The representation of space in mental models derived from text

WILLIAM LANGSTON

Denison University, Granville, Ohio

and

DOUGLAS C. KRAMER and ARTHUR M. GLENBERG

University of Wisconsin, Madison, Wisconsin

Mental models of text are representations of what the text is about (i.e., situations), rather than representations of the text itself. Many mental model theories propose that mental models, like real situations, are played out in a medium analogous to a Euclidean space so that distance has functional consequences. For example, when one mentally manipulates one element of the representation, one will *notice* other elements that are spatially close to it, and this will enhance their short-term accessibility. In a test of this noticing hypothesis, participants read texts that described the object-by-object construction of a spatial layout. According to the text, a critical object ended up close to a target object (in the spatial layout) or far from the target object. In neither case, however, was the relation between the critical object and the target object explicitly described in the text. The noticing hypothesis predicts that the accessibility of the target object will be enhanced when the critical object is close to it. We tested this prediction in seven experiments in which we also manipulated the number of objects described, whether the description was accompanied by a diagram, the presentation modality of the description, the number of dimensions in the spatial layout, and the measurement of accessibility. We failed to find consistent support for the noticing hypothesis. The data compel the conclusions that (1) spatial representations can be formed when one is reading, (2) these representations do not support automatic noticing of implicit spatial relations, (3) it is likely that the spatial representation is more topological or functional than Euclidean.

Researchers are reaching a consensus that an important component of language comprehension consists in the construction of mental models (Gentner & Stevens, 1983; Johnson-Laird, 1983) or situational models (van Dijk & Kintsch, 1983). In essence, what is meant by a mental model is a representation of what the language (or text) is about, rather than a representation of the language itself. Apart from this essence, however, there is little agreement as to how to characterize a mental model. Is it an image? A schema? A set of propositions? Importantly, does the mental model have the properties of a Euclidean space?

In the experiments described here, we investigated properties of spatial mental models in order to answer some of the questions posed above. In brief, we found that spatial mental models are unlikely to be Euclidean. The experiments were based on three assumptions: (1) Readers will form a mental model when reading a spatial text; (2) this mental model has analogical properties (such that

increasing distance in the model is similar to increasing distance in a real environment); and (3) when items are spatially close in the model, readers will encode this relationship. The first two assumptions are shared by most researchers who investigate text comprehension. The third assumption, called the "noticing" hypothesis, is based on the conclusions of Glenberg and Langston (1992). We will discuss empirical support for each of these assumptions below.

Assumption 1: Representation in Mental Models

Much of the research supporting the concept of mental models of discourse has traded on spatial relations. Garnham (1992) has discussed one reason for this: Texts that describe spatial layouts can often be constructed so that the propositional structure of the text is different from the spatial structure of the situation described by the text. That is, when objects are close in space, the words used to refer to and describe those objects need not be close (spatially, temporally, or propositionally) in the description. Thus, demonstrating an effect on comprehension of the structure of the situation indicates that it must be considered in addition to the structure of the description. Two examples of this strategy are the work of Mani and Johnson-Laird (1982) and O'Brien and Albrecht (1992). Mani and Johnson-Laird concluded that readers construct particular spatial representations when the texts are specific, but that readers use a more verbatim representation when the spatial lay-

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out is indeterminate given the text (but see Payne, 1993, for an impressive failure to replicate). O'Brien and Albrecht demonstrated that readers are sensitive to the location of a protagonist, because information inconsistent with that location (even when presented much later in the text) slowed reading.

Assumption 2: Mental Models Are Constructed in an Analogical Spatial Medium

Various scientists have proposed that mental models not only capture spatial relations, but that they are constructed in a spatial medium, a medium in some way analogous to the three-dimensional space of everyday experience. For example, such a claim is made by Johnson-Laird (1983, p. 422), and it is an important component of the computer simulation described by Glenberg, Kruley, and Langston (1994). In discussing accessibility of representations in a mental model encoding objects and a protagonist, Rinck and Bower (1995) imply an analogical representation by statements such as "The accessibility of objects should gradually decrease with increasing distance from the protagonist" (p. 112). In fact, Morrow, Bower, and Greenspan (1989) demonstrated this sort of spatial distance effect, but Wilson, Rinck, McNamara, Bower, and Morrow (1993) note a qualification. Rinck and Bower (1995) replicated the effect using a different dependent variable not subject to the qualification, and they concluded, "Taken together, the four experiments reported here provide evidence for the claim that spatial distance in the reader's situation model of a narrative influences the accessibility of referents for anaphoric expressions" (p. 129). In short, the data are consistent with an analogical view in which spatial distance is functional.

Denis and Cocude (1989, 1992) demonstrated that scanning a representation of an island produces similar results whether the scan is controlled by a mental representation formed from a linguistic description, a mental representation formed from observing a map, or a physical representation—that is, the map itself. Denis, Gonçalves, and Memmi (1995) conclude that "These data support the claim that images generated from verbal descriptions can have metric properties." Finally, Glenberg, Meyer, and Lindem (1987) showed effects of spatial distance between a protagonist and a critical object. In these experiments the critical object (such as "sweatshirt") was described as spatially close to the protagonist in the associated condition, as in "After doing a few warm-up exercises, [John] put on his sweatshirt and went jogging." In the dissociated condition, the critical object and the protagonist were described as spatially separated, as in "After doing a few warm-up exercises, [John] took off his sweatshirt and went jogging." Accessibility of the critical object (here the sweatshirt) was assessed after subjects read another sentence in which John was foregrounded but the sweatshirt was never mentioned. The accessibility of "sweatshirt" was found to be greater in the spatially close, associated condition than in the spatially separated, dissociated condition.

A frequent interpretation of these findings is that readers construct analog spatial mental models to understand what they are reading, and that these models have properties of Euclidean space: All dimensions are equivalent to one another and there is no intrinsic structure. Thus, degree of spatial relationship between two elements (such as the protagonist and the critical object in Glenberg et al., 1987) is solely a function of Euclidean distance. We will show that this interpretation is unlikely to be correct. Note, however, that ruling out a Euclidean form of mental representation for text does not imply that mental representation of spatial information must be propositional (i.e., not analog). It is possible to have representations that are analog, but not Euclidean. We will expand on these ideas in the General Discussion.

Assumption 3: The Noticing Hypothesis

Glenberg and Langston (1992) proposed that under certain circumstances spatial mental models could be used to represent nonspatial relations. In those experiments, participants read descriptions of the temporal order of the steps in multistep procedures, and each participant was tested on memory for the order in which the steps should be performed, not the order of the description of the steps in the text. The texts were completely explicit regarding the order in which the steps should be performed, but because two of the steps were to be performed at the same time, whereas their descriptions proceeded serially, the order of performance could be dissociated from the order of description. The data suggested that the structure of memory for order was affected by order of description, but that when the texts were accompanied by diagrams in which spatial distances among the steps were analogous to temporal separations, the effect of order of description was much reduced. In the latter case, memory reflected the mental model—that is, the representation of how to perform the multistep task, not memory for the description itself. Importantly, when a diagram was available, readers seemed to have noted temporal relations among steps spatially close in the diagram (and presumably close in the mental model based on the diagram) more readily than temporal relations among steps spatially distant in the diagram.

Glenberg and Langston (1992) used their results to develop the *noticing* hypothesis, which sets the stage for the experiments described here. The noticing hypothesis provides one explanation for why forming mental models enhances comprehension: The spatial medium in which the model is constructed supports a type of inference making called *noticing*. The hypothesis is based on the following assumptions: (1) Mental models are constructed in a spatial medium, such as the limited-capacity visuospatial scratchpad identified by Baddeley (1986). (2) Text-relevant dimensions (e.g., time) can be assigned to spatial dimensions, although the assignment may require expertise in a domain or visual support such as that provided by a diagram. (3) Text-relevant concepts (e.g., steps in a procedure) are represented by pointers arrayed within the me-

Table 1
Sample Texts From Experiments 1 and 2

Four-Item Notice Version From Experiment 1

Sam was setting up his fish aquarium decorations.
Sam put the castle down first.
Next, he put the plastic diver right of the castle.
Then Sam put the big rock under the plastic diver.
Then Sam put the seaweed left of the big rock.
{Probe: castle}
Next, he put the treasure chest left of the seaweed.
Finally, Sam put the sunken boat over the treasure chest.
When Sam put the fish in, it was scared by all of the stuff.

Four-Item Not-Notice Version From Experiment 1

Sam was setting up his fish aquarium decorations.
Sam put the castle down first.
Next, he put the plastic diver right of the castle.
Then Sam put the big rock under the plastic diver.
Then Sam put the seaweed right of the big rock.
{Probe: castle}
Next, he put the treasure chest left of the seaweed.
Finally, Sam put the sunken boat over the treasure chest.
When Sam put the fish in, it was scared by all of the stuff.

Four-Item Far Notice Version From Experiment 2

Sam was setting up his fish aquarium decorations.
Sam put the castle down first.
Next, he put the plastic diver *way* right of the castle.
Then Sam put the big rock under the plastic diver.
Then Sam put the seaweed *way* left of the big rock.
{Probe: castle}
Next, he put the treasure chest left of the seaweed.
Finally, Sam put the sunken boat over the treasure chest.

dium, and each pointer is associated with information about the concept in memory. Furthermore, the spatial distances between pointers is cognitively meaningful. That is, pointers that are spatially close in working memory represent concepts that are more closely (or strongly) related along the text-relevant dimension assigned to the spatial dimension. (4) Mental models are updated by introducing new pointers or rearranging existing pointers to reflect the situation described by the text. (5) When an existing pointer is moved, or when a new pointer is introduced into the model, that pointer is attended, and any pointer within the "spotlight" of attention is noticed. "Noticing" means that the relation between the pointers is specifically encoded and added to the associated information in memory. The operation of this noticing process was formalized in a computer simulation described by Glenberg et al. (1994).

We found the noticing hypothesis appealing for several reasons. First, it provides one reason why forming a mental model facilitates comprehension: The mental model allows for a type of inference making (noticing on the basis of spatial contiguity) not easily available to a propositional system. Second, unlike many schemes for inference generation, noticing is highly constrained: It occurs only along text-relevant dimensions assigned to spatial dimensions; it is constrained by the capacity limits of working memory; it occurs only during updating a mental model and then only between spatially close pointers. Third, the simulation model bears at least a family resemblance to

models developed by Johnson-Laird (e.g., Johnson-Laird, Byrne, & Tabossi, 1989) to account for reasoning using mental models. Fourth, Glenberg et al. (1994) show how a simulation model incorporating noticing can account for much of the data reviewed above. Finally, the noticing hypothesis is implied by many of the theoretical claims about the operation of spatial mental models (e.g., Denis & Cocude, 1992; Rinck & Bower, 1995). As documented above, hypotheses that assume a Euclidean medium for mental models assume that distance within the medium has functional consequences; items that are farther apart are less likely to interact.

The seven experiments reported here were designed to test the noticing hypothesis. The basic logic was to have participants read (or listen to) a text describing a spatial layout. An example of such a text appears in Table 1. Each text described the relations between some objects explicitly while the spatial relations between other objects were left implicit. A speeded recognition task (Experiments 1–4) or a sentence reading task (Experiments 5–7) was used to assess the accessibility of the items in the layout. The primary manipulation was that of the distance (in the described spatial layout, not the text) between the probe item and another *most recently mentioned item*. The most recently mentioned item is an item that is described in the text immediately before the probe is presented. In Table 1, "seaweed" is the most recently mentioned item. Sometimes the most recently mentioned item was near to the probe in the spatial layout (notice condition), and sometimes it was far from the probe (not-notice condition). Importantly, the spatial distance between the probe and the most recently mentioned item was never described explicitly. Instead, the relation between the most recently mentioned item and some other object (the "big rock" in Table 1) controlled the relation between the probe and the most recently mentioned item. In the notice condition, when the most recently mentioned item was near to the probe (in the spatial layout, and hence in the putative spatial model), more noticing of the probe should occur than when the two objects were separated from one another, as in the not-notice condition. We assessed the degree of noticing by measuring the accessibility of the probe soon after the most recently mentioned item was introduced by the text.

Table 2 summarizes the results of the seven experiments, and it provides a guide to the detailed exposition that follows. The two dependent variables that we used are listed in the DV column. One dependent variable was speeded recognition, the time to recognize the probe word as an item that occurred in the text. The probe word occurred immediately after the most recently mentioned item. Speeded recognition is a common measure of accessibility that is sensitive to spatial relations (see, e.g., de Vega, 1995; Glenberg et al., 1987; see also Experiment 4 for a specific test of sensitivity). The other dependent variable was time to read an *about* sentence. The about sentence followed the most recently mentioned item, and the sentence referred to the target item. Hence the time to read the sentence included the time needed to make an anaphoric ref-

Table 2
Summary of the Experiments

Experiment	DV	Modality	Item/ Dimension	Picture	Notice Effect	t_{med}				t_z			
						Standard	n	Loose	n	Standard	n	Loose	n
1	Recognition	visual	4/2	no	21.7	1.33	41	1.20	41	.72	36	.32	41
			4/2	yes	17.3	-.29	38	.75	39	.11	36	.61	39
			6/2	no	6.7	-.45	41	.28	41	-.32	36	.74	41
			6/2	yes	28.0	.66	38	1.51	39	.65	36	.97	39
2	Recognition	visual	4/2	no	-21.1	-.61	27	-.99	29	.37	9	.57	29
			4/2	yes	10.8	2.11	27	.53	29	1.22	17	1.88	27
			4/2	unlabeled	30.0	.04	27	1.13	27	.41	17	.89	27
			4/2 (far)	no	-23.3	.80	27	-1.09	29	.16	9	-1.32	29
			4/2 (far)	yes	-0.4	-1.03	27	-.02	29	.35	17	.27	27
			4/2 (far)	unlabeled	-14.4	.13	27	-.68	27	.61	17	-1.17	27
			6/2	no	54.4	3.00	27	1.35	29	.98	9	2.43	29
			6/2	yes	19.9	-.65	27	.67	29	-.44	17	-.64	27
			6/2	unlabeled	-45.7	-.76	27	-1.67	27	-1.18	17	-1.21	27
			6/2 (far)	no	4.3	-.14	27	.15	29	.57	9	-.35	29
			6/2 (far)	yes	-11.5	-.84	27	-.42	29	-1.18	17	.49	27
			6/2 (far)	unlabeled	-54.4	-1.26	27	-1.44	27	-1.07	17	-2.11	27
3	Recognition	visual	4/2	no	7.3	.60	17	.23	17	.60	17	.13	17
		visual	4/2	yes	36.1	.43	17	.92	17	-.08	17	-.09	17
		auditory	4/2	no	-47.3	-.34	17	-.23	17	-.48	17	-.51	17
		auditory	4/2	yes	45.4	.97	17	.67	17	-.19	16	-1.12	16
4*	Recognition	visual	3/1	no	-11.7			-.36	22			-1.10	22
5	Reading	visual	4/2	no	1.8	1.09	45	.03	50	.72	45	1.26	50
6†	Reading	visual	4/2	no	36.9	.13	36	.65	39	.21	36	1.29	39
7‡	Reading	visual	3/1§	no	50.4								
			3/1	no	34.9								

Note.—DV = dependent variable, either speeded recognition of a probe (recognition) or time to read an *about* sentence (reading). Item/Dimension = number of items before the probe or about sentence, and number of spatial dimensions required to arrange the items. "Far" indicates that the noticing effect was computed as the difference between the notice and far conditions (see description of Experiment 2 for details). Notice Effect = difference between medians (in milliseconds) for the not-notice and notice conditions in the loose analysis. t_{med} = value of the t statistic for the medians in the standard and loose analyses, respectively. t_z = value of the t statistic for the z scores in the standard and loose analyses, respectively. n = sample size. *Data are collapsed across Items 1 and 2; because there was no comprehension question, the standard analysis could not be performed. †Data are from the condition in which the target was Item 1. ‡Because correct responding was forced, there is no distinction between standard and loose. §For the first row, data are from the condition in which the frame is on Item 2. For the second row, data are from the condition in which the frame is on Item 3.

erence to the target item. Sentence reading time is a common measure of accessibility of the referents of anaphors that also appears to be sensitive to spatial relations (see, e.g., Rinck & Bower, 1995). In most of the experiments, we used visual presentation of the text (as indicated in the Modality column of Table 2), but we also report one experiment (Experiment 3) in which we used auditory presentation. The next column (Item/Dimension) indicates the item number of the most recently mentioned item. Thus, across the experiments, the spatial layout of three, four, or six items was described before accessibility of the target item was assessed. The number following the slash mark indicates whether the spatial layout was in one or two dimensions.¹ In most of the experiments, the distance in the spatial layout between the most recently mentioned item and the target item was confounded with number of intervening items (in the arrangement). That is, no items intervened in the notice condition, and several items might intervene in the not-notice condition. This confound was removed in the conditions labeled "far" in Table 2. For those comparisons, we computed the noticing effect as the difference between the notice-far and the far conditions (see Experiment 2). In those conditions, the spatial dis-

tance (in the layout) between the target and the most recently mentioned item was manipulated without intervening items. The column labeled "Picture" indicates whether the verbal description of the layout was accompanied by a picture illustrating the layout of the first three items. The "unlabeled" picture condition in Experiment 2 illustrated the layout with tokens (boxes), but did not label the tokens with the item names.

One index of the noticing effect is the difference between the median value of the dependent variable in the not-notice condition and the median value of the dependent variable in the notice condition. The noticing hypothesis predicts a positive difference. This index is provided in the column labeled "Notice Effect." The remaining columns present statistical assessments of the generalizability of the notice effect; for each analysis, the number of participants entering into the analysis is also reported. A noticing effect that is significantly different from zero is set in boldface. Columns 7 and 9 report the value of the paired t statistic comparing the medians. The *standard* analysis eliminated individual observations if (1) response to the probe was incorrect, or (2) response to a comprehension question presented after the text was incorrect. The *loose*

analysis eliminated observations according to Condition 1, but not Condition 2. Thus, the medians computed in the loose analysis are based on more observations. Bush, Hess, and Wolford (1993) have demonstrated that comparisons based on medians may not be statistically powerful. Hence, we also include two analyses (standard and loose) based on a set of transformations that Bush et al. found to be the most powerful without sacrificing protection against Type I errors. The transformations are intended to achieve power by (1) elimination of outliers by removing the longest and the shortest observations in each condition for each participant and then using means rather than medians, (2) normalization of skewed reaction time distributions by using the logarithm of the speeded recognition or reading times, and (3) elimination of between-subjects variability in the size of the effect by using z scores computed for each participant. Thus, after elimination of outliers, the individual observations were converted into logarithms. Next, a single mean and standard deviation were computed for all of a given participant's scores (regardless of condition), and the participant's mean and standard deviation were used to compute z scores for all of the observations. Finally, a mean z score was computed for each participant in each condition. The mean of these mean z scores will always equal zero (so that there is no between-subjects variability), but within-subjects differences among conditions are still preserved. Columns 11 and 13 in Table 2 present the results of the dependent sample t test comparing the mean z scores of the notice and not-notice conditions.

Thus, over the course of seven experiments, we manipulated several independent variables that should have directly affected the amount of noticing. The size of the noticing effect was sometimes substantial, but it was never consistently statistically significant. Although the direction of the noticing effect was often that which the noticing hypothesis predicted (positive), we believe that this should be discounted for several reasons. First, the effect was rarely statistically significant, and it was sometimes significantly reversed. Second, as we will describe more fully in the discussion of Experiment 6, there is reason to believe that many of the small positive effects in Table 2 were due to a subtle confound: The layouts in the not-notice condition tended to be a bit more complicated than the layouts in the notice condition, leading to longer responding in the not-notice condition. Third, an analysis of variance (ANOVA) of the *loose* z scores in which we used experiment as an independent variable indicated that the variation in the size of the notice effect across experiments was not reliable [$F(6,371) = 1.14$, $MS_e = .32$]. Fourth, although statistical power is modest in any individual experiment, the power over this set of experiments was very high. On the basis of the *loose* z -score analysis, the power to detect a small effect of 0.2 standard deviations was .97. The power to detect an effect as small as .14 standard deviations was .80. In fact, however, over all of the data (when the number of items was 3 or 4), the mean *loose* z -score noticing effect was .04, the standard error was .03,

and $t(387) = 1.25$ is not significant. Thus, if there is a noticing effect, it is likely to be very small. Our conclusion is that spatial mental models do not support noticing, and hence they are not likely to be Euclidean.

EXPERIMENT 1

We designed the first experiment to test the hypothesis that readers would use a mental model to notice relations not mentioned in a text. The notice condition texts described arrangements in which the target item and the most recently mentioned item ended up adjacent to one another in the spatial layout, although their relation was not described explicitly in the text. In the not-notice condition, the target and most recently mentioned item were not adjacent in the spatial layout.

Two manipulations were used to encourage participants to form a spatial model of the layouts. First, for half of the participants, the texts were accompanied by pictures that illustrated part of the spatial layout. The reasoning was that the pictures might serve as a frame to guide participants' spatial representations (Glenberg & Langston, 1992). Stronger noticing effects were expected in the with-picture condition than in the no-picture condition. Also, all participants performed a diagram verification task. After reading each text, the participants were presented with a diagram of the layout of the items, and their task was to verify whether or not the diagram portrayed the same layout as that described in the text.

Glenberg and Langston (1992) assumed that spatial mental models are constructed using the spatial component of working memory. To test this assumption, a second manipulation was included: size of the putative mental model at the time of the probe. For half of the texts, the participants were probed after the fourth item was added to the layout (but the text then continued with a description of the other two items). For the other half, the participants were probed after the sixth item. We reasoned that participants were likely to have enough capacity to represent four items, but that six items would be likely to exceed this capacity. So, we expected to find a larger noticing effect in the four-item condition (because the target item should still be represented in the model when the probe was presented) than in the six-item condition.

Method

Participants. Eighty students participated in partial fulfillment of a course research requirement.

Materials. Participants read a total of 51 texts—48 experimental texts and 3 practice texts. Of the 48 experimental texts, 32 were critical texts (8 in each of four conditions) and 16 were filler texts. Each text described an arrangement of six items. Sample texts are presented in Table 1. Associated with each text was a seventh item that could plausibly be a part of the arrangement in the text, and this item was used when the correct answer to the speeded recognition probe was "no, this item was not mentioned in the text."

For with-picture participants, the texts were accompanied by a picture depicting the spatial arrangement of the first three items in the text (the entire arrangement was *never* illustrated). For the sentence describing the first item, the picture was a box surrounding

the name of the first item. When the sentences describing the second and third items were presented, the picture was updated by adding boxes appropriately located relative to the first box. The picture remained on the screen, with no further changes, while additional items were described. The picture was not visible when the probe appeared. Thus, although the picture could aid memory, in two ways it forced noticing to be based on a cognitive model. First, the critical most recently mentioned (fourth or sixth) item was not displayed in the picture. Second, the picture was not visible when the probe appeared.

Participants also verified a diagram after each text. The diagram was composed of six boxes arranged on the screen, with the names of the six items written in the boxes. Half of the time, these diagrams corresponded to the layout described by the text. When the diagram did not match the description in the text, the same spatial layout was used, but two items were chosen at random and their locations in the diagram were switched.

The 48 experimental texts were randomly ordered at the beginning of the experiment (the same three texts were always used for practice). The texts were then randomly assigned to one of the conditions. Conditions were assigned in such a way that in each block of six texts there was one text from each of the critical conditions plus two filler texts. These six conditions were randomly ordered in each block, and there was a total of eight blocks.

For filler texts, the probe was either the name of a seventh item (which did not appear in the text), or the name of some item in the text other than the first. Approximately two thirds of the filler texts had the seventh item as the probe (because all of the critical texts required a "yes" response, the majority of the fillers required a "no" response to provide some balance). The remaining one third of the filler texts had an item other than the first as the probe. Probes in the filler texts could appear after any sentence except those describing the fourth and sixth items (to break up the pattern of always probing after these sentences).

Design. The first independent variable, picture presence (picture or no picture), was manipulated between subjects. The second independent variable, size of the putative mental model at the time of the probe, was manipulated within subjects. For half of the critical texts, the fourth item was the most recently mentioned item, and for half of the texts, the sixth item was the most recently mentioned item. The third independent variable, noticing condition, was manipulated within subjects. The most recently mentioned item was either adjacent to the probed item in the spatial layout (the notice condition) or not adjacent to the probed item (the not-notice condition). The main dependent variable was response time to the probe. Probe question accuracy and the diagram verification question accuracy were also recorded.

Procedure. Experimental sentences were presented for a duration specified by the following equation:

$$\text{duration} = 1,000 + (\text{milliseconds/letter}) \\ * (\text{number of characters in the sentence}).$$

The result of the computation was a duration in milliseconds, and sentences were presented for that period of time. Before the experiment, each participant set the milliseconds/letter parameter to a comfortable reading speed using a staircase procedure.

Texts were presented to the participant one sentence at a time. Participants were instructed to imagine the layout on the table in front of them. At a predetermined point during the presentation of the text, a single word (or very short phrase) probe appeared on the screen with three asterisks on either side of it. Participants answered "yes" or "no" to the question "Was this word or phrase in the text you're currently reading?" Participants were instructed to respond to these probes as quickly as possible without making errors. Affirmative responses were made with the participant's dominant hand.

For critical texts, the probe word was always the first item in the text. For four-item texts, the probe appeared immediately after par-

ticipants read the sentence describing the placement of the fourth item. These texts continued after the probe with the placement of the fifth and sixth items. For six-item texts, the probe appeared immediately after participants read the sentence describing placement of the sixth item. After the entire text was presented, participants verified whether the arrangement of items in a diagram matched the arrangement in the text.

Results

Four separate analyses were conducted for all of the experiments reported in this paper. Two analyses were performed on median response times. For each participant the observations were sorted by condition, and then a median was computed for each condition. The data were analyzed using both the standard and loose analyses described above. The other two analyses were performed using mean log-trimmed *z* scores (Bush et al., 1993) as described in the introduction. These means were also computed using the standard and loose procedures.

Because the results of these four analyses were very similar for all of the experiments, we have elected to report in the text only the results from the loose medians analysis. We chose this analysis because it discarded few observations and because median reaction times are easier to interpret than *z* scores. Nonetheless, the critical notice versus not-notice comparisons from the other analyses are reported in Table 2. For all analyses, the significance level was set at .05.

The data were analyzed with a three-way ANOVA. The noticing hypothesis predicts a main effect for noticing: Participants should respond faster in the notice condition than in the not-notice condition. This main effect was not significant [$F(1,78) = 3.06$, $MS_e = 8,883$], although participants did respond faster in the notice condition ($M = 1,008$ msec) than in the not-notice condition ($M = 1,026$ msec). None of the other main effects or interactions was significant.

A second analysis was conducted with percent correct on the probe as the dependent variable. In this analysis, none of the main effects or interactions was significant. Overall accuracy was 93%.

A final analysis was conducted with performance on the diagram verification task as the dependent variable. In this analysis, the main effect for size was significant [$F(1,78) = 28.38$, $MS_e = 0.03$]. Participants were more accurate in the four-item condition ($M = 78\%$) than in the six-item condition ($M = 68\%$). The interaction between picture and notice was marginally significant [$F(1,78) = 3.82$, $MS_e = 0.02$, $p < .06$]. No-picture participants responded approximately equally accurately in the notice and not-notice conditions, whereas with-picture participants responded more accurately in the notice condition than in the not-notice condition.

Discussion

The results are not consistent with the noticing hypothesis. Participants did not respond to the probe significantly faster in the notice condition than in the not-notice condition. The failure of the hypothesis cannot be attributed

to participants' not encoding spatial information: Performance on the diagram verification task was well above chance. Also, the standard analysis is based only on the texts in which participants were successful in the diagram verification task.

Nonetheless, there was a hint (given the direction of the difference between notice and not-notice) that a noticing effect was present. One possibility is that noticing did take place, but that the distance manipulation in the first experiment was too weak. It might be that in both conditions, notice and not-notice, the two objects were either too close together or too far apart for a noticing effect to be detected. The plan for Experiment 2 was to refine the distance manipulation to better cover the range of distances between the most recently mentioned item and the target item.

EXPERIMENT 2

The notice variable (we will refer to it as the *distance* variable in this experiment) was expanded to include five distances. The first distance was equivalent to the notice condition in the previous experiment, in that the items in the layout were all immediately adjacent to one another and the most recently mentioned item ended up adjacent to the target item. The second distance was the notice-far condition. For texts in this condition, there was a gap in the layout. This gap was created by describing an item as being placed "way [direction]" with respect to some other item (e.g., "way left of"). An example is presented in Table 1. In this condition, the most recently mentioned item was still (ostensibly) adjacent to the target item, but there was a gap somewhere else in the arrangement. Depending on how participants treated the instruction to place an item "way" away from another item, the distance between the most recently mentioned item and the probed item could be identical to that in the notice condition, or, if the "way" relation was interpreted as signifying an ambiguous distance, the most recently mentioned item could be close to, but not adjacent to, the probed item.

The third distance was the far condition. Texts in this condition described a layout with a gap, but in this case the gap separated the most recently mentioned item and the target item. For this condition, the target item and the most recently mentioned item were not adjacent (in the layout), but there were no intervening items between them. The fourth distance was equivalent to the not-notice condition of Experiment 1: The target and most recently mentioned items were not adjacent, and there were intervening items between them. The fifth distance was the not-notice-far condition. For this condition, the most recently mentioned item was not adjacent to the target item, there were intervening items between them, and there was a gap in the arrangement.

We were also a bit worried that the picture condition used in Experiment 1 might have been misleading or confusing. That is, the pictures had boxes surrounding the names of the items, rather than analog representations of

the items. Perhaps the participants were confusing the boxes with the items themselves. To try to alleviate this problem, we added a third picture condition with unlabeled boxes. We hoped that participants would treat the boxes as simple spatial markers, rather than the objects themselves.

Method

Participants. Ninety students participated in partial fulfillment of a course research requirement. Data from 1 participant were lost because of a computer error.

Materials and Procedure. There were 55 texts: 40 critical texts (4 in each condition), 12 filler texts, and 3 practice texts. Each of the critical texts was presented twice, so that there was a total of eight observations in each condition. The presentation patterns used in the second half were the patterns used in the first half rotated 90° clockwise. An unlabeled-picture condition was added. This was the same as the picture condition in Experiment 1, except that the names of the items were not written in the boxes.

Design. The first independent variable, picture condition (picture, no picture, or unlabeled picture), was manipulated between subjects. The second independent variable, distance (notice, notice-far, far, not-notice, and not-notice-far), was manipulated within subjects. The third independent variable, size of the arrangement (four items or six items) was manipulated within subjects. The main dependent variable was response time to the probe. Accuracy for the probe question and accuracy for the diagram verification question were also recorded.

Results

The data were analyzed in a three-way ANOVA. The noticing hypothesis predicted a main effect of distance. This main effect was not significant [$F(4,328) = 0.90$, $MS_e = 9,685$]. The means for the five distance conditions were notice $M = 976$ msec, notice-far $M = 992$ msec, far $M = 976$ msec, not-notice $M = 984$ msec, and not-notice-far $M = 978$ msec. A second analysis was conducted with just the four-item-notice, six-item-notice, four-item-not-notice, and six-item-not-notice conditions in order to check the replication of the results of Experiment 1. In this analysis, the main effect of notice was not significant [$F(1,82) = 0.52$, $MS_e = 10,626$], although participants did respond a bit faster in the notice condition ($M = 976$ msec) than in the not-notice condition ($M = 984$ msec).

The main effect of picture was significant [$F(2,82) = 5.36$, $MS_e = 392,815$]. Participants responded faster in the with-picture ($M = 912$ msec) and unlabeled-picture ($M = 954$ msec) conditions than in the no-picture condition ($M = 1,078$ msec). The main effect of size was significant [$F(1,82) = 13.55$, $MS_e = 17,056$]. Participants responded faster when the probe occurred after four items ($M = 965$ msec) than after six items ($M = 998$ msec). None of the interactions was significant.

A second analysis was conducted with percent correct on the probe as the dependent measure. In this analysis, the main effect of size was significant [$F(1,82) = 9.00$, $MS_e = 0.013$]. Participants responded more accurately in the four-item condition ($M = 90\%$) than in the six-item condition ($M = 88\%$). The interaction between size and distance was also significant [$F(4,328) = 2.41$, $MS_e = 0.010$]. In the four-item conditions, participants were approxi-

mately equally accurate at all five distances, but in the six-item conditions, participants were more accurate in the far, not-notice, and not-notice-far conditions than in the notice and notice-far conditions. None of the other main effects or interactions was significant.

A final analysis was conducted with performance on the diagram verification task as the dependent variable. In this analysis, none of the main effects or interactions was significant. Overall accuracy on the diagram verification task was 65%.

Discussion

The results of Experiment 2 failed to support the noticing hypothesis. There was no consistent pattern of differences among the five distance conditions. Furthermore, close examination of Table 2 reveals that there were no distance effects for any of the comparisons between the various pairs of distance conditions, even with the more powerful log-trimmed z transformation. Perhaps limitations on working memory capacity were making it difficult for participants to form mental models.

EXPERIMENT 3

By hypothesis, spatial mental models are constructed with the use of the visuospatial sketchpad of working memory (Baddeley, 1986). Construction of the model may be interfered with, however, by the necessity to guide the eyes over the text (and picture). To test this idea, an auditory text presentation condition was added. If noticing takes place in the visuospatial medium of working memory, reducing the interference caused by eye-movements should enhance the noticing effect.

Method

Participants. Sixty-eight participants contributed data in partial fulfillment of a course research requirement.

Materials and Procedure. There were 50 texts: 48 experimental texts and 2 practice texts. Each text described an arrangement of four items. The texts were digitized one sentence at a time using a MacRecorder (in the monaural mode, sampling at a rate of 11 MHz). The texts were read by a female assistant in a normal speaking tone and at a rate approximating conversational speech. Two versions were digitized for the critical texts so that they could be presented in either the notice or the not-notice condition.

The texts were presented to the participants one sentence at a time. In the auditory condition, the texts were played through the Macintosh's internal speaker. The presentation rate in the visual condition was set to approximate the presentation rate in the auditory condition. For both conditions, probe words appeared on the screen.

Design. Picture presence (picture or no picture) and modality (reading or listening) were manipulated between subjects. Noticing condition was manipulated within subjects. In the notice condition, Item 4 was adjacent to Item 1 (the target item), and in the not-notice condition item, Item 4 was not adjacent to Item 1. The main dependent variable was response time to the probe. Accuracy for the probe and diagram verification questions was also recorded.

Results

The data were analyzed in a three-way ANOVA. According to the noticing hypothesis, participants should re-

spond faster in the notice condition than in the not-notice condition. This main effect was not significant [$F(1,64) = 0.55$, $MS_e = 14,045$]. However, participants did respond a bit faster in the notice condition ($M = 983$ msec) than in the not-notice condition ($M = 998$ msec). None of the other main effects or interactions was significant.

A second analysis was conducted with percent correct on the probe as the dependent variable. In this analysis, none of the main effects or interactions was significant. Overall accuracy was 93%.

A final analysis was conducted with performance on the diagram verification task as the dependent measure. In this analysis, the main effect of picture was significant [$F(1,64) = 10.92$, $MS_e = 0.03$]. Participants were more accurate in the with-picture condition ($M = 85\%$) than in the no-picture condition ($M = 75\%$). The main effect of modality was also significant [$F(1,64) = 25.58$, $MS_e = 0.03$]. Participants were more accurate in the auditory condition ($M = 88\%$) than in the visual condition ($M = 72\%$). The main effect of notice was also significant [$F(1,64) = 7.08$, $MS_e = 0.01$]. Participants were more accurate in the not-notice condition ($M = 82\%$) than in the notice condition ($M = 77\%$). The interaction between picture and modality was marginally significant [$F(1,64) = 3.81$, $MS_e = 0.03$, $p = .06$]. Participants in the with- and no-picture conditions were more accurate with auditory presentation than with visual presentation, but the effect was more pronounced for participants in the no-picture condition. None of the other interactions was significant.

Discussion

The results from Experiment 3 provide little support for the noticing hypothesis. Participants showed about the same noticing effect in the auditory and visual conditions, and the overall difference was very small. Performance on the diagram verification task indicated that the picture and modality manipulations had the desired effect. That is, participants represented the spatial layout of the items more accurately in the conditions designed to reduce interference with spatial working memory, but there was still no noticing effect in those conditions.

EXPERIMENT 4

Experiments 1–3 demonstrated that noticing did not seem to take place even under conditions that should have been optimal (with a picture for perceptual support, with auditory presentation freeing up working memory). The various results from the diagram verification task demonstrate that participants did form a spatial representation, but that representation does not support noticing. However, some potential methodological problems could weaken the conclusion that noticing was not taking place. The problems were: (1) Item 1 was often the critical probe item. This might have engendered guessing strategies and it might have encouraged special effort to keep the item activated, thus overriding any effect of noticing. (2) The correct answer to the recognition probe was more frequently

Table 3
Sample Text From Experiment 4

Text	
	Alan was arranging some modes of transportation according to how comfortable they seem to him.
	Alan started with trains.
	Then way in front of trains Alan placed planes because they seem more comfortable.
	Then immediately in back of planes Alan placed cars because they seem less comfortable.
Probes	
	Notice: trains
	End: planes
	Item 3: cars
	"No": buses
Verification Sentences	
	trains seem more comfortable than planes (F)
	trains seem more comfortable than cars (F)
	planes seem more comfortable than cars (T)
	planes seem more comfortable than trains (T)
	cars seem more comfortable than trains (T)
	cars seem more comfortable than planes (F)

"yes" than "no," suggesting that participants might have adopted a strategy to respond "yes" most of the time. (3) The evidence that the item recognition task was tapping a spatial representation is not as convincing as it might be. (4) The evidence that readers were forming spatial representations is not as convincing as it might be.

Experiment 4 was designed to address these objections. All of the texts described arrangements of three items. An example is given in Table 3. To correct the first problem, half of the notice and not-notice probes were Item 1 and half of the notice and not-notice probes were Item 2. Item 3 was also used as the probe item with the same frequency as Items 1 and 2, in order to eliminate any potential focusing strategy that might be employed by the participants. However, data from the item three probes did not enter into the analyses. To correct the second problem, there were equal numbers of "yes" and "no" probes.

To correct the third problem, we used a set of "spatial" probes² to demonstrate that the item recognition probes are tapping into a spatial representation. From the participant's point of view, these spatial probes were identical to the notice and not-notice probes; that is, the spatial probes were item recognition probes. Half of the spatial probes involved an item at an end of the dimension, and half of the spatial probes involved an item in the middle of the dimension. Note that "end of the dimension" refers to the dimension formed by comprehension—that is, a dimension in a spatial representation—and it does not correspond to the literal order of mention. Items 1 and 2 were used as the spatial probes equally often. If there is a difference between response times to items from the end of the dimension and items in the middle, this would indicate that the item recognition task is sensitive to spatial location. If there is an effect of spatial location in the absence of a noticing effect, this would indicate that the lack of a noticing effect is *not* due to insensitivity of the item recognition probe to spatial representations.

Experiments 1–3 demonstrated that readers formed spatial models with a diagram verification task. To demonstrate that readers formed a spatial representation in Experiment 4, we replaced the diagram verification task with a symbolic distance task. The symbolic distance effect is that when items are arranged along a dimension (the dimension is *comfort* for the example in Table 3), judgments about pairs of items that are near on the dimension take longer than judgments about pairs of items that are far apart on the dimension (Moyer, 1973; Potts, 1972). For the text in Table 3, participants should verify "planes seem more comfortable than trains" faster than "planes seem more comfortable than cars," since planes and trains are farther apart on the dimension of comfort. If participants in this experiment formed an appropriate representation of the spatial arrangement of the items in the text, then we ought to get a symbolic distance effect. Note, again, that because the order in which the items were described in the text was different from their order on the dimension, correct performance on the symbolic distance task required forming the appropriate spatial ordering.

The design of the experiment was not ideal for examining the symbolic distance effect. The problem is that there was a confounding of "distance" between items on the dimension and whether the items were on the ends of the dimension. This confounding was not a problem here, however, because whether the symbolic distance effect was due to end items or distance was irrelevant. In either case, observing the effect was sufficient to conclude that readers were constructing the appropriate spatial representation because both "end item" and "distance" were defined in terms of the constructed representation, not the order of occurrence of the items in the text.

Method

Participants. Twenty-six participants contributed to the experiment. Two participants failed to complete the experiment, and data from 2 participants were lost because of computer failure.

Materials. There were 98 texts: 96 experimental texts and 2 practice texts. Of the 96 experimental texts, 8 had notice probes, 8 had not-notice probes, 8 had spatial-end probes, 8 had spatial-middle probes, 16 had item three probes, and 48 had "no" probes.

Each text described an arrangement of three items. Item 1 and Item 2 probes were notice, not-notice, spatial-end, or spatial-middle probes. There are two features to note in these texts. First, the relation between the last mentioned item (item three) and the target was always implicit, rather than given directly in the text. Thus we could ask whether accessibility of the target varies with its spatial proximity to the last mentioned item. Second, the locution "way in front of" or "way behind" was used in every text to describe the relation between the first and second items. This was done to leave room (in a spatial layout) for the possible insertion of the object named by the third item. Because the results from Experiment 2 indicated that near versus far in a spatial model (with no intervening items) had little effect on noticing, we were not concerned about the introduction of this locution.

After each text, participants responded to six true/false symbolic distance questions. Each question was a statement about the relative positions of a pair of items from the text on the dimension. Sample questions are presented in Table 3. The six questions contained all possible combinations of the three items in the text, and the order of the questions was randomized independently for each text for each

Table 4
Sample Notice Text From Experiment 5

Kelly was arranging things on her night table.
She put the book down first.
Then she put the jewelry box to the right of the book.
Next, Kelly put the alarm clock in front of the jewelry box.
Then she put the photograph to the left of the alarm clock.
The book was a gift.
Finally, Kelly moved the book in front of the alarm clock.

Comprehension Question

How was the book obtained?

participant. For half of the questions, the correct response was "true," and for half of the questions, the correct response was "false."

Design. All independent variables were manipulated within subjects. The independent variables associated with the item recognition probes were noticing condition (notice, not-notice), location (end, middle), and item (one, two). The independent variable associated with the symbolic distance questions was distance (near, far). The dependent measures were response time and accuracy.

Procedure. Participants were presented with instructions via computer. Each text was presented one sentence at a time, and the presentation time for each sentence was set as $(\text{length}(\text{sentence}) \times 33) + 2,000$ msec. After presentation of the sentence describing the location of the third item, the participants responded to an item recognition probe. The participants always responded "yes/true" with their dominant hand. Incorrect responses were followed by a beep. After responding to the probe, the participants responded to the six symbolic distance sentences.

Results

Three separate analyses were performed. First, the data from the spatial probes were analyzed in a two-way ANOVA with location and item as the factors. According to the spatial hypothesis, we expected a main effect for location. This main effect was significant [$F(1,21) = 6.22$, $MS_e = 13,408$]. Participants responded faster to the middle item ($M = 1,012$ msec) than to the end item ($M = 1,074$ msec). The main effect of item and the interaction between location and item were not significant. These data indicate that the item recognition task used in the experiment was sensitive to a spatial representation. A second ANOVA was conducted with percent correct for the spatial probes as the dependent measure, in order to check for a speed-accuracy tradeoff. In this analysis, none of the effects was significant. Overall accuracy was 96%.

If participants were forming a lasting representation of the spatial arrangement, we ought to see a symbolic distance effect. In particular, participants ought to have responded faster to sentences containing pairs of items that were far on the dimension than to sentences containing pairs of items that were near on the dimension. This effect was significant [$t(21) = 6.17$, $SEM = 44.93$]. The mean for far sentences was 1,294 msec, and the mean for near sentences was 1,572 msec. These data indicate that participants were forming an appropriate representation of the arrangements described in the texts. An analysis of accuracy data from the symbolic distance questions also showed an effect of distance [$t(21) = -3.91$, $SEM = 0.011$]. Parti-

cipants were more accurate in the far condition ($M = 89\%$) than in the near condition ($M = 85\%$).

In the third analysis, to investigate the noticing effect, we used a two-way ANOVA³ with notice condition and item (the target item was Item 1 or 2) as the factors. If the noticing hypothesis were correct, we would expect participants to have responded faster to notice probes than to not-notice probes. This main effect was not significant [$F(1,21) = 0.28$, $MS_e = 18,782$], although participants did respond a bit faster in the notice condition ($M = 1,074$ msec) than in the not-notice condition ($M = 1,090$ msec). The main effect of item and the interaction were not significant. An analysis of the accuracy data showed no main effects or interactions. Overall accuracy was 95%.

Discussion

All items were used as the probe item equally often and there were equal numbers of "yes" and "no" responses, ruling out the possibility that participants were using simple guessing strategies. Data from the symbolic distance task indicate that participants were clearly forming an accurate representation of the arrangements described in the texts. The data from the spatial probes indicate that the item recognition task was sensitive to spatial arrangement. In spite of this, the results of Experiment 4 failed to support the noticing hypothesis. That is, the spatial representation does not seem to be a Euclidean space.

One component of these data seems a bit unusual. For the spatial probes, responding was faster for items in the middle of the ordering than for items on the ends. The expectation of an advantage for end items arises, in part, from work on the symbolic distance effect: Symbolic distance comparisons involving end items are fast. However, the spatial probes did not involve comparisons, only access. To our knowledge, there are no data demonstrating faster access to end items with the use of a recognition probe. Faster responding to middle items is consistent with a spatial representation if it is assumed that participants are focusing on the middle items in a spatial representation (perhaps looking at them with the mind's eye) in an attempt to keep all items equally available.

EXPERIMENT 5

Experiments 5–7 also addressed the potential problem that item recognition is not sensitive to spatial representations (although the results of Experiment 4 seemed to rule this out). The dependent variable was the time to read an *about* sentence. This sentence always provided a new fact about the target item. An example is given in Table 4. The *about* sentence was presented immediately following the description of the fourth item, which was either adjacent to the target item in the spatial layout (notice condition) or separated from the target item (not-notice condition). We hypothesized that when constructing the model, participants would be more likely to access the target item in the notice condition than in the not-notice condition, and that

this noticing should speed reading of the about sentence in the notice condition.

Following the about sentence was a *move* sentence. It described how the protagonist moved one of the previously located items (the target item for the critical texts) to a new location. The move sentence was included to ensure that participants were building a mental model that was capable of being updated, rather than a static representation.

Method

Participants. Fifty students participated in partial fulfillment of a course research requirement.

Materials. Thirty-five texts—32 experimental texts and 3 practice texts—were used in the experiment. The experimental texts were each used twice and were randomly reassigned to conditions for the second pass. This resulted in 16 notice texts, 16 not-notice texts, and 32 filler texts for each participant. Each text described an arrangement of four items. After the description of the location of the fourth item, an about sentence was presented. This sentence described something about the target item. This was followed by a move sentence describing the movement of an item to another location.

Design. A single factor within-subjects design was used. The independent variable was the noticing condition. In the notice condition, Item 4 was adjacent to Item 1 (the target item) in the spatial layout, and in the not-notice condition, Item 4 was not adjacent to Item 1. The main dependent variable was reading time for the about sentence. Accuracy in responding to a diagram verification task was also recorded.

Procedure. Participants began the experiment with three practice texts. If the participant answered incorrectly on the diagram verification for all three of the practice texts, he/she was prompted to alert the experimenter, who made sure that he/she understood the procedure. Texts were presented to the participants one sentence at a time. The presentation rate was self-paced. After the sentence describing the location of the fourth item, the about sentence was presented, and reading time was collected.

After reading the text, participants answered the diagram verification question. The diagram verification task was in a multiple-choice format. Four layouts for the items in the text were displayed, and the participant selected the one that correctly represented the layout after the move sentence. The participants used the keyboard to type their answers to the comprehension question.

Results

The difference between the notice and not-notice conditions was not significant [$t(49) = 0.03$, $SEM = 55.4$]. Median reading time in the notice condition ($M = 1,538$ msec) was virtually the same as in the not-notice condition ($M = 1,539$ msec).

A second analysis was performed with percent correct on the diagram selection task as the dependent variable. The difference between the percent correct for the two conditions was significant [$t(49) = 4.94$, $SEM = 0.03$]. Participants were more accurate in the notice condition ($M = .75$) than in the not-notice condition ($M = .59$).

Might the degree of noticing be related to individual differences? In several of the earlier experiments, we investigated whether noticing was correlated with individual differences in comprehension or individual differences in spatial memory capacity. We did not report this work

for the earlier experiments because we did not find any significant relations that replicated across experiments. We take up the question again here, in part because it provided a major motivation for the next experiment. We reasoned as follows. Noticing presupposes that people are building mental models and comprehending the texts. In fact, if individuals are not attempting to comprehend the spatial layouts, it is unlikely that they would show a noticing effect. Thus, we predicted a positive correlation between size of the noticing effect and performance on the diagram selection task. The correlation was not significant, however [$r(48) = .14$].

Discussion

The results from Experiment 5 provided little support for the noticing hypothesis. Nonetheless, we were encouraged (perhaps perversely) by the correlational analysis. Although the correlation from the loose medians analysis was not significant, other versions of the correlation flirted with statistical significance. Thus, we thought it worth another try.

The correlation might have had a source having little to do with noticing, however. The not-notice conditions had arrangements that were, in some ways, more complex than the arrangements used in the notice conditions. For example, most of the patterns in the notice condition conformed to a square or rectangular layout of objects, whereas many of the patterns in the not-notice condition were more akin to a *z* shape. Perhaps the not-notice patterns were more difficult to construct or hold in memory. This difference in pattern complexity could explain the trend to have slower reaction times and slower reading times in the not-notice conditions (see Table 2). Differences in pattern complexity might also give rise to the correlation between the size of the noticing effect and performance on the diagram selection task. Consider, first, a participant who is working hard to comprehend. This participant will do well on the diagram selection task. Also, because the participant is representing the spatial layouts while reading, the participant will read the complex not-notice texts more slowly than the less complex notice texts. That is, the participant will produce a noticing effect by virtue of complexity's affecting reading time, not noticing. Now consider a participant who is not working diligently to comprehend. This participant will perform poorly on the diagram selection task. In addition, because this participant is not constructing the spatial layouts, the participant will not be adversely affected by the complex not-notice texts. Considering the patterns produced by these two types of participants, a positive correlation between performance on the diagram selection task and the size of the noticing effect might be due to a relation between comprehension and susceptibility to the more difficult not-notice arrangements, rather than a relation between comprehension and noticing on the basis of distance between elements in a spatial mental model.

Table 5
Sample Texts From Experiment 7

Introduction

Doug was setting up for a picnic.
First, he positioned the cake.

Notice Text, Frame of Reference on Item 3

Then he put the picnic basket to the right of the cake.
Next, he put the box of chicken directly to the left of the picnic basket.
So, the picnic basket is on the box of chicken's right.
The cake was strawberry.
The picnic basket broke.

Notice Text, Frame of Reference on Item 2

Then he put the picnic basket to the right of the cake.
Next, he put the box of chicken directly to the left of the picnic basket.
So, the box of chicken is on the picnic basket's left.
The cake was strawberry.
The picnic basket broke.

Not-Notice Text, Frame of Reference on Item 3

Then he put the picnic basket to the right of the cake.
Next, he put the box of chicken directly to the right of the picnic basket.
So, the picnic basket is on the box of chicken's left.
The cake was strawberry.
The picnic basket broke.

Not-Notice Text, Frame of Reference on Item 2

Then he put the picnic basket to the right of the cake.
Next, he put the box of chicken directly to the right of the picnic basket.
So, the box of chicken is on the picnic basket's right.
The cake was strawberry.
The picnic basket broke.

Test Questions

Is the cake anywhere to the right of the box of chicken?
Is the picnic basket anywhere to the left of the cake?
Was the cake chocolate?
Did the picnic basket break?

EXPERIMENT 6

The design of Experiment 6 allowed us to discriminate between the two explanations for the correlation between noticing and performance on the diagram selection task. In the target Item 1 condition, participants read exactly the same texts as did the participants in Experiment 5. If the correlation between the size of the noticing effect and performance on the diagram selection task was due to noticing, then participants in the target Item 1 condition should produce a noticing effect and a correlation between the size of the noticing effect and performance on the diagram selection task. In the target Item 2 condition, participants read texts that were modified so that the about sentence described a fact about the second item in the text. When Item 2 was the target, the most recently mentioned item (Item 4) was diagonally removed from the target in both the notice and not-notice conditions. Thus, the distance between the most recently mentioned item and the target item was the same in the notice and not-notice conditions. In this case, if distance between elements in a mental model produced a noticing effect, there should be no noticing effect in the target Item 2 condition. Nonetheless, in the target Item 2 condition, the not-notice arrangements were more complex than the notice arrangements. Thus, if complexity of arrangements produced the "noticing ef-

fect" (in quotes because it is an effect of complexity, not noticing), participants in the target Item 2 condition should produce a "noticing effect" and a correlation between the size of the "noticing effect" and performance on the diagram selection task. To summarize, if distance in the mental model was the operative variable, only participants in the target Item 1 condition would produce a noticing effect and a correlation. On the other hand, if complexity of arrangement was the operative variable, participants in both conditions would produce the "noticing effect" and the correlation.

Method

Participants. Seventy-eight people participated in the experiment in partial fulfillment of a course research requirement.

Materials and Procedure. Half of the participants (those in the target Item 1 condition) saw texts that were identical to those in Experiment 5. Importantly, the about sentence (for which we collected reading time) referred to Item 1. For the other participants (those in the target Item 2 condition), the about sentence pertained to Item 2.

Design. A mixed-factorial design was used. The between-subjects independent variable was target item. In the target Item 1 condition, the about sentence referred to Item 1. In the target Item 2 condition, the about sentence referred to Item 2. The within-subjects independent variable was the noticing condition. In the notice condition, Item 4 was adjacent to Item 1 in the spatial layout, and in the not-notice condition, Item 4 was not adjacent to Item 1. The main dependent variable was reading time for the about sentence. Accuracy in responding to the diagram selection task was also recorded.

Results

The data were analyzed in a two-way ANOVA. According to the hypothesis, participants in the target Item 1 condition should read notice texts faster than not-notice texts, but participants in the target Item 2 condition should not show any difference between notice and not-notice texts. Thus, the hypothesis predicted an interaction between noticing condition and target item. This interaction was not significant [$F(1,76) = 0.08$, $MS_e = 64,909$]. The reading times for target Item 1 showed the predicted pattern in that the about sentence was read faster in the notice condition ($M = 1,615$ msec) than in the not-notice condition ($M = 1,652$ msec). However, approximately the same difference was found in the target Item 2 condition: The about sentence was read faster in the notice condition ($M = 1,606$ msec) than in the not-notice condition ($M = 1,666$ msec). No main effects or interactions were significant [for the main effect of noticing, $F(1,76) = 1.41$, $MS_e = 64,909$].

A second analysis was performed with percent correct on the diagram selection task as the dependent variable. The main effect for noticing was significant [$F(1,76) = 14.58$, $MS_e = 0.02$]. Participants were more accurate in the notice condition ($M = .74$) than in the not-notice condition ($M = .65$). No other main effects or interactions were significant.

Correlations between the size of the noticing effect and performance on the diagram selection task were computed separately for target Item 1 and target Item 2 conditions. They were $-.11$ and $-.04$, respectively, and neither was statistically significant.

Discussion

The results from Experiment 6 provide little support for the noticing hypothesis. The differences between notice and not-notice median times to read the about sentence were in the predicted direction. But (1) the difference was not significant; (2) the same magnitude of difference was found in the target Item 2 condition, which should not have produced a noticing effect according to the noticing hypothesis; and (3) the correlation between size of the noticing effect and performance on the diagram selection task was not significant, and it was not even in the right direction. As in Experiment 5, there was a significant difference between the notice and not-notice conditions in the diagram verification task. Apparently, the not-notice layouts were a bit more complex than the notice layouts. This difference in complexity may well underlie the small positive noticing effects reported in Table 2.

EXPERIMENT 7

In Experiment 7, we manipulated a frame of reference variable (as in Logan, 1995).⁴ In all of the previous experiments, the most recently mentioned item was located in reference to another item. Thus, in the example text in Table 5, the box of chicken is located to the left or right of the picnic basket. In other words, to locate the most recently mentioned item, attention must be directed to the *other* item, not the most recently mentioned item. With attention directed to the *other* item, items spatially close to the *other* item may be noticed, but all of our attempts to measure noticing had been in relation to the most recently mentioned item, not the *other* item. In this experiment, we manipulated whether the frame of reference remained on the *other* item (Item 2), or whether it was shifted to the most recently mentioned item (Item 3). This manipulation was accomplished by adding to the text a *verification* sentence between the sentence locating Item 3 and the about sentence. The verification sentence restated the relation between Item 3 and Item 2, but in a manner that could shift the frame of reference. In the example in Table 5, with the verification sentence "So, the box of chicken is on the picnic basket's left," the frame of reference remains on Item 2, the picnic basket. In the verification sentence, "So, the picnic basket is on the box of chicken's right," the frame of reference is located on Item 3, the most recently mentioned item. Both versions of the verification sentence describe the same spatial layout. The slightly odd wording for the verification sentence was chosen to avoid verbatim repetition of the previous sentence in the not-notice condition. The frame-of-reference-modified noticing hypothesis predicted greater noticing when the frame of reference was shifted to Item 3 (the most recently mentioned item) than when the frame remained on Item 2.

A second issue consisted in how we encouraged participants to maintain a spatial layout. In the previous experiments, we tested memory for spatial layout and depended on the participant's motivation to do well on the test. In Experiment 7, we upped the motivational ante. After read-

ing a text, participants responded to two questions about the spatial layout and two questions about the about sentences. If the participant missed one or more of these questions, the condition was repeated later in the session. The participants were forewarned of this, and they were given feedback following each text. Of course, we did not want to have some participants continuing indefinitely, so (unknown to the participants) the maximum number of texts that could be repeated was 10.

Method

Participants. Forty people participated in the experiment in partial fulfillment of a course research requirement. Two participants withdrew from the experiment, and the data from a 3rd participant were lost because of computer failure.

Materials. Participants read, initially, a total of 43 texts: 40 experimental texts (32 critical texts and 8 filler texts) and 3 practice texts. Each text described an arrangement of three items. Each text also contained a verification sentence, which served to put the frame of reference on the desired item, and two about sentences, one of which referred to Item 1, the other to Item 2. The initial about sentence always referred to Item 1, and we measured the reading time of this sentence as an index of noticing. The second about sentence was included so that the initial about sentence would not be the last sentence in the passage.

Instead of a diagram selection test, participants answered two test questions regarding the spatial layout described in the text. The specific questions were randomly selected for each participant and text so that the correct answer was approximately equally often *yes* or *no*. In addition, participants responded to two yes or no questions regarding the about sentences.

Design. Both independent variables were manipulated within subjects. The first independent variable was frame of reference. In the Item 2 frame-of-reference condition, the verification sentence was worded to place the frame of reference on Item 2. In the Item 3 frame-of-reference condition, the verification sentence was worded to place the frame of reference on Item 3. The other independent variable was the noticing condition. In the notice condition, Item 3 was adjacent to Item 1 (the target item) in the spatial layout, and in the not-notice condition, Item 3 was not adjacent to Item 1. The main dependent variable was the reading time for the initial about sentence. Accuracy in responding to the four questions was also recorded and used to determine the necessity for repetition of a text in a particular condition.

Procedure. Texts were presented one sentence at a time. Presentation rate was self-paced. Participants were required to correctly answer all questions on the three practice texts before going on to the experimental texts. For each text, the participants answered two yes/no questions regarding the layout of the items described in the text, as well as a yes/no question for each of the two about sentences. If any of these four questions was missed, the participant had to read an additional text in that condition following completion of the initial 40 experimental texts. The particular text reread was selected at random from the 40 experimental texts, but was presented in the same condition as was the text for which the participant answered a question incorrectly.

Results

If participants missed any of the test questions, the data from that text were dropped and the condition was repeated after the initial pass through the 40 texts. The participants reread an average of 3.27 (2.27) notice texts, 2.38 (2.24) not-notice texts, and 2.03 (2.02) filler texts. By the end of the experiment, 30 participants had contributed

eight observations to each of the critical conditions, and 7 participants had fewer than eight observations in each critical condition either because they had missed questions on more than 10 texts in the initial pass, or because they missed questions during the second pass. We used the data from all 37 participants to maximize statistical power.

The times to read the initial about sentences were analyzed in a two-way ANOVA. The frame-of-reference-modified noticing hypothesis predicted (1) a main effect of noticing condition and (2) an interaction between notice and frame of reference. The main effect was not significant [$F(1,36) = 0.62$, $MS_e = 107,867$], nor was the interaction significant [$F(1,36) = 0.02$, $MS_e = 110,841$]. In the Item 3 frame-of-reference condition, participants read the initial about sentence faster for notice texts ($M = 1,762$ msec) than for not-notice texts ($M = 1,797$ msec). The same was true for the Item 2 frame-of-reference condition (notice text $M = 1,762$ msec, not-notice text $M = 1,812$ msec).

Discussion

Although there was a hint of a noticing effect in the z score analysis (see Table 2), because it was of borderline significance, because we had done so many analyses, and because the interaction with frame of reference was not close to being significant, we believe that the apparent effect of noticing was not real.

GENERAL DISCUSSION

The empirical conclusion is inescapable: Noticing rarely occurs. To say it differently, readers do not seem to infer relations in a mental model on the basis of spatial contiguity alone. The caveat "alone" is important. One can imagine situations in which a reader might well infer unstated spatial relations by using past experience or when the spatial relations were particularly important. In any event, we have demonstrated that simply forming a cognitive representation of stated spatial relations does not engender noticing of additional spatial relations.

It is also clear from our data, as well as from the data from many other laboratories, that readers encode spatial relations and that they are functional. Notice the good performance on the various types of spatial comprehension questions as well as the symbolic distance effect reported for Experiment 4. It appears, however, that the sorts of spatial relations encoded from text are all explicitly stated in the text, are based on past experience, are depicted in an accompanying picture, or are based on repeated presentations of the text and task demands to form a detailed spatial representation (e.g., Denis & Cocude, 1992; Glenberg & Langston, 1992; Rinck, Hähnel, Bower, & Glowalla, 1997; Wagener & Wender, 1985). There is little evidence that readers infer spatial relations on the sole basis of contiguity in a spatial mental model; that is, there is little evidence for noticing.

These experiments join a growing body of literature questioning the assumption that the representation of spatial information is Euclidean. That is, mental models are

more than simple, unstructured spaces in which proximity alone can drive inference making. McNamara (1986) demonstrated that after subjects had learned locations of objects, objects near to one another primed each other more effectively than those farther away. However, objects in a single bounded region led to greater priming than did equally distant objects in two regions. In other words, spatial priming was not a simple function of distance; region also affected the degree of relation. McNamara, Hardy, and Hirtle (1989) were able to show that subjective regions (as opposed to those marked explicitly on a map) also affected spatial priming. The conclusion is that spatial information is not represented in a system that is Euclidean, but that hierarchical or topological relations (e.g., regions) also affect performance.

Tversky and her colleagues (e.g., Bryant, Tversky, & Franklin, 1992; Franklin & Tversky, 1990) have proposed that spatial descriptions are retrieved (and perhaps encoded) by using a "spatial framework" that is decidedly not Euclidean. Their basic findings come from a paradigm in which readers first read about and memorize a three-dimensional spatial layout of objects. The reader is then instructed to imagine facing one of the objects (or the protagonist in the text is described as facing one of the objects). Finally, the reader is instructed to retrieve the names of objects in various directions such as up/down, front/back, and left/right. The basic finding is that retrieval times are a function of the direction, with the fastest times being for up/down and the slowest for left/right. Once again, the conclusion is that the representation of spatial layout (or the retrieval of objects from the representation) does not reflect an unstructured space.

There is also reason to question the analogical interpretation of the distance effects observed in the Morrow and Bower paradigm (e.g., Morrow et al., 1989). For example, in Rinck and Bower (1995) and Rinck et al. (1997, from which the following examples are taken), participants memorized the spatial layout of a building and then read about the movements of a protagonist through the building. A *motion sentence* such as "Then he walked from the storage room into the lounge" described the movement of the protagonist from a source room (storage room) to a goal room (lounge), and the sentence implied a path that traversed an unnamed path room (in this case, a repair shop). After reading the motion sentence and a motivating sentence that provided a context for the target sentence, the participants read a target sentence that referred to an object in the source, path, or goal rooms. An example of a target sentence is, "He decided that the cart should not be so dirty tomorrow." Time to read the target sentence was a monotonically increasing function of distance of the room containing the object from the protagonist's location in the goal room. This result is consistent with the claim that spatial distance from the protagonist is a critical factor in comprehending reference to objects. However, Rinck et al. report data that strongly question the idea of a Euclidean representation affecting text comprehension. In these experiments, the memorized layout

included "path" rooms that were either divided (so that there were two path rooms implied by the motion sentence) or undivided. The divided and undivided path rooms contained the same objects and occupied the same space. Rinck et al. tested whether the time to read a sentence referring to an object in the path room was sensitive to distance of the object (in the path room) from the protagonist. In fact, when the path room was divided, distance affected reading time so that sentences about objects in the path room far from the protagonist took longer to read than sentences about objects in the path room closer to the protagonist. This effect could have been due either to distance or to a category effect based on the number of (divided) rooms. The critical conditions involved the undivided path room containing objects that were literally as far from the protagonist as they were when the path room was divided. In this case, distance played no role in reading time. Apparently, number of rooms, rather than distance, produced the effect. Interestingly, Rinck et al. did find evidence that spatial representations could incorporate analogical components. When the participants were asked to judge the relative distance of objects from the protagonist, the speed of the judgments was inversely related to the distance between the objects. This result corresponds to the finding in Experiment 4 that participants' performance on the symbolic distance task seemed to reflect distance. Overall, the results from the Rinck et al. experiments imply that spatial information derived from a memorized layout may be represented with analogical properties, but that those properties do not affect text comprehension processes (simple distance is not the whole story).

Much of the data appear to be covered by a relatively simple generalization. Cognitive representations derived from perception, pictures, or many repetitions of a text (see Denis & Cocude, 1992) may well have Euclidean components, but the Euclidean nature of those components does not necessarily affect text comprehension. This is consistent with work by Zwaan and van Oostendorp (1993) demonstrating that when readers are understanding a real (but edited) mystery novel, they have difficulty answering questions involving spatial inferences without special instructions emphasizing constructing models. Furthermore, on the basis of the experiments reported here, reading in the absence of pictures or multiple passes at the text is unlikely to result in a representation that is Euclidean.

We began this investigation with questions about the nature of mental models. Can we say anything positive about that nature? Again, one conclusion is clear: For texts read without the support of pictures and multiple passes, the representation of space is not Euclidean. An alternative is to conclude, along with van Dijk and Kintsch (1983), that mental models are intrinsically propositional. There are strong grounds to question this alternative, however (see Barsalou, 1993; Glenberg, 1997; and Lakoff, 1987). In brief, propositions are composed of abstract symbols that are difficult or impossible to associate with external referents. Thus, propositional systems are inherently syntactic and represent only relations to other propositions, not relations

to the world. Mental models, on the other hand, are quintessentially semantic; they encode our understanding of particular situations in the world, not just relations among abstract symbols.

After propositional and Euclidean representations have been discounted, many possibilities remain, although none are currently as well developed as the propositional account. Several of these are related to the concept of embodiment (Johnson, 1987; Lakoff, 1987; see Rinck et al., 1997, for other possibilities). In contrast to propositional representations, embodied representations are not constructed from abstract symbols. Instead, the basic elements of the system are shaped by how the body interacts with the environment. Thus, Johnson (1987) has described how the physical nature of our bodies leads to consistent, structured, experiences of *in-out*, such as putting food into our bodies and moving into and out of rooms. This sort of basic bodily experience is proposed to underlie our understanding of concepts such as containment, as well as our understanding of more metaphorical uses of spatial terms such as to *wake out* of a deep sleep. In contrast to representations built out of Euclidean space, embodied representations are highly structured. For example, Lakoff (1987) describes the structure of the *container schema* as having an inside, an outside, and a boundary. Importantly, the schema specifies how being in a container carries many implications (e.g., that what is in the container is under the control of the container). Embodied accounts of meaning are being developed by Lakoff and others (e.g., Barsalou, 1993; Glenberg, 1997; Lakoff, 1987).

Consider how such an account might handle the contrast between the results of Glenberg et al. (1987, described in the introduction), which suggest a strong contribution of analogical spatial relations to comprehension, and the results of the present experiments, suggesting the opposite. When the protagonist, John, puts on his sweatshirt to go jogging, the sweatshirt is spatially close to him. What may be more important, however, is that the sweatshirt is literally attached to John. Attachment is just the sort of relation that can arise from bodily interactions with the world, such as holding hands with one's parents (see Lakoff's [1987] discussion of the "Link" schema). One of the consequences of attachment is a dependency, so that the sweatshirt goes where John goes. When John takes off his sweatshirt, the attachment relation is broken and the dependency no longer applies. Given these functionally different relations, we would suspect that having the sweatshirt on or off would affect comprehension, and it does. In contrast, consider the spatial arrangement described by the sample text in Table 1. Whereas the objects have different spatial relations to one another, there is little or no differentiation in regard to functional, topological, or embodied relations. For example, all of the objects in the text in Table 1 can be considered to be in the same container (the aquarium), and thus all are equally likely to interact with each other and equally likely not to interact with objects outside of the aquarium. On this analysis, and consistent with the experiments reported here, because the objects

are not differentiated in regard to embodied relations, they are not differentiated in regard to effects on comprehension.

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NOTES

1. All of the patterns of spatial layouts are available from the first author.
2. There was only one item recognition probe for each text. So, for a given text, the probe could be notice, not notice, spatial end, spatial middle, Item 3, or some item not in the text (a "no" probe).
3. The noticing effect reported in Table 2 is different from that reported here, because the data in Table 2 combine notice and not-notice probes from Items 1 and 2 whereas the data in the text separate Items 1 and 2.
4. Thanks to Morton Ann Gernsbacher and Karen Luh for suggesting many of the novel features of this experiment.

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