

# Visuospatial Cues for Reinstating Mental Models in Working Memory During Interrupted Reading

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Reading involves constructing a mental representation in long-term working memory of the world described by the text. Disrupting short-term working memory can interfere with the maintenance of mental models (sets of retrieval cues) needed to access these representations, producing detrimental effects on reading time. In two experiments, subjects read passages that included pairs of coreferential sentences interrupted by unrelated text. As in previous research, reading times increased for the first sentence after the interruption, likely reflecting a reinstatement process for mental models in working memory. In the present research, pictures were provided as visuospatial cues to aid the reinstatement process. The interruption effect was found to be smaller with pictures related to the passages than with unrelated pictures (Experiment 1) or titles (Experiment 2); however, both of these effects occurred only for slow readers. The authors hypothesize that slow readers take the time needed to integrate visuospatial information into their mental models, providing more resilient access to long-term working memory.

*Keywords:* reading, mental models, working memory, interruption, pictorial cues

Reading is a complex cognitive activity that involves constructing and maintaining coherent mental representations in working memory. Information derived from text must be stored, processed, and integrated with knowledge retrieved from long-term memory to understand the text. Mental models (Garnham, 1981; Johnson-Laird, 1983), situation models (van Dijk & Kintsch, 1983), and referential representations (Just & Carpenter, 1987) are all terms that have been used to describe the mental representations constructed by readers of the world described by the text. The goal of the present study was to explore the extent to which these mental models of text incorporate detailed visuospatial information. Using an interrupted reading procedure, we found that only some readers spontaneously include such information in their mental models, indicating possible differences in the strategies or cognitive abilities used in reading.

## Mental Models and Long-Term Working Memory

Our theoretical approach to mental models and reading is based on the theory of long-term working memory proposed by Ericsson and Kintsch (1995). They argued that highly skilled activities involve the construction of mental representations in long-term working memory and the maintenance of retrieval cues in short-term working memory. The long-term working memory representations are assumed to be relatively stable, whereas the retrieval

cues and their associated structures in short-term working memory are more transient. Thus, when short-term working memory is disrupted, retrieval cues may be temporarily lost and access to mental representations in long-term working memory may be impaired. Access can be restored by reconstructing the retrieval structure in short-term working memory. In reading, these retrieval structures can be construed as mental models that permit access to long-term working memory representations of the text (cf. Ledoux & Gordon, 2006; McNamara & Kintsch, 1996). This idea is similar to one proposed by Glenberg and Langston (1992), who argued that the constituent elements of mental models serve as pointers to more detailed information represented in long-term memory.

To support their concept of long-term working memory, Ericsson and Kintsch (1995) cited a number of studies by Glanzer and colleagues (Fischer & Glanzer, 1986; Glanzer, Dorfman, & Kaplan, 1981; Glanzer, Fischer, & Dorfman, 1984) that investigated what happens when reading is occasionally interrupted by performing a distractor task. The main finding in these studies was that reading time increased for the first sentence after the distractor task and then returned to normal levels for subsequent sentences. We will refer to the increase in reading time after the distractor task as the *interruption effect*. From the theoretical perspective of Ericsson and Kintsch, the interruption effect could be interpreted as follows: Before the interruption, short-term working memory holds the retrieval structure (i.e., the mental model) used to access the evolving mental representation of the text. The distractor task also requires the use of short-term working memory, and, as a consequence, the mental model may be displaced. The interruption effect represents the time needed to reinstate the mental model in short-term working memory as needed for accurate comprehension.

This interpretation is supported by the finding that the interruption effect is associated with situations in which textual information preceding the interruption is needed for comprehension. For

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example, the effect is found only with text that forms a coherent discourse (Glanzer et al., 1984; see also Lorch, 1993, Experiment 4). In addition, the interruption effect is greater for sentences linked by coreference or conjunction than for sentences that have no such links (Fischer & Glanzer, 1986). It has also been found that the interruption effect is greater when the interruption occurs in the middle of a sentence than when it occurs between sentences, especially with difficult text (McNamara & Kintsch, 1996).

An implication of this analysis is that providing readers with suitable cues after the interruption should improve their ability to reinstate their mental models and thereby reduce the interruption effect. Glanzer et al. (1984) found that presenting a thematically related cue word or repeating an earlier sentence from the text did not reduce the interruption effect. However, repeating an earlier sentence that was coreferential with the current sentence or repeating the two sentences preceding the distractor task did reduce the effect. Using a similar procedure, Lorch (1993) provided cues for information from the sentence immediately preceding the interruption or from the paragraph in which the interruption was embedded. Both types of cues were effective at reducing the interruption effect, even when the first sentence after the interruption did not include references to previous text (Lorch, 1993, Experiment 3). Our interpretation of these results is that the distractor task displaces the mental model maintained in short-term working memory, and that this mental model is needed as a retrieval structure in the comprehension of coherent text. If an effective cue is provided that allows one to reinstate this information, the interruption effect is reduced.

### Visuospatial Information in Mental Models

Based on this interpretation, we used the interruption effect to identify the role of visuospatial information in mental models. The mental models constructed during reading are multidimensional in that they may contain information about spatial, temporal, or object-based properties of the text under various circumstances (Zwaan & Radvansky, 1998). Indeed, many researchers have demonstrated that mental models can include detailed visuospatial information under at least some conditions. For example, Bower and colleagues (Bower & Morrow, 1990; Morrow, Bower, & Greenspan, 1989; Rinck & Bower, 1995) conducted a series of experiments in which subjects memorized a building floor plan, then read statements about a protagonist moving from room to room. They found that subjects were faster at reading statements about objects in close proximity to the protagonist, suggesting that subjects had used the memorized floor plans as part of their mental models for interpreting the text. However, intentionally memorizing spatial layouts may have induced task demands that are unlike those usually encountered in reading. For example, Wilson, Rinck, McNamara, Bower, and Morrow (1993) suggested that readers may not always construct mental models with detailed spatial fidelity.

There is other evidence for the role of visuospatial information in mental models that does not involve memorizing elaborate spatial configurations. For example, Glenberg and Langston (1992) found evidence that providing visuospatial information may induce spatial properties in mental models when such properties might not otherwise be present. They required subjects to read procedures that were sometimes accompanied by flowcharts.

A key manipulation was that a critical pair of steps in some of the procedures had to be performed concurrently. In the text, these steps could only be mentioned serially, whereas in the flowchart they could be depicted in parallel. After reading the texts, subjects were probed regarding the correct ordering of different elements in the procedures. Accuracy was higher when a flowchart had accompanied the text than when it was absent, one of many results that led Glenberg and Langston to infer that the structure of readers' mental models resembled the flowcharts rather than the linear structure of the text and that the spatial properties of the flowcharts were being used to enhance their mental models. Glenberg and Langston proposed that the construction of mental models could involve the integration of text and pictorial information as a form of "working memory management" that facilitates the noticing of relationships and generation of inferences required for adequate comprehension. This idea is consistent with the argument by Glenberg and McDaniel (1992) that readers can use organizational knowledge derived from visuospatial information in pictures and combine it with their prior knowledge when constructing a mental model.

Readers can also construct mental models containing visuospatial information derived solely from text. For example, Tversky and colleagues (Bryant, Tversky, & Franklin, 1992; Franklin & Tversky, 1990) conducted experiments in which subjects read narratives describing naturalistic scenes and were probed as to the locations of objects around observers in the scenes. No external visual aids (e.g., pictures, maps, or diagrams) accompanied the narratives; therefore, subjects had to determine where objects were located by incorporating and accessing three-dimensional spatial information in their mental models of the text. Probe response times indicated that subjects constructed spatial frameworks involving three axes (above/below, front/back, and left/right) based on body characteristics and relations of the body to the physical world. Although this research suggests that mental models can include detailed spatial information, it is unclear whether such information is typically extracted from text that does not have an overtly spatial character.

An indirect approach to demonstrating the visuospatial content of mental models was taken by Fincher-Keifer (2001). In her experiments, subjects read short texts while processing resources were taxed with a secondary task. In the first experiment, a spatial processing load was incurred by maintaining high-imagery sentences in memory; in the second experiment, subjects retained an array of dots. The generation of a mental model was assessed by measuring the contradiction effect—the increased time needed to process sentences that are inconsistent with an earlier statement in the text (e.g., O'Brien & Albrecht, 1992). In both experiments, the contradiction effect was reduced when the text was read with a concurrent spatial-processing load but not with other types of load, suggesting that mental models have a visuospatial component. However, because the contradictions generally did not pertain to spatial or pictorial aspects of the mental model, the results do not speak to the degree of visuospatial fidelity or detail that readers generally incorporate in their mental models.

Zwaan, Radvansky, Hilliard, and Curiel (1998) found evidence that spatial relationships are included in mental models only if that information is relevant to readers' goals. They examined reading time as a function of the nature of discontinuities in the text. Although there were clear effects of discontinuities in the mental

model with respect to goal, protagonist, time, and causation, spatial discontinuities only had an effect when subjects had been familiarized with the spatial layout described in the narrative (reminiscent of the approach of Bower and colleagues described above). Thus, these results suggest that spatial content in mental models is normally either absent or not very detailed unless readers are motivated to use such information. This conclusion is consistent with the results of Tversky and colleagues (Bryant et al., 1992; Franklin & Tversky, 1990); in those experiments, the spatial information in the text had to be represented in readers' mental models if they were to perform accurately on the probe task. In sum, previous research suggests that visuospatial information may be incorporated in mental models under some circumstances, but it remains unclear how much detail is involved and precisely what conditions induce the use of such visuospatial information.

### Individual Differences in the Use of Visuospatial Information

Glenberg and Kruley (1992) suggested that visuospatial information can facilitate reading comprehension by helping to reorganize working memory for easier access to critical information, but only for some readers. In support of this point of view, they conducted a set of experiments in which subjects read text that included anaphoric references that were contiguous ("near" anaphors) or separated by intervening sentences ("far" anaphors). A detailed diagram was sometimes present when reading the anaphors. Glenberg and Kruley found an anaphoric distance effect (slower reading of far anaphors) only when a picture was present. Critically, when subjects were divided into fast and slow readers, they found that although slow readers took longer to process the far anaphors than fast readers, they had better comprehension scores than fast readers. This suggested that slow readers may have spent more time integrating visuospatial information from the pictures into their mental models in working memory, resulting in improved reading comprehension. Further support for this interpretation comes from Kruley, Sciamia, and Glenberg (1994), who implicated the visuospatial sketchpad (see Baddeley, 1986) in maintaining information from pictures in working memory.

These individual differences suggest that readers vary in how much visuospatial information they typically include in the mental models they generate from text. "High-detail" readers may generate rich representations that incorporate information concerning the specific visual appearance of objects, the orientation and position of elements of the mental models, and the spatial relationships amongst those entities. "Low-detail" readers may fail to encode or generate much of this information and maintain only minimal, schematic mental models that suffice to solve coreference problems while reading. Van den Broek's account of "standards of coherence" (van den Broek, Ridsen, & Husebye-Hartman, 1995) may be relevant for understanding this variation. He suggested that readers control the extent to which inference processes are engaged to identify coherent relationships amongst entities in mental models. In the present context, we hypothesize that high-detail readers may be those with high coherence standards who spend additional effort to represent spatial relationships in their mental models. It seems plausible to suppose that because of this additional processing, high-detail readers will generally be slower than low-detail readers. As a consequence, groups of fast and slow

readers will tend to represent low- and high-detail readers, respectively.

Several other sources of evidence are consistent with this analysis of the difference between fast and slow readers. For example, MacLeod, Hunt, and Mathews (1978) demonstrated that subjects could use either a verbal or a pictorial strategy for solving picture-sentence verification problems and that performance using these strategies was related to spatial skills. By extension, we conjecture that in narrative comprehension, there may be a spatial strategy for solving (for example) coreference problems that involves developing high-detail spatial mental models and a verbal strategy that involves developing more schematic mental models. Slow readers may be those who elect to use a spatial strategy, whereas fast readers may be those who use a verbal strategy. Other evidence indicates that the additional time needed to draw inferences (such as those involved in developing a high-detail mental model) is reflected in reading time. For example, Magliano (1999) noted that causal inferences in narrative comprehension required additional time in reading, and Day and Gentner (2007) found that additional time was taken in reading to draw analogical inferences. Similarly, an analysis of the results reported by Dixon, LeFevre, and Twilley (1988) indicates that when controlled for vocabulary, slow readers tended to perform better on a test of deep, model-based inferences. Of course, there are a number of other reasons why subjects might be fast or slow in reading speed, so such a grouping variable will only provide an imperfect index of spatial detail. For example, slow readers may be less adept at constructing mental models in general or less skilled at reading. Nevertheless, the hypothesis that slow readers are slow in part because they devote resources to drawing spatial and other inferences provides a possible interpretation of the results of Glenberg and Kruley (1992).

A general conclusion from studies of this sort is that "presenting pictures that depict the content of the text they accompany may facilitate the construction of a mental model" (Gyselinck & Tardieu, 1999, p. 197), at least for some readers. Integrating this conclusion with the long-term working memory theory of Ericsson and Kintsch (1995), we hypothesize that accompanying pictures can provide, for those readers, a visuospatial framework on which a mental model can be built. Roughly speaking, the picture may provide a stage that can be populated with the elements of the narrative as it unfolds. In this way, the picture can provide organizational and relational information that dictate how elements will be incorporated into the developing mental model. Moreover, because the mental model would be constructed to reflect the relations as they appear in the picture, the picture ought to provide an effective mnemonic for maintaining the mental model in short-term working memory, as long as readers take the time needed to generate a mental model with the requisite visuospatial detail. This analysis was evaluated in the present study.

### The Present Study

The purpose of the present study was to use the interruption effect to investigate the involvement of visuospatial information in mental models. In the reported experiments, pictures of the settings of narrative passages were provided as cues. Each pictorial cue provided both visual information about the setting (e.g., the appearance of the environment and some of the objects within it) and spatial information about the arrangement of objects and the nature

of the space in which the narrative takes place. We hypothesized that the visuospatial information in the pictures would provide spatial frameworks for mental models of the narratives for at least some readers. As a consequence, those pictures should constitute effective cues for the reinstatement of the mental models after an interruption. Our prediction was thus, that the interruption effect should be reduced when a contextually appropriate picture for the passage is provided as a cue, but only for those readers who incorporate detailed visuospatial information into their mental models. Such an effect would support our theoretical analysis of the interruption effect and would provide evidence for the use of pictorial information in the construction of mental models.

This study provides a number of advances over previous work. First, we sought to establish whether visuospatial information could modulate the interruption effect, just as verbal information is able to do (cf. Glanzer et al., 1984; Lorch, 1993). Such a result would support the analysis that the interruptions can interfere with the maintenance of spatial relations in a mental model. Second, instead of using artificial stimuli such as maps (e.g., Bower & Morrow, 1990), flowcharts (Glenberg & Langston, 1992), or diagrams (Glenberg & Kruley, 1992) for visuospatial information, we used real-world photographs as cues for narratives that did not have an overtly spatial character (cf. Franklin & Tversky, 1990). Thus, it would be difficult to attribute effects of the pictorial cues to unusual task demands or idiosyncratic characteristics of our materials. Third, we examined the effectiveness of pictorial cues as a function of reader characteristics (viz., reading speed). This allowed us to assess whether incorporating visuospatial detail in a mental model is common or only occurs under some circumstances or for some readers. Finally, in contrast to previous research, our pictures did not explicitly represent any of the critical information mentioned in the text in the region of the interruption. Instead, the pictures depicted a setting in which elements from the text might conceivably be placed. Thus, we evaluated whether the pictorial cues provide an effective mnemonic for mental models rather than merely information relevant to narrative comprehension. This last point is crucial because we think that pictures can provide a useful visuospatial context for constructing mental models even if they do not depict any central elements from the narrative.

### Experiment 1

In Experiment 1, we evaluated whether a pictorial cue accompanying a narrative text could reduce the interruption effect. The interruptions were spanned by anaphoric references, such that adequate comprehension required the reinstatement of textual information preceding the interruption. Three different cue conditions were associated with the text: no picture, related picture, and unrelated picture. A related picture depicted a plausible setting for a passage and provided appropriate contextual details, whereas an unrelated picture depicted an alternative and unlikely setting for a passage (e.g., a picture of an office accompanying a passage about activities in a kitchen). If our theoretical perspective has merit, then a related pictorial cue should reduce the interruption effect relative to the no-picture and unrelated-picture conditions. However, an alternative possibility is that any pictorial information might have some mnemonic benefit. If this were the case, both the related- and unrelated-picture conditions should show less of an interruption effect than the no-picture condition.

Based on our interpretation of the results of Glenberg and Kruley (1992), we suspected that the effect of a pictorial cue might be mediated by reading speed. As we indicated previously, it seems plausible to suppose that if readers vary in the extent to which they incorporate visuospatial detail into their mental models, this tendency should be correlated with the time taken to process the text. In particular, processing the visuospatial information in the narrative undoubtedly takes time, and consequently those readers who carefully attend to that information can be expected to be slower on average than comparable readers who do not. Because there are a range of other variables that contribute to reading speed, such a correlation is unlikely to be very high. However, examining the effects of a pictorial cue as a function of reading speed should provide at least a rough index of whether the use of visuospatial information in narrative comprehension is an important individual difference.

### Method

*Subjects.* Forty-eight undergraduate psychology students at the University of Alberta served as subjects in exchange for course credit. Subjects were divided into fast and slow reader groups based on a median split of the mean reading time per word for all nonmanipulated sentences from the narrative text in all cue conditions. (Nearly identical groupings were obtained using reading times from the no-picture condition only.)

*Materials.* The stimuli consisted of 16 pictures and passages and 48 comprehension questions. Each picture was a  $14.0 \times 10.5$  cm digital color photograph of a real-world setting with an on-screen resolution of 72 dpi. An example of a picture is shown in Figure 1, and an excerpt from the related passage is shown in Table 1. Each passage was related to one of the pictures in the stimulus set and was 31 sentences in length. A description of one or more persons engaged in a conventional activity in a fixed setting formed the substantive portion of each passage. Although a related picture depicted that setting, none of the characters and at most one or two items mentioned in the text appeared in the picture. Critically, none of the items mentioned in the coreferential sentences spanning interruptions appeared in the picture (e.g., the pen mentioned in the Table 1 excerpt does not appear in Figure 1).

In each passage, four pairs of coreferential sentences were selected as possible locations of interruptions. The first sentence in each pair contained a noun phrase used as a critical referent; the second sentence referred to that referent with a pronoun anaphor. The interruption locations were never within the first four sentences nor the last three sentences of a passage, and they were always separated by at least five sentences. For each passage, the interruption material consisted of eight expository sentences that were unrelated to the passage. (See Ledoux & Gordon, 2006, for results concerning the use of narrative vs. expository texts as the interruption material for narrative passages.) The unrelated interruption text for a given passage pertained to a single topic (chosen from a wide range of topics, with a different topic for each passage) and was divided into four pairs of sentences, one pair for each interruption. There were also two filler sentences for each possible interruption location that were constructed to fit naturally in the text just before the referent sentence (see Table 1). The filler sentences consisted of elaborative information that was related to



Figure 1. Picture related to the passage in Table 1.

the narrative text but did not add any new information that would affect the macrostructure of the passage.

The placement of the unrelated and filler texts with respect to the coreferential sentences in each passage is indicated in the excerpt in Table 1. In the *interrupted* condition, the two sentences of unrelated text were inserted between the coreferential sentences. This produced the sequence: referent sentence, unrelated sentence, unrelated sentence, anaphor sentence. In the *uninterrupted* condition, the unrelated material was not used (so the coreferential

sentences were adjacent), but the two lines of filler text were inserted before the referent sentence to equate the total number of sentences in the interrupted and uninterrupted portions of the text. This produced the sequence: filler sentence, filler sentence, referent sentence, anaphor sentence. Following the logic of Glanzer et al. (1984), the unrelated sentences were intended to interrupt the normal flow of the reading process and to interfere with the maintenance of a mental model for the narrative. Positioning the interrupting material between an anaphor and its referent was intended to create a circumstance in which that mental model would be critical for comprehension and hence likely to generate a large interruption effect.

Finally, three comprehension questions followed each of the passages. Two of these questions concerned information presented in the narrative text, whereas the remaining question concerned the general topic or theme of the unrelated text. The narrative questions generally required subjects to recognize paraphrases of the narrative sentences and to solve coreference problems. Subjects were informed that there were no questions directly concerning any of the pictures. The questions were in multiple-choice format with three possible responses.

*Design.* The experiment used a 3 (cue condition)  $\times$  2 (interruption condition)  $\times$  2 (reading speed) mixed design. Subjects were presented with one of the following cue conditions with each passage: no picture, related picture, or unrelated picture. The interruption condition refers to whether coreferential sentences were separated by unrelated text (interrupted) or remained contiguous and were preceded by filler text (uninterrupted).

For each subject, four passages were seen in each of the three cue conditions. The four remaining passages from the set of 16 were not used, and the corresponding pictures were used as cues in the unrelated picture condition. The assignment of passages to conditions was rotated across groups of four subjects (independent of reading speed) so that within each group, each passage was used

Table 1

*Representative Excerpt From a Passage*

The members of the marketing committee entered the boardroom and took their seats.

Dr. Rogers, chairman of the committee, called for everyone's attention.

Tim, who sat to the left of Dr. Rogers, rolled his eyes and prepared himself for a dull speech.

Uninterrupted	Interrupted
He thought board meetings were unproductive and a waste of his time. (filler)	To alleviate his boredom, he took out a pen and began twirling it around with his fingers. (referent)
Tim wished that he could be elsewhere for the next couple of hours. (filler)	First-degree murder is a serious crime that has a maximum penalty of life in prison. (unrelated)
To alleviate his boredom, he took out a pen and began twirling it around with his fingers. (referent)	Treason is the crime of betraying one's country and in some places is punishable by death. (unrelated)
It accidentally fell from his hand and landed right in front of Dr. Rogers. (anaphor)	
He glared at Tim as he picked up the pen and put it in Tim's outstretched hand.	

once in each cue condition and was not used once. The initial assignment of passage to condition (or the unused designation) was done randomly for each group of four subjects. The order of passages (and conditions) was also randomized for each subject. Within each passage, two of the interruption locations were used in the interrupted condition and two were used in the uninterrupted condition. The six possible ways of assigning these conditions to the four possible interruption locations in each passage were used equally often for each passage in each cue condition. Thus, the narrative text was interrupted at different locations across passages, making the interruptions unpredictable. In summary, each subject viewed a subset of 12 of the 16 passages, with four passages in each cue condition, and with half of the four pairs of coreferential sentences interrupted and the other half uninterrupted in each passage. This produced eight pairs of coreferential sentences for each combination of the cue and interruption conditions for each subject.

**Procedure.** Subjects were seated individually at computers equipped with a mouse. All stimuli were presented on a standard computer monitor. A picture (when present) was centered in the middle of the screen and each sentence of a passage was displayed in 18-point Times New Roman font near the bottom of the screen. Although viewing distance was not restricted, subjects typically viewed the screen at a distance of approximately 50 cm. At this distance, a picture subtended about 15.8° (horizontally) by 11.9° (vertically) of visual angle, and a line of text subtended about 0.7° (vertically) of visual angle. Subjects read each passage silently at their own pace, one sentence at a time, progressing to subsequent sentences by clicking the mouse. After a mouse click, the sentence was erased from the screen and immediately replaced by the next sentence. Similar to the procedure used by Glanzer et al. (1984), but unlike that of Lorch (1993), the transition between narrative and unrelated text was not signaled. If a picture was present, it remained on-screen until the end of the passage. After the final sentence of each passage, subjects proceeded to answer the three comprehension questions, one at a time, using the mouse to select their response. Following the comprehension questions, subjects began reading the next passage. Reading times (in milliseconds) were recorded for all sentences and both response times and answers were recorded for the comprehension questions. A few reading times (< 0.1%) were lost because of failures to correctly register subjects' mouse clicks.

**Reading time.** Operationally, reading time was measured from the onset of a sentence to the registration of the mouse click that cleared the sentence from the screen. Because it was possible for subjects to attend to stimuli besides the words comprising each sentence, this measure should not be interpreted as a pure measure of the time spent reading. In particular, in the related- and unrelated-picture conditions, subjects presumably attended to the pictures for some period of time, inflating the measured reading time. However, our analyses of interruption effects were based on differences in reading time within each cue condition for each reader group and as a consequence are not contaminated by such processes.

**Analysis.** To minimize variability because of the length and nature of the sentence being read, reading time per word was used as the principal dependent variable, and these values were adjusted by subtracting the effect of sentence (i.e., the difference between the mean for each sentence and the overall mean across sentences)

averaged across subjects and conditions. The results were analyzed by comparing nested linear models using likelihood ratios (Glover & Dixon, 2004). The likelihood ratio (denoted by  $\lambda$ ) indicates the likelihood of the data given the best fit of one model relative to the likelihood of the data given the best fit of the other; thus, a likelihood ratio much larger (or smaller) than 1 indicates that one model provides a substantially better fit than the other. Following the procedure suggested by Glover and Dixon (2004), the likelihood ratios were adjusted for differing degrees of freedom by using a correction based on the small-sample approximation of the Akaike Information Criterion (Akaike, 1973; Hurvich & Tsai, 1989).

## Results and Discussion

**Reading groups.** The mean reading time for the nonmanipulated sentences was 205 ms/word ( $SD = 29$  ms) for fast readers and 337 ms/word ( $SD = 56$  ms) for slow readers.

**Anaphor sentences.** Reading times for the anaphor sentences in each condition are shown in Table 2. Because reading time per se is not necessarily comparable across cue conditions, we focused our interpretation on the magnitude of the interruption effect, that is, the difference between mean reading times per word for interrupted and uninterrupted anaphor sentences. These differences are shown in Figure 2 for fast and slow readers across cue conditions. Two results are apparent in these data: First, it is clear that in the absence of a cue, both groups of readers were susceptible to the interruption effect, replicating the basic findings of Glanzer et al. (1984) and Lorch (1993). Second, and more importantly, the interruption effect was markedly reduced for slow readers when they were cued by related pictures (13 ms/word) compared with unrelated pictures (72 ms/word). There was no such reduction for fast readers.

To quantify this evidence, nested linear models were fit to the data. First, we wanted to assess the evidence for the basic interruption effect. To do this, an additive model was fit in which reader group and cue condition were assumed to have additive effects, and this was compared to a model that also included the effect of interruption condition. The latter model provided a substantially better fit,  $\lambda > 1,000$ , demonstrating that there was a large interruption effect across conditions and reader groups. Second, we wanted to assess the evidence for the pattern of results apparent in Figure 2, in which the interruption effect for slow readers was smaller with a related picture than with an unrelated picture. To do

Table 2  
Mean Reading Time per Word in Milliseconds (and Standard Errors) for Anaphor Sentences in Experiment 1

	Cue condition		
	Unrelated picture	No picture	Related picture
Fast readers			
Uninterrupted	187 (7)	169 (8)	180 (6)
Interrupted	241 (9)	222 (9)	250 (14)
Slow readers			
Uninterrupted	303 (13)	299 (10)	320 (11)
Interrupted	375 (11)	347 (10)	333 (12)

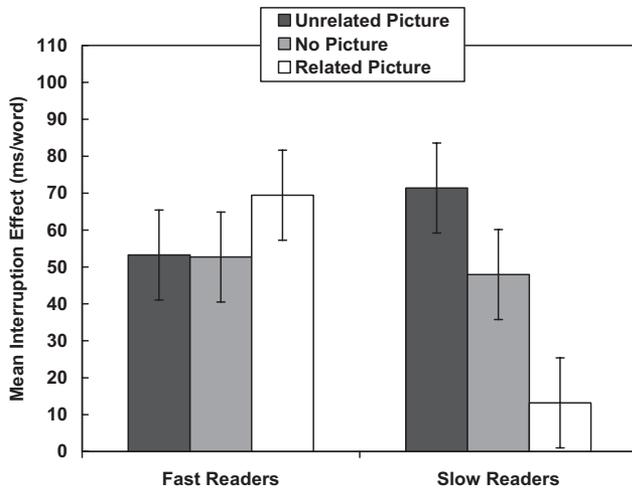


Figure 2. Mean interruption effect (ms/word) for anaphor sentences across cue conditions for fast readers and slow readers in Experiment 1. Error bars represent the standard errors of the means.

this, an interaction model was constructed that also included a contrast embodying this difference. This interaction model fit substantially better than the previous additive model,  $\lambda = 18.4$ . Finally, to assess whether this description of the data was adequate, a full model (incorporating all possible degrees of freedom) was also fit to the data, but when adjusted for degrees of freedom, it actually fit worse than the interaction model,  $\lambda = 0.01$ .

The results for the anaphor sentences suggest that appropriate pictorial cues are useful for recovering from interruptions for slow readers but not for fast readers. We hypothesize that fast readers may use a different reading strategy that does not rely upon the visuospatial information available in the related pictures. Such a strategy may be dispositional or at least habitual and may reflect a particular style of reading comprehension. We elaborate further on this possibility in the General Discussion.

The results provide no support for the view that pictures have mnemonic value regardless of their relationship to the text; only related pictures reduced the magnitude of the interruption effect. In fact, the interruption effect tended to be larger in the unrelated-picture condition than in the no-picture condition for slow readers, suggesting that in this case the cue actually interfered with subjects' ability to reinstate the appropriate mental model.

*Initial passage sentences.* One possible interpretation of the results for fast readers is that they simply ignored the pictures. To assess the extent to which this might be the case, mean reading times per word were calculated for the first two sentences of each passage in each of the cue conditions. These results are shown in Table 3. As found previously, reading time decreased from the first to the second sentence (e.g., Kieras, 1981; Ledoux & Gordon, 2006; McNamara & Kintsch, 1996). As might be expected, this effect was more pronounced for slow readers because they started out much slower on the first sentence. For both fast and slow readers, though, reading time varied with cue condition and was longer with related and unrelated pictures than with no picture. These results imply that readers were not simply ignoring the pictures and suggest that, at least initially, both fast and slow

Table 3  
Mean Reading Time per Word in Milliseconds (and Standard Errors) for the First Two Sentences of the Passages in Experiment 1

	Cue condition		
	Unrelated picture	No picture	Related picture
Fast readers			
Sentence 1	421 (19)	323 (20)	367 (22)
Sentence 2	269 (22)	223 (14)	231 (10)
Slow readers			
Sentence 1	665 (35)	568 (31)	637 (41)
Sentence 2	376 (30)	366 (35)	403 (28)

readers were likely attempting to integrate the pictorial information with the text. However, our interpretation is that only the slow readers used the pictures as a basis for mental models of the text.

To quantify this evidence, a likelihood ratio was calculated that compared a model that included the effects of sentence serial position, reader group, and the interaction with a model that also included an effect of cue condition on the first sentence. The second model fit substantially better,  $\lambda = 48.9$ . A full model that included all possible degrees of freedom was no better,  $\lambda = 0.03$ .

*Comprehension accuracy.* Accuracy for each cue condition, reader group, and question type is shown in Table 4. Accuracy was very high for both groups, regardless of cue condition. There was little evidence that the slow readers were any more accurate than the fast readers, perhaps because of the relatively shallow nature of the comprehension questions.

## Experiment 2

Although the reading times for the initial passage sentences imply that even fast readers did not ignore the cues completely, there is one aspect of the design of Experiment 1 that may have undermined the use of the cues as retrieval aids: Half of the pictorial cues to which subjects were exposed were unrelated to the passages. The high proportion of unrelated cues may have confused readers, especially if they were trying to integrate the visuospatial information from these pictures into their mental models of the text. Consequently, there may have been a tendency to simply ignore the pictorial cues (both related and unrelated) as a mne-

Table 4  
Proportion Correct (and Standard Errors) on Comprehension Questions in Experiment 1

	Cue condition		
	Unrelated picture	No picture	Related picture
Fast readers			
Narrative text questions	.95 (.02)	.96 (.01)	.95 (.02)
Unrelated text questions	.96 (.02)	1.00 (.01)	.97 (.02)
Slow readers			
Narrative text questions	.96 (.01)	.97 (.01)	.94 (.01)
Unrelated text questions	.99 (.01)	.99 (.01)	1.00 (.01)

monic because they did not serve as consistently valid cues for the mental model constructed for the passage. Although there is evidence that fast readers did attend to the pictures initially, it is possible that they only used them to provide an introductory context for what they would be reading, and this may have been unrelated to their comprehension as they progressed through the passage. By the time they encountered the anaphor sentences, they may have no longer found the pictorial cues to be informative.

The issue of cue validity was considered in Experiment 2 by replicating the basic method from the first experiment with two changes. First, the cue conditions were altered so that the cues were always related to the passage. Two types of cues were used: a related picture and a suitable title for the passage. A title is clearly related to the material and consequently "valid" in some sense; thus, it would not provide any incentive for ignoring the cues as irrelevant to the narratives. However, unlike a related picture, a title affords no visuospatial detail to incorporate into a mental model. Second, the cue accompanying each passage disappeared for the two sentences of unrelated text in the interrupted condition, returning with the presentation of the anaphor sentence. This change was intended to further increase cue validity by having the cues associated only with the narrative text in each passage and not with the unrelated, interrupting material. If cue validity was related to the pattern of results in Experiment 1, one might expect to see an effect of cue condition on the interruption effect even for fast readers under these new conditions.

### Method

**Subjects.** Twenty-four undergraduate psychology students at the University of Alberta served as subjects in exchange for course credit. None of them had participated in Experiment 1. As before, subjects were divided into groups of fast and slow readers based on their mean reading time per word for all nonmanipulated sentences in both cue conditions.

**Materials.** A subset of 12 passages and their related pictures was selected from the 16 passages used in Experiment 1. The only change to the materials was the addition of a title for each passage that indicated the general theme of the narrative text. For example, "Getting Ready for a Night Out" was the title for a passage about a girl preparing to go out on her first date.

**Design.** The experiment used a 2 (cue condition)  $\times$  2 (interruption condition)  $\times$  2 (reading speed) mixed design. For the cue condition, subjects saw either the title for the passage or the related picture. The interruption manipulation was identical to that in Experiment 1.

The randomization and counterbalancing of the materials was similar to that of the first experiment except that no passages were designated as unused because there was no need for unrelated pictures. Each subject read 12 passages, with six passages in each cue condition, and with half of the four pairs of coreferential sentences interrupted and the other half uninterrupted in each passage. The six possible orderings of the interruption-condition assignments within a passage each occurred once per cue condition amongst the 12 passages for each subject. This assignment of conditions and orders was rotated across passages in groups of 12 subjects (independent of reading speed), and a new random assignment was constructed for each group. The order of passages was random for each subject.

**Procedure.** The procedure was the same as in Experiment 1, except for the two changes described earlier: In the title condition, a thematic title was presented rather than a picture, and the cue (either picture or title) was removed from the screen during the interruption.

**Analysis.** Reading times were averaged and adjusted in the same manner as in Experiment 1.

### Results and Discussion

**Reading groups.** Data from one subject were excluded because of a mean reading time for anaphor sentences that was more than five standard deviations above the mean for the other slow subjects. Consequently, the reported analyses are based on the data of the remaining 23 subjects. The mean reading time for the nonmanipulated sentences was 181 ms/word ( $SD = 28$  ms) for fast readers and 240 ms/word ( $SD = 20$  ms) for slow readers.

**Anaphor sentences.** Mean reading times per word for anaphor sentences are shown in Table 5. The magnitude of the interruption effect is shown in Figure 3 across cue conditions for both groups of readers. As before, all readers were susceptible to the interruptions. However, slow readers showed a smaller interruption effect (51 ms/word) with related pictures than with titles (88 ms/word); fast readers showed identical interruption effects in both conditions (54 ms/word).

To quantify this evidence, a likelihood ratio was calculated that compared an additive model that included the effects of interruption condition, cue condition, and reader group with an interaction model in which the interruption effect was smaller with related pictures than with titles only for slow readers. The interaction model provided a better fit,  $\lambda = 3.5$ . When adjusted for degrees of freedom, the full model provided a worse fit than the interaction model,  $\lambda = 0.17$ .

These results are generally consistent with those of Experiment 1 and indicate that cue validity was not responsible for the differences observed between fast and slow readers. Other possible accounts of the results will be explored in the General Discussion. Meanwhile, one important difference did emerge between the experiments: In Experiment 1, the related picture virtually eliminated the interruption effect for slow readers, whereas in the present experiment there was still a substantial interruption effect under the same conditions. In other words, slow readers in Experiment 2 did not seem to benefit from the related pictorial cues nearly as much as their counterparts in Experiment 1. There are at least two possible explanations for this discrepancy. First, the

Table 5  
Mean Reading Time per Word in Milliseconds (and Standard Errors) for Anaphor Sentences in Experiment 2

	Cue condition	
	Title	Related picture
Fast readers		
Uninterrupted	163 (8)	173 (7)
Interrupted	217 (9)	227 (8)
Slow readers		
Uninterrupted	213 (5)	227 (10)
Interrupted	301 (8)	278 (9)

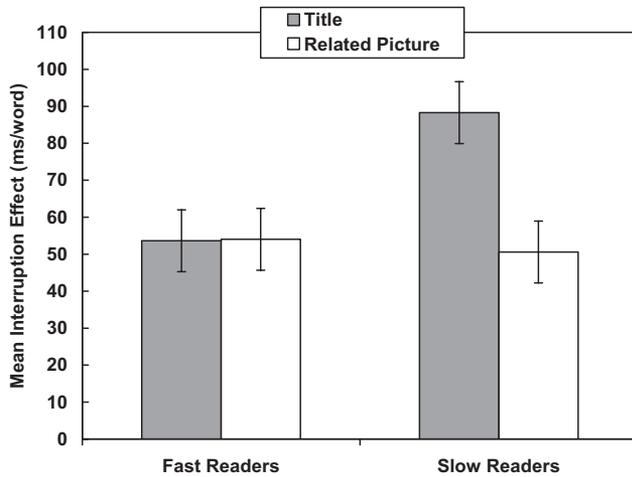


Figure 3. Mean interruption effect (ms/word) for anaphor sentences across cue conditions for fast readers and slow readers in Experiment 2. Error bars represent the standard errors of the means.

change may be because of the absence of the cues during the presentation of the unrelated text in the present experiment. In Experiment 1, readers would have been chronically reminded of the narrative setting while reading the interrupting material, and this may have eliminated any tendency for the interrupting material to displace the mental model from short-term working memory. Such an advantage would not have occurred in Experiment 2. Second, the discrepancy may have nothing to do with the experimental manipulations and instead may be because of differences in subject sampling. For whatever reason, the readers in Experiment 2 were relatively fast on average, and the mean reading time for the “slow” readers in Experiment 2 was closer to that of the fast readers than the slow readers of Experiment 1. Thus, the slow reader group in Experiment 2 may have contained a smaller number of “high-detail” readers who attempted to integrate the pictorial cues with their mental models.

*Initial passage sentences.* As in Experiment 1, reading time was substantially longer for the first sentence in a passage than for successive sentences (see Table 6). Reading time for the first sentence was also affected by cue condition. However, this effect interacted with reader group: Slow readers took more time with the

Table 6  
Mean Reading Time per Word in Milliseconds (and Standard Errors) for the First Two Sentences of the Passages in Experiment 2

	Cue condition	
	Title	Related picture
Fast readers		
Sentence 1	317 (13)	323 (10)
Sentence 2	205 (11)	208 (13)
Slow readers		
Sentence 1	488 (22)	416 (20)
Sentence 2	293 (20)	287 (18)

title cue than with the picture cue, but fast readers showed no such effect.

To quantify this evidence, a model that included the effects of sentence serial position and reader group was compared with a model that also included an effect of cue condition for slow readers on the first sentence. The latter model fit substantially better,  $\lambda = 23.0$ . A full model that included the remaining degrees of freedom was worse,  $\lambda = 0.12$ .

Although the results for the initial passage sentences in Experiment 1 suggest that both fast and slow readers attended to the cues, the present results indicate that their processing of the cues was distinct. One possible interpretation is that fast readers took a similar amount of time reading sentences accompanied by titles and by pictures because they were processing the titles and pictures similarly: In both cases, they may have been using the cues merely as indicators of the general thematic content of the passage. For example, fast readers may have used pictures to identify the setting without making use of the visuospatial details the pictures provide. On the other hand, slow readers may have attempted to construct a spatial mental model for the narrative scene based on the cues. This would be relatively easy when the cue was a picture rather than a title.

*Comprehension accuracy.* As in Experiment 1, accuracy for the comprehension questions at the end of each passage was very high and varied little across conditions (see Table 7). These results clearly replicated the first experiment and were not subjected to further analysis.

### General Discussion

In both experiments, the presence of a related picture as a visuospatial cue substantially reduced the magnitude of the interruption effect for slow readers but not for fast readers. This result suggests that only some readers spontaneously integrate pictorial cues with their mental models. Although we assume that all readers construct mental models in the course of narrative comprehension, fast readers in our experiments may have used a low-detail strategy in which only schematic or piecemeal spatial information was incorporated in their mental models, whereas slow readers may have used a high-detail strategy in which visuospatial information from contextually appropriate pictorial cues was incorporated in their mental models. Below, we discuss our interpretation of how the visuospatial cues were used to reduce the interruption effect and describe some possible interpretations of the difference between fast and slow readers in these experiments.

Table 7  
Proportion Correct (and Standard Errors) on Comprehension Questions in Experiment 2

	Cue condition	
	Title	Related picture
Fast readers		
Narrative text questions	.99 (.01)	.99 (.01)
Unrelated text questions	.99 (.01)	1.00 (.01)
Slow readers		
Narrative text questions	.98 (.02)	.99 (.02)
Unrelated text questions	.97 (.02)	.97 (.02)

### *Reducing the Interruption Effect*

Our analysis of the interruption effect is based on the ideas of Ericsson and Kintsch (1995): We assume the interruption effect reflects the time needed to reactivate a set of retrieval cues that serve as a mental model in short-term working memory. This mental model provides a retrieval structure that allows one to access representations of the text in long-term working memory (Ericsson & Kintsch, 1995). Before the interruption, the reader only has to maintain a mental model for the narrative text. Presumably, when readers encounter the unrelated text during an interruption, they realize it is incongruent with their existing mental representation and construct a second model for accessing the new information (Radvansky & Zacks, 1991). The competition and interference that ensues leads to the loss of elements of their mental model for the narrative text. After the interruption, readers will need time to update short-term working memory by reinstating any missing or temporarily displaced elements of their mental model, especially if that information is critical to text comprehension (e.g., for resolving anaphors).

Given this analysis, introducing appropriate retrieval cues during or after the interruption should reduce the effect of the interruption. Glanzer et al. (1984) and Lorch (1993) demonstrated that this could be done with verbal information that restates critical information from the text. The present research has provided evidence that at least for some readers, an appropriate visuospatial cue accompanying the text can reduce the interruption effect even when the cue contains none of the critical information from the text. An important feature of the present materials is that a related picture only depicted the general setting of the narrative and did not include any of the critical referents from the coreferential sentences. Thus, the picture itself did not provide the information needed in comprehending the critical sentences; instead, it provided a cue for the mental model in which that information was presumably embedded.

We think that the related pictures in the present research were useful cues for the slower, high-detail readers in our experiments because they provided the visuospatial foundation for their mental models. Previous research suggested that an explicit pictorial representation of the situation described by the text can foster the construction of spatial mental models (e.g., Glenberg & Langston, 1992; Morrow et al., 1989); the present research demonstrates that the pictorial representation of merely the visuospatial context of a narrative can effectively set the stage for constructing a spatial mental model by providing information about spatial relations and visual appearance. This idea is consistent with research in which the presence of a relevant picture facilitated comprehension of abstract text by providing an appropriate context (Bransford & Johnson, 1972). In the present research, viewing an accompanying picture provides the reader with retrieval cues for the visuospatial elements of their mental models, supporting reading processes necessary for comprehension even in the face of interruptions.

### *Individual Differences in Mental Models*

We hypothesize that high-detail readers integrated the pictorial information with their mental model of the text and as a consequence read more slowly on average. This strategy is akin to what readers were explicitly asked to do in the experiments of Morrow and colleagues (e.g., Morrow et al., 1989). Presumably, the high-

detail readers in our experiments, like those in the Morrow et al. experiments, constructed mental models with a reasonable degree of spatial fidelity. However, this approach was apparently not adopted spontaneously by all readers. Although Experiment 1 provided evidence that fast readers did not ignore the related pictures, they may have been low-detail readers who failed to incorporate the spatial layout depicted in those cues in their mental models. We assume that these readers constructed mental models that included a variety of relational information; accurate comprehension of the text would not be possible without such representations. However, their representations may have included only schematic or partial information pertaining to spatial arrangements or visual appearance. As a consequence, the pictorial cues would have been largely irrelevant to the comprehension process because they did not closely match the information in their mental models.

It is unclear at this point whether the different comprehension processes hypothesized for high- and low-detail readers represent a malleable, heuristic strategy or more stable dispositions or habits. On the one hand, there have been many experiments that demonstrate that readers can construct spatial mental models and use these during comprehension given sufficient motivation and external support. Such evidence could support the conclusion that all readers could have used the pictorial cues to modulate the interruption effect if they so desired. Thus, the differing results for the two groups of readers may represent different strategies adopted in this particular reading context. Indeed, there is evidence suggesting that comprehension does not benefit from pictures unless readers are given special instructions that orient them to the pictorial information (Weidenmann, 1989). Readers were not directed to use the pictures in our experiments; therefore, the differences between reader groups may reflect varying degrees of intentional integration of pictorial information with mental models of the text. On the other hand, there is a wide range of spatial and imaginal abilities in the population, and some readers may be much more adept at constructing mental models with visuospatial details. For example, MacLeod et al. (1978) found that the adoption of spatial strategies in a sentence verification task was related to spatial abilities as measured by standardized tests. A comparable proclivity for one approach or another to the present narrative comprehension task may have been operating here.

Reading speed is related to other individual differences that might also underlie the present differences. For example, slow readers generally have less verbal fluency than fast readers. As a consequence, they may have been more motivated to use pictorial cues as an aid in comprehension. Furthermore, fast readers may be more strategic and more adept at adapting their reading processes to the task at hand (cf. DiStefano, Noe, & Valencia, 1981). Thus, they may have decided that there was little benefit to devoting resources to encoding the pictorial cues. Alternatively, it is conceivable that the effects obtained here were related to how subjects responded to the experimental task demands. For example, fast readers may have been those who were less motivated to carefully read the passages and were similarly less motivated to encode and use the pictorial cues. However, regardless of the source of these reading time differences, the present results demonstrate that some readers spontaneously benefited from the pictorial cues while others did not, and we argue that the immediate cause of this difference is the degree of visuospatial information incorporated in their mental models.

## Conclusion

Mental models involved in reading comprehension can integrate many different types of information, including complex visual elements and spatial relations under some circumstances. The present study contributes to our knowledge by demonstrating that mental models can have a visuospatial foundation even when the materials and task do not expressly require information about spatial relations or visual appearance. However, this result was only found for some readers, suggesting more broadly that the nature and content of mental models could be determined by a wide range of reader strategies, skills, and aptitudes.

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## Résumé

Lire requiert la construction d'une représentation mentale en mémoire de travail à long terme du monde décrit dans le texte. Perturber la mémoire de travail à court terme peut interférer avec la maintenance des modèles mentaux (ensemble d'indices de rappel) nécessaires pour accéder à ces représentations, ce qui a des effets néfastes sur le temps de lecture. Dans deux expériences, les participants devaient lire des passages incluant des paires de phrases coréférentielles interrompues par du texte sans lien. Conformément aux études précédentes, les temps de lecture pour la première phrase ont augmenté après l'interruption, reflétant probablement un processus de rétablissement des modèles mentaux en mémoire de travail. Dans la présente recherche, des images étaient fournies à titre d'indices visuo-spatiaux afin de faciliter le processus de rétablissement. L'effet d'interruption s'est révélé plus faible avec des images liées aux passages qu'avec des images sans lien (Expérience 1) ou des titres (Expérience 2); cependant, ces deux effets ne se sont manifestés que pour les lecteurs lents. Nous proposons l'hypothèse que les lecteurs lents prennent le temps nécessaire pour intégrer l'information visuo-spatiale dans leurs modèles mentaux, facilitant l'accès à la mémoire de travail à long terme.

*Mots-clés* : lecture, modèles mentaux, mémoire de travail, interruption, indices picturaux

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