively good performance on the comprehension question task suggests that gist traces are maintained even in the face of an interruption (although the decrement in the second experiment for some questions suggests that strong manipulations of interruption interfere with gist representation). On the other hand, the reading time data suggest that the formation of gist traces may be susceptible to semantic interference during text processing. Within this framework, it would be interesting to see if the use of other behavioural tasks, ones that encourage reliance on verbatim memory, would show similar or different effects of interruption during reading. Some results from our own lab, using the probe-word technique (in which participants are asked to respond as quickly as possible whether a given word was part of the passage they had just read), suggest that verbatim memory is much more susceptible to interruption; that is, performance (as assessed by reaction time and accuracy measures) in responding to a memory probe is worse following an interruption by unrelated text, even when gist memory (as measured by comprehension question accuracy) for the same passages is spared (Ledoux, 2003).

The interruption paradigm described here was based on the one developed by Glanzer and colleagues in a series of reading experiments (Fischer & Glanzer, 1986; Glanzer et al., 1981, 1984). Although highly similar, both our materials and our results differed from theirs in some ways. Perhaps the biggest difference was the length of the passages; the earlier Glanzer experiments typically used longer experimental passages (usually consisting of eight sentences each) than did ours. Our choice of passages was determined by the ready availability and detailed character-isation of a set of narratives that had been used in several studies of co-reference in our lab (Gordon, Hendrick, Ledoux, & Yang, 1999; Gordon & Scearce, 1995). These passages included a direct, well-controlled manipulation of dependency that allowed a comparison of the effects of interruption on more- and less-dependent passages in a concurrent study, the results of which are described elsewhere (Ledoux, 1998).

The type of interrupting task used, and the method of interruption, also differed between our experiments and the previous ones. In some cases, Glanzer and colleagues used an unrelated distractor task that differed greatly from the primary task of reading (doing addition problems or recalling digits). When reading was used as the distractor task, the interrupting text was generally several sentences that were unrelated to the primary text and unrelated to each other. The three experiments that are most similar in design to those described here were reported by Glanzer et al. (1984), in which two passages were presented on each trial. In the interleaved condition, participants saw the first four sentences from the first passage consecutively before seeing the first four sentences of the second passage; they were then presented with the second half of the first passage, and finally the rest of the second passage.

It is, of course, possible that this difference in materials led to some of the differences in results that we see between our experiments and those of Glanzer et al. One such difference is the magnitude of the interruption effect; our results suggest a more moderate effect of interruption on reading time than that described previously, even in the three experiments that were most similar in design to ours. Glanzer et al. (1984) reported finding interruption effects on both passages in the pair, whereas our effects were limited primarily to the second passage. It is possible that the length of the passages used in our study, or the use of narrative passages half of the time, allowed readers to better handle the disruption caused by the interruption. Nonetheless, the finding of interruption effects on reading is of importance, especially in light of the interaction of this effect with passage similarity.

In summary, our two experiments used interleaved texts to examine the effect of interruption on reading. Our results support the view that a major role of working memory during language processing is the creation and maintenance of an elaborate, semantic representation of a text and the efficient retrieval of this representation from long-term memory.

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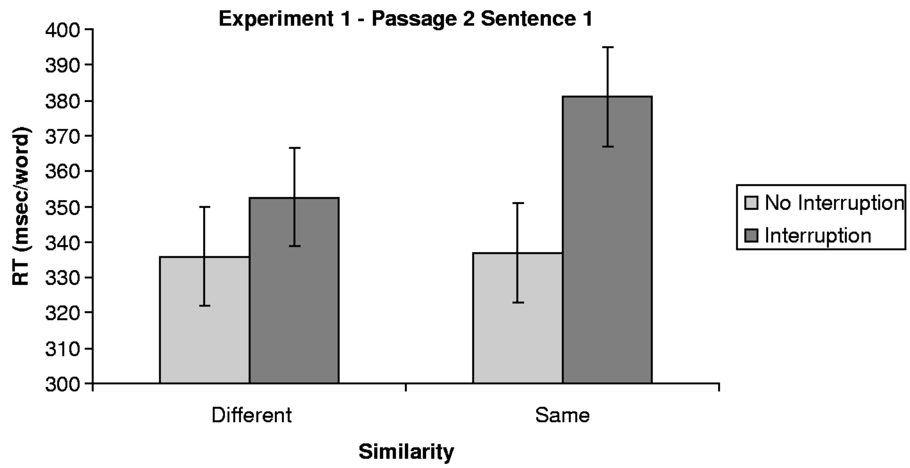

Figure 1.
Mean reading time per word (ms) for similar and dissimilar secondary passages in both continuous and interleaved presentation forms in Experiment 1.

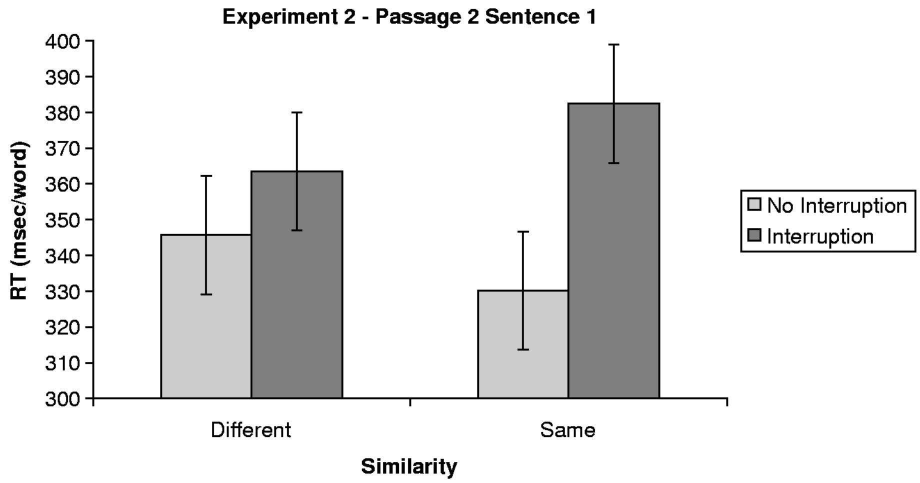

Figure 2.
Mean reading time per word (ms) for similar and dissimilar secondary passages in both continuous and interleaved presentation forms in Experiment 2.

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TABLE 1

Sample stimulus set

a. 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 metre and the 500 metre 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.]
b. 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 metre and the 500 metre 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.]
c. 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 civilisation 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 civilisation was at its peak around 2500 BC.]
d. Exposition interrupted by exposition	Neanderthal men walked erect and had big brains
	[+]The peak of Minoan civilisation 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 civilisation was at its peak around 2500 BC.]
e. 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 civilisation 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 civilisation was at its peak around 2500 BC.]
f. Narrative interrupted by exposition	Susan wanted to buy Tom a puppy as a Christmas present.
	[+]The peak of Minoan civilisation 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 civilisation was at its peak around 2500 BC.]

g. 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 metre and the 500 metre 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.]
h. 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 metre and the 500 metre 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.]

A sample stimulus set, created by combinations of a primary and secondary narrative and a primary and secondary exposition in continuous and interleaved forms. The plus signs (explicit markers of the secondary passage) were present in Experiment 1, but removed in Experiment 2. The second comprehension question was included in Experiment 2 (but not in Experiment 1). 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).

TABLE 2

Internal similarities between successive sentences of a passage as determined by LSA

	Narrative	***Exposition***
First passage	0.388	0.298
Second passage	0.344	0.314

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TABLE 3

Similarities between passages as determined by LSA

		Narrative	*Exposition*
First passage	Matched	0.052	0.125
	Non-matched	0.004	0.013
Second passage	Matched	0.037	0.113
	Non-matched	−.001	0.011

TABLE 4

Reading time: Experiment 1

Similarity	Presentation	Primary passage: Sentence 1	Primary passage: Sentences 2–4	Secondary passage: Sentence 1	Secondary passage: 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

Mean reading time per word (ms) at each sentential position for primary and secondary passages (in both continuous and interleaved presentation forms) in Experiment 1.

TABLE 5

Comprehension question accuracy: Experiment 1

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

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

TABLE 6

Reading time: Experiment 2

		Primary passage		Secondary 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

Mean reading time per word (ms) at each sentential position for primary and secondary passages (in both continuous and interleaved presentation forms) in Experiment 2.

TABLE 7

Comprehension question accuracy: Experiment 2

	First questions		***Second questions***	
	Continuous	***Interleaved***	***Continuous***	***Interleaved***
Same	84%	78%	85%	82%
Different	83%	82%	83%	84%

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