Mental maps in memory retrieval and comprehension

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How do people use spatial information stored in maps? This question has been explored in a number of domains, such as memory and language comprehension, with differing results. Some studies of how experimentally learned maps are organised in memory, using primed recognition, have found temporal information to influence mental map organisation. In contrast, studies of narrative comprehension, using probe identification and anaphoric reading times, have observed spatial effects. This study combines these two research traditions and shows that the organisation observed in long-term memory differs from the organisation in narrative comprehension, even when both tasks refer to the same map.

To what extent does the organisation of a mental map affect later cognitive processing? One way to address this question is to have people memorise a map to see how mental representation that is created influences their subsequent use of that map information. This approach has been used in studies investigating the organisation observed when retrieving map information from long-term memory (Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara, Ratcliff, & McKoon, 1984), as well as in studies investigating how spatial information influences the updating of situation models created during narrative comprehension (Morrow, Bower, & Greenspan, 1989; Morrow, Greenspan, & Bower, 1987; Rinck & Bower, 1995). The results of long-term memory retrieval studies have indicated that the temporal proximity information available during learning may play a primary role over spatial information in the organisation of a mental map (Clayton & Habibi, 1991; Curiel & Radvansky, 1998). In contrast, studies of narrative comprehension have consistently revealed a general spatial influence in updating situation models (Morrow et al., 1987, 1989; Rink & Bower, 1995; but see deVega, 1995; Gray Wilson et al., 1993; Zwaan, Radvansky, Hilliard & Curiel, 1998).

The aim of the present study is to further investigate the differences observed in memory retrieval and narrative comprehension. On the one hand, it may be that due to differing goals, a memory retrieval task, such as item recognition, may not involve processes that are involved in narrative comprehension. Specifically, during recognition, one needs to identify whether an object was present on the previously memorised map, which presumably involves searching an existing memory representation. In contrast, during comprehension, one needs to integrate information from a number of sources, such as linking the incoming text to previous text representations, and elaborate on given information, such as using prior knowledge to make inferences. On the other hand, it may be that the different organisations are due to methodological differences, such as the level of detail represented in the maps used in these studies, or the manner in which map information was learned (Curiel & Radvansky, 1998). If so, then we might expect the pattern of data to be more consistent when the methodologies are combined.

Because the tasks here involve long-term memory retrieval and narrative comprehension, a summary of research in each area is presented.

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LONG-TERM MEMORY RETRIEVAL

In memory retrieval, evidence for the spatial organisation of mental maps has been reported using a number of tasks that explicitly test spatial information, such as distance estimation, direction judgement, and region judgement (e.g., Presson & Hazelrigg, 1984; Stevens & Coupe, 1978). One task that has been advocated as providing a less biased picture of mental map organisation is primed recognition (McNamara, 1986; McNamara et al., 1984). Research by McNamara and colleagues used primed recognition to provide support for the idea that mental maps are spatially organised. A study by McNamara (1986) investigated the influence of Euclidean and region information on mental map organisation. People memorised a map containing 32 objects. The map was divided into four regions of equal size with eight objects in each region. After memorisation, people were then given recognition, distance estimation, and direction judgement tasks. Notably, the pattern of performance was similar among the three tasks. For the recognition test, objects in the same region showed greater priming than those in different regions. This region effect was mediated by Euclidean distance. McNamara argued that mental maps were partially hierarchical representations, in that region information determined the organisation at higher levels and Euclidean information at lower levels. For the present purposes, it is sufficient to note that a spatial organisation was observed.

Subsequent studies have questioned the nature of this spatial priming effect. Clayton and Habibi (1991; see also Sherman & Lim, 1991) tested an alternative explanation. Because the entire map is available for study when it is learned, people may have been more likely to study together map items that were spatially close than map items that were spatially far apart. Thus the spatial priming effects in previous studies were observed when spatial and temporal proximity were confounded. Clayton and Habibi presented map objects one at a time, so that items that were spatially close were not close to one another in the temporal order. Thus, spatial and temporal proximity were deconfounded. They did not observe spatial priming but they did observe temporal priming. The critical determinant of "distance" between objects in the mental map was temporal, not spatial, proximity. This indicates an influence of temporal information on the retrieval of map information and limits the influence of spatial information.

McNamara, Halpin, and Hardy (1992) also showed that temporal information can affect performance in tasks that require the use of spatial information. In their study, people learned a map of objects that were presented in an order such that prime–target pairs could be spatially and temporally close, spatially close but temporally far, spatially far but temporally close, or spatially and temporally far. Significant priming was only observed in comparisons involving the spatially/temporally close condition, a location judgement task showed temporal priming at spatially far distances, as well as spatial priming at temporally far distances. This provides evidence for both a temporal and spatial influence on map organisation. However, the spatial effect depends on information being temporally close in the learning order.

Finally, Curiel and Radvansky (1998) found that the nature of the learning task influenced the organisation observed in primed recognition and free recall when spatial and temporal proximity were deconfounded. When maps were learned by naming map objects, temporal priming and a greater temporal organisation in recall was observed. This parallels Clayton and Habibi (1991) and McNamara et al. (1992). This temporal influence was observed even when the salience of spatial information was increased by having fewer objects per region, or by giving explicit instructions to expect a later spatial retrieval task. Spatial priming was never observed when there was no consistent temporal order. However, when maps were learned by pointing to object locations, spatial priming and a greater spatial organisation in recall were observed. The differences observed between the learning groups were attributed to a flexible use of spatial and temporal information in associating map objects together.

In sum, this research has limited the role that spatial information has in the organisation and retrieval of map information from long-term memory. Other influences, such as the temporal order of learning map locations, seem to play a more prominent role in mental map organisation.

NARRATIVE COMPREHENSION

Successfully comprehending a text involves creating an accurate situation model that represents the elements of the situation (Glenberg, Meyer, & Lindem, 1987; Johnson-Laird, 1983; van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). A topic that has received considerable interest is the extent to which spatial location information is stored in the situation model. The idea is that because spatial information is important to defining the situation, readers should be sensitive to the changes in spatial information that occur in the text.

A study by Glenberg et al. (1987) demonstrated the use of spatial information in situation models. In this study, people read stories in which an object was mentioned that was spatially associated with the story protagonist (e.g., John *put on* his sweatshirt and went jogging) or was spatially dissociated from the protagonist (e.g., John *took off* his sweatshirt and went jogging). Sentence reading times and a probe recognition test indicated that the spatially associated object was more available from the situation model.

The granularity of this effect was further investigated by Morrow, Bower, Rinck, and their colleagues (e.g., Morrow et al., 1987, 1989; Rinck & Bower, 1995; Zwaan et al., 1998). In the studies by Morrow and colleagues, people memorised a map of a research centre that contained ten rooms and four objects in each room (see Figure 1). This map provided a common source of information for all subjects and allowed for the testing of a greater number of spatial distances. After memorising the map, people read a series of short stories that took place in the research centre. These stories contained sentences that described a protagonist's motion from a *Source Room* where the movement was initiated, through a *Path Room*, to a final *Goal Room*. After reading these sentences, people were interrupted with probes that consisted of either two object names or the protagonist's name and an object name. The task was to identify whether both items were located in the same room at that point in the story. The results revealed a *spatial gradient* of availability. Response times were fastest when both objects

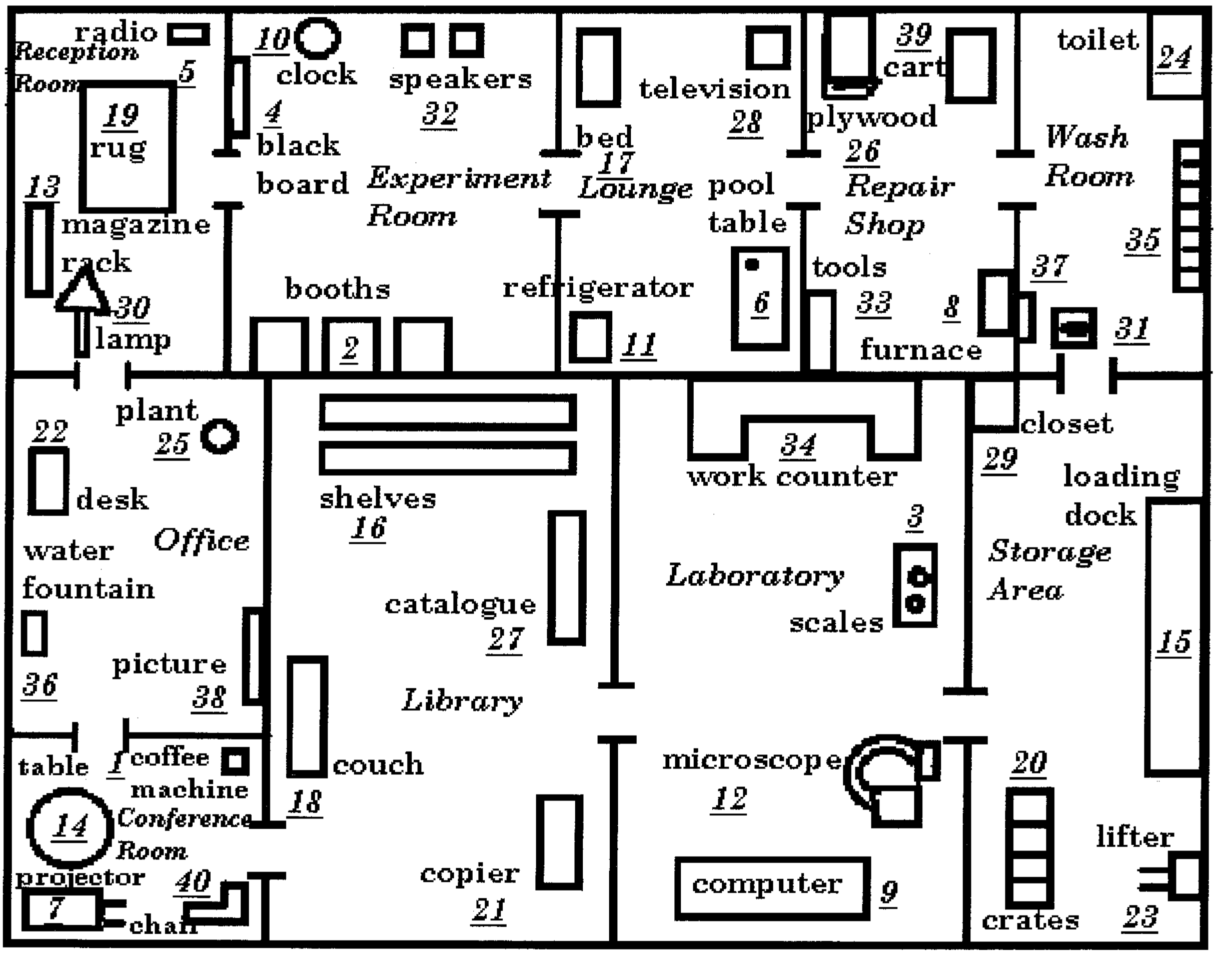

Figure 1. The 10-room map of the research centre used in many studies of map learning and narrative comprehension, first used by Morrow et al. (1987). Numbers indicate a possible temporal order of presenting objects.

were located in goal room, slower for the path and source rooms, and slowest when the objects were located in an *Other Room* in the building. People seemed to be using the spatial information learned from the map to update their situation models.

One problem with these results is that the story probes disrupted the reading process. Rinck and Bower (1995) solved this by using reading times for sentences presented immediately after motion sentences that contained an anaphor referring to an object that could be in the Goal Room, Path Room, Source Room, or Other Room. Rinck and Bower observed a spatial gradient that was analogous to what was observed in the probe response times. Rinck and Bower demonstrated that this effect occurs under a number of circumstances. Of importance here was their Experiment 4 in which they attempted to deconfound spatial and temporal proximity when the map was learned. This was done by presenting and testing the map *rooms* separately. The order in which these rooms were studied was the same across learning trials but each participant learned the map with a different random order. Even under these circumstances, a spatial gradient was observed, which is consistent with an interpretation that spatial information from the map is used to update the situation model.

INTEGRATING NARRATIVE COMPREHENSION AND MEMORY RETRIEVAL RESEARCH

The current study attempts to integrate findings from research in long-term memory retrieval and narrative comprehension. Rinck and Bower (1995) showed a *spatial* gradient of availability in resolving referents when map rooms were presented in an order that did not correspond to their spatial position on the map. This finding differs from that observed in long-term memory retrieval research. Clayton and Habibi (1991) and Curiel and Radvansky (1998) showed a *temporal* organisation in primed recognition when spatial and temporal information were deconfounded. This indicates that the organisation observed in long-term memory retrieval may not be highly related to the organisation observed in narrative comprehension. There are a number of explanations for this.

Map differences

The first, and least interesting, possibility involves differences in the maps used. Specifically, the maps used in memory retrieval studies tended to have fewer objects (18–32) than those used in narrative comprehension studies (40). In addition, in the memory retrieval studies, the maps were perceptually divided up into fewer spatial regions (1–4) than those used in narrative comprehension studies (10). These differences may have resulted in a greater prominence of spatial information for the map used in the narrative comprehension studies, thereby resulting in a greater ease of organising map information by spatial region.

Map detail

The second possibility is the degree to which the experimental maps resembled "real world" maps. In the memory retrieval experiments, the maps did not convey much detailed information. Object locations (or city names) were randomly scattered within the region(s), which were not named. Thus, there was no semantic relation between the objects and the region in which they were located. In contrast, the maps in the narrative comprehension studies conveyed additional information. The map was of a contained environment (e.g., a research building), regions were identified with room names, and the objects had obvious semantic relations to the regions that they were in (e.g., the microscope was in the laboratory). This additional information may have reinforced the spatial relations among objects in the map (e.g., McNamara et al., 1989; McNamara & LeSueur, 1989; Merrill & Baird, 1987).

Temporal order

A third possibility is that Rinck and Bower's (1995) deconfounded spatial and temporal proximity was at a more general level than has been achieved in memory retrieval. Rinck and Bower defined spatial proximity at the region (room) level, whereas memory retrieval studies have defined spatial proximity at the object level. Although Rinck and Bower did not present the whole map at once, objects located within a room were presented together. Thus, although the order in which rooms were presented did not correspond to their spatial position, people were still able to study together objects in the same room. This may have resulted in an organisation where objects in the same room were stored together, but rooms were not highly connected to one another. This may explain why Rinck and Bower observed a weaker spatial gradient, and concurs with research indicating that the spatial gradient of availability occurs at the categorical region level than at a more fine-grained Euclidean distance level (i.e., Rinck et al., 1997).

Task goals

The final possibility involves the differences between the goals in memory retrieval and language comprehension tasks. The general goal of a memory retrieval task is to remember previously presented information. In a recognition task, memory retrieval has been described as involving the activation of concepts that are linked in a network representation, and priming presumably reflects the distance between concepts. The organisation that is observed in recognition presumably reflects the organisation of a long-term memory representation, such as a mental map. In contrast, the general goal in a comprehension task is to understand the information that is being presented. Understanding presumably involves the on-line integration of information across sentences to create situation models that reflect the events described in the text (e.g., Johnson-Laird, 1983, 1989; van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). Prior knowledge, such as information from mental maps, is important to this process.

THE CURRENT STUDY

The purpose of the current study was to examine the plausibility of the four accounts. This required a blending of narrative comprehension and memory retrieval paradigms by using methods from both traditions. Subjects memorised the map used by Rinck and Bower (and others, e.g., Morrow et al., 1987, 1989) of a 10-room research centre with the 40 objects distributed throughout the building (see Figure 1). Rather than present *map rooms* one at a time in a deconfounded order as Rinck and Bower did, *objects* were presented one at a time in an order that completely deconfounded spatial and temporal proximity, as has been done in memory retrieval studies (Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara et al., 1992). After the map was memorised, subjects were given a recognition test like that used by Curiel and Radvansky followed by the narrative comprehension test used by Rinck and Bower.

Predictions

If the differences in organisation between memory retrieval and narrative comprehension are due to the number of map objects and/or the number of spatial categories in the map, then the organisation observed in memory retrieval should be similar to the organisation observed in narrative comprehension. Because the map that is used is the same as those used in the narrative comprehension studies, a spatial organisation would be predicted in both tasks.

The degree of map detail also differed. In memory retrieval studies, maps tended to be stripped of semantic information, whereas the semantic information of the maps in the narrative comprehension studies reinforced the spatial relations between the object and its location. If the differences in organisation are due to the additional information represented in the map, then the organisation observed in the memory retrieval should be similar to the organisation observed in narrative comprehension. Because the map is from the narrative comprehension studies, a spatial organisation would be predicted in both tasks.

The third possibility is that the differences in organisation were due to differences in how spatial and temporal information were deconfounded. If the spatial organisation that was observed in narrative comprehension was due to the temporal order during map learning, then no spatial organisation should be observed when spatial and temporal proximity are completely deconfounded. Temporal priming, but not spatial priming, would replicate the organisation in memory retrieval when spatial and temporal proximity are completely deconfounded and no spatial organisation should be observed in the narrative comprehension task.

The final possibility is that the differences in organisation reflect differences in the goals underlying the memory retrieval and narrative comprehension tasks. Recognition involves the retrieval of a mental map from long-term memory, whereas comprehension involves constructing a situation model. When spatial and temporal information are deconfounded, mental maps are organised by temporal order, so a temporal organisation, but not a spatial organisation, would be expected in the recognition task. Because spatial information is relevant to defining the situation, a spatial organisation would be expected in narrative comprehension, even when the map's spatial information does not correspond to the temporal learning order.

EXPERIMENT 1

Experiment 1 combines aspects of the experimental paradigms used in the Rinck and Bower (1995) and Curiel and Radvansky (1998) studies. People memorised a map that was similar to the one used by Rinck and Bower. However, like Curiel and Radvansky, spatial and temporal information were completely deconfounded. This was done by presenting objects one at a time so that temporally close objects were not in the same spatial region (room). After people memorised the map, they were given recognition and narrative comprehension tasks.

Method

Subjects. Forty-eight subjects were tested. They were recruited from the University of Notre Dame subject pool and given partial class credit or paid $10 for their participation. An additional 23 subjects were replaced, 18 for having an error rate greater than 33% on the narrative comprehension questions and 5 for failing to learn the map. The replacement rate is high but is comparable to Rinck and Bower (1995).

Materials and procedure. The map was of a research centre that had 10 rooms with four objects in each room. The map was 18×13.5 cm in size and was displayed on an IBM-PC compatible computer.

Subjects first memorised the map of the research centre. Prior to memorisation, they were informed that they would be given a recognition test and would read a series of short stories that were related to the map (see Appendix A). Subjects learned the map via a study–test procedure. During study, an outline of the entire building was presented on the computer screen in black on a white background. Object names, along with symbols representing the objects, were presented. In an effort to have people relate the objects to the room in which they were located, the name of the room was presented as well. The object name was presented in red and the name of the room was presented in blue. The different objects located in the building were presented one at a time for 5 seconds each, with the restriction that objects in the same room could not be presented consecutively. A different presentation order was given to each subject but the presentation order for a given subject was the same throughout memorisation. This procedure took elements from the memory retrieval studies in terms of the presentation of the object names, and elements from the narrative comprehension studies in terms of the map that was studied and the presentation of the room names.

After all of the objects had been presented, subjects were given a cued recall test to assess whether the map had been memorised. Again, the entire outline of the building and rooms were present throughout the test period. The cued recall test involved having a dot appear on the screen at a location corresponding to a map object. This dot blinked three times, and then turned red. The name of the room where the object was located also appeared (in blue). At the bottom of the map the question "What is the name of this object?" was presented. Subjects typed their responses into the computer. Because the computer was looking for an exact response, misspellings were counted as errors. Whether the response was correct or incorrect was provided as feedback. Additional feedback in the form of the correct name of the object was given when the participant was incorrect. Subject cycled through this memorisation procedure until two recall tests were completed without error.

The recognition test was composed of 560 trials. Half of the objects were actually presented on the map (studied trials) and the rest were distractors that were similar objects, or objects that could plausibly be found in a research centre (nonstudied trials). The studied and nonstudied objects are listed in Appendix B. The object names were presented one at a time in white on a black background. The subjects' task was to indicate whether the object was located on the map or not by pressing one of the two computer mouse buttons. The left mouse button was marked with a "Y" and indicated "Yes, this item was on the map", and the right mouse button was marked with an "N" and indicated "No, this item was not on the map". Subjects were encouraged to respond as fast and as accurately as possible.

Subjects were not told that the recognition test contained prime–target pairs that tested either spatial or temporal organisation. There were three kinds of spatial prime–target pairs. For *Same Room* pairs, the prime was in the same room as the target object, for *Close Room* pairs, the prime was in a room adjacent to the target object, and for

Far Rooms pairs, the prime was two rooms away from the target object. These spatial prime conditions were selected because they were similar to the Room conditions used in the studies by Bower and colleagues and would thus provide a way to relate the results of the narrative comprehension test. In addition, there were two kinds of temporal prime–target pairs. For *Temporally Close* pairs, the prime was the immediately previous item in the temporal learning order for that subject, whereas for the *Temporally Far* pairs, the prime and the target were separated by four items in the temporal learning order. These temporal prime conditions were selected based on previous map learning studies deconfounding spatial and temporal information during learning. There were 20 prime–target pairs in each condition, with a different object on each trial, and two objects per room serving as the target. The rest of the positive responses were fillers so that each object name would be presented the same number of times. There was a 200 ms interval between a subject's response and the presentation of the next trial. Subjects were given a self-timed break halfway through the recognition test.

Prior to the recognition test itself, subjects were given 18 practice trials to familiarise them with the response buttons. During this practice period, the computer displayed a line that read either "OBJECT STUDIED" or "OBJECT NOT STUDIED", and the subject responded accordingly. No feedback was provided during either the practice period or the recognition test itself.

The recognition test always preceded the narrative comprehension task. This was done because information from the stories may interfere with retrieval of map information. For the narrative comprehension task, subjects read the versions of the stories used by Rinck and Bower (1995) in their Experiments 3 and 4 that included movement and motivating sentences. Furthermore, only those target sentences that contained an explicit reference to the room the critical object was in, as well as the object itself, were included. Three of the stories comprised practice and 16 comprised the experiment proper. The stories were 22 to 27 sentences in length ($M = 23.4$). Each experimental story contained three anaphoric (target) sentences that could be one of four versions: Goal, Path, Source, and Other. A Goal sentence referred to an object that was in the same room as the protagonist at that point in the story. A Path sentence referred to an object that was in the room that was along the protagonist's line of movement and was the room between the Goal and Source sentences. A Source sentence referred to an object in the room where the movement was initiated. Finally, an Other sentence referred to an object from another room, specifically the room prior to the Goal sentence. These critical sentences appeared at or about the 9th, 14th, and 19th sentence in each story.

During the narrative task, subjects read each story one sentence at a time, pressing a space bar to proceed to the next sentence. Reading times were recorded to a file. At the end of each story, subjects were presented with a set of three comprehension questions. These questions asked about general information about what happened in the story and were yes–no questions. None of the questions referred to the information presented in the critical sentences. Subjects responded to these questions by pressing one of two buttons on the computer mouse, with the left mouse button corresponding to the statement, "Yes, the information in the question is true", and the right mouse button to the statement "No, the information in the question is untrue". The entire experimental session typically lasted from 1½ to 2 hours.

Results

The results of the recognition and narrative comprehension tasks replicated previous research. Significant temporal, but not spatial, priming was observed in recognition. A spatial gradient of availability was observed for anaphoric sentences referring to map objects and shifts in spatial location increased sentence reading times in narrative comprehension.

Learning. Subjects took from 3 to 8 ($M = 5.0$; $SD = 1.1$) study–test cycles to memories the map.

Recognition. Before the recognition time data were analysed, correct responses that were less than 200 or greater than 5000 ms (2%) were identified as outliners and discarded.

Subjects made an average of 3.5% errors. For the spatial conditions, the average error rates were 1.7% ($SD = 2.8\%$) for the spatial same targets, 1.4% ($SD = 2.7\%$) for the spatial close targets, and 1.5% ($SD = 2.7\%$) for the spatial far targets. There was no significant difference among the means, $F < 1$ (unless otherwise mentioned, a rejection level of $p < .05$ was used for all statistical tests). For the temporal conditions, the average error rates were 2.5% (SD = 4.1) for the temporally close targets and 2.8% (SD = 4.4%) for the temporally far targets. There was no significant difference between the means, $F < 1$.

The mean response times for each condition are presented in Figures 2 and 3. For the response time data, both spatial and temporal priming were calculated by subtracting the RT of a shorter distance from a longer distance. There was little evidence of spatial priming on the recognition test. The spatial priming effect was 8 ms between the Same Room and Close Room conditions, 11 ms between Close Room and Far Room, and 19 ms between Same Room and Far Room. Although these effects are in the right direction, none was statistically significant, all ts < 1. Thus, if there is an effect of spatial information on the organisation of information in long-term memory, it is very weak. However, in agreement with previous long-term memory retrieval studies, a 45 ms temporal priming effect was observed, $t(47)$ = 2.28. This pattern of response times replicates previous research on memory that has observed a temporal organisation in memory retrieval when spatial and temporal proximity are deconfounded.

Narrative comprehension. Reading times for the critical anaphoric sentences were analysed in terms of milliseconds per syllable and are shown in Figure 4. Separate one way ANOVAs on the reading times

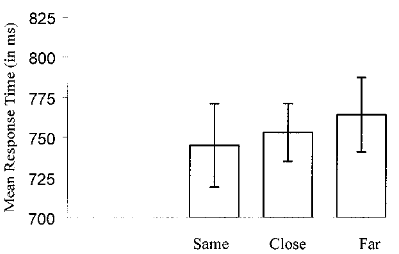

Figure 2. Mean recognition times for spatial conditions in the recognition test.

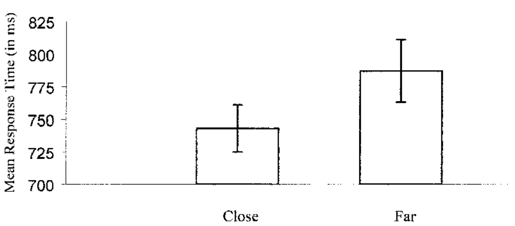

Figure 3. Mean recognition times for temporal conditions in the recognition test.

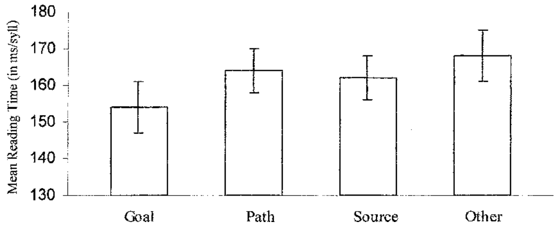

Figure 4. Mean reading times for anaphor sentences in the narratives.

are reported, the first with subjects as a random variable and the second with stories as a random variable. There was a significant effect of sentence condition, $F_1(3, 141) = 3.73$, $MSe = 1840$; $F_2(3, 141) =$ 4.99 $MSe = 2548$. This effect is primarily due to faster reading times for Goal sentences than Path sentences, $F_1(1, 47) = 5.38$, $MSe = 2636$; $F_2(1, 47) = 5.98$ MSe = 3365 and Other sentences, $F_1(1, 47)$ = 11.29, $MSe = 5207$; $F_2(1, 47) = 11.82$, $MSe = 7336$. Although Goal sentences were faster than Source sentences, this difference was not significant for the subject analysis $F_1(1, 47) = 2.67$, $MSe = 1794$, $p = 11$; and was only marginally significant for the story analysis $F_2(1, 47) = 3.79$, $MSe = 2233$, $p = .06$. There were also no significant differences between Path, Source, and Goal sentences, although the story analysis for the Source vs. Other comparison was marginally significant, $F(1, 47) = 3.76$, $MSe = 1474$, $p = .06$.

This pattern of reading times is similar to the spatial gradient reported by Rinck and Bower (1995), although there were some differences. First, Rinck and Bower observed a linear increase in reading time, with fastest response times to Goal Sentences, slower response times to the Path and Source motion sentences, and slowest response times to Other Sentences. In contrast, while reading times were fastest to the Goal Sentences, reading times for the other three conditions did not differ. This decrease in the magnitude of the spatial gradient may have been due to the complete deconfounding of spatial and temporal information during learning. Nevertheless, the data from the anaphor sentences suggest that the availability of information in the situation model is influenced by spatial information even when spatial and temporal information are deconfounded during learning.

Another idea that was explored was that deconfounding spatial and temporal information during learning could have affected the processing of spatial shifts. To see if this was the case, the reading time data for each person were analysed using a multiple regression analysis. Because the stories read in this study were the same as those read in Zwaan et al.'s (1998) Experiments 2 and 3, the predictor variables used in these analyses were the same as in their analyses. These variables included both auxiliary and situation model factors. The auxiliary factors are text-level characteristics that are known to affect reading times. These were (a) number of syllables, (b) serial position, (c) number of low-frequency words in the sentence (Francis & Kucera, 1982), (d) number of new arguments, and (e) argument overlap. The theoretical factors were included based on predictions about creating and updating situation models, such as whether there are shifts on situation dimensions. These were (a) changes in spatial location, (b) changes in time, (c) the introduction of a new entity, (d) the introduction of a goal, and (e) the introduction of actions without a prior causal antecedent. The individual's beta-weights derived from these regression analyses were then used in ANOVAs to see whether each was a significant reading time predictor.

The beta-weight results of the multiple regression analyses are presented in Table 1. Each of the auxiliary variables was significantly different from zero. All of the situation model variables were also significantly different from zero. This included the spatial factor. These results generally correspond to the Zwaan et al. (1998) results, namely that a shift in spatial location was a significant predictor of reading times, and suggest that completely deconfounding spatial and temporal information during learning has little effect on how spatial shifts are processed.

Discussion

When spatial and temporal information were completely deconfounded during learning, temporal organisation was observed in recognition memory and spatial organisation was observed in narrative comprehension.

The results of the recognition and narrative comprehension tasks allow us to draw a number of conclusions regarding the nature of the differences observed between previous studies of memory retrieval and comprehension. First, the level of spatial and semantic detail represented in the map or the structural organisation does not seem to have a major influence on the subsequent organisation that is observed in primed recognition. This was indicated by weak spatial effects in the recognition task, analogous to those observed in earlier studies (Clayton & Habibi, 1991; Curiel & Radvansky, 1998). Rather, when spatial and temporal information are deconfounded during learning, temporal order is the basis for the organisation observed in long-term memory retrieval. As for narrative comprehension, although completely deconfounding spatial and temporal information may have a slight effect on the use of spatial information, the reading times indicated that people were sensitive to the spatial information. Thus, the spatial gradient observed by Rinck and Bower (1995) does not seem to be due to differences in the map but rather due to the goal of comprehending information from the text. This finding is consistent with the idea that spatial information is incorporated into situation models and reflects processes that enable the successful construction of situation models.

The primed recognition and narrative comprehension results are inconsistent with the explanation that the different organisations previously observed in memory retrieval and narrative comprehension are due to superficial map differences, such as the number of map objects to be learned, or the number of perceptual boundaries depicted in the map. The temporal priming

TABLE 1
Reading time beta-weights for Experiment 1

		Auxiliary variables		
Syllable	*Serial position*	*New argument*	*Argument overlap*	*Frequency*
.447*	−.062*	.022*	.029*	.022*

		Situation model variables		
Space	*Time*	*Entity*	*Causality*	*Intentionality*
.051*	.088*	.049*	.071*	.035*

*$p < .05$

observed in recognition is also inconsistent with the explanation that the different organisations observed in both tasks are due to differences in degree of map detail. Finally, these data are also inconsistent with the idea that the different organisations observed in primed recognition and narrative comprehension are due to how spatial and temporal information was deconfounded during learning. Although reading times to anaphor sentences indicated that objects in the same room as the protagonist were most available in readers' situation models, there was no linear increase as the distance between the object and the protagonist increased, as has been observed by Rinck and Bower. This indicates that completely deconfounding spatial and temporal proximity may have a slight impact on the use of spatial information in a situation model. However, a spatially deconfounded temporal order does not seem to influence the processing of spatial shifts. Reading times were longer when a change in spatial location occurred, indicating that people were updating this change in their situation model. This reading time increase replicates Zwaan et al. (1998) where spatial and temporal information were confounded during learning. These results suggest that if there is an influence of spatial–temporal deconfounding on narrative comprehension, it is minimal, and not strong enough to eliminate the use of spatial information in updating a situation model.

EXPERIMENT 2

In Experiment 1 a spatial gradient of availability was observed, indicating that readers were using spatial information to update situation models. Because a temporal organisation was observed in recognition, it is unclear how available spatial information is when it is explicitly tested. One possibility is that, although it is temporally organised, spatial information is stored in the mental map. The other possibility is that spatial information is not stored and the use of spatial information in the comprehension test simply reflects processes related to the goal of comprehending the text. This possibility is consistent with the finding from the regression analysis that a spatial shift resulted in increased reading times, much like the influence of shifts in the other situation dimensions.

Experiment 2 was conducted to assess these two explanations using free recall. After learning the map, subjects were instructed to organise their recalls by the rooms in the research centre. If the spatial gradient does not reflect the availability of spatial information from the mental map, then subjects should not be able to organise their recalls by the room categories. If the spatial gradient reflects the availability of room information from the mental map, then they should be able to organise their recalls by the room categories when explicitly told to do so.

Method

Subjects. Twelve subjects from the University of Notre Dame subject pool participated in this experiment. One additional subject was replaced for failing to follow instructions. None had participated in the previous experiment.

Design and procedure. Subjects memorised the map of objects as in Experiment 1. After memorising the map, a recall test was given. The instructions were to recall the entire set of map objects (but not the map rooms). They were explicitly told to recall objects that were located in the same room together. People typed in their responses into the computer and pressed the Enter key on the keyboard after each object. This cleared the previous response from the screen so that it would be a less effective retrieval aid. After recalling as many of the map objects as possible, subjects typed "done" to end the recall test.

Results and discussion

Learning. Subjects took from 4 to 7 (M = 5.3; SD = 1.2) study–test cycles to learn the map.

Recall. Subjects recalled from 36 to 40 (M = 39.5; SD = 1.2) of the 40 items. People generally followed the instructions and organised their recalls by the room categories. Subjects' recall protocols were analysed using ARC (Adjusted Ratio of Clustering) scores. An ARC score represents the ratio of observed to expected recall clustering by predefined categories, in this case the rooms in the research centre, accounting for chance (Roenker, Thompson, & Brown, 1971). An ARC score of 1 represents perfect clustering by room category, whereas ARC scores close to 0 represent chance clustering. Of the 12 subjects, 10 showed perfect clustering by the spatial categories, that is, they had ARC scores of 1. The other two subjects had ARC scores of 0.6 and 0.8, which still reflected a high level of clustering. The overall mean ARC score was .95 ($SD = .13$). Thus, people were able to use spatial information in recall when explicitly told to do so.

Subjects' recall protocols were also analysed using ARC′ scores. An ARC′ score represents the ratio of observed to expected recall by a predefined order, in this case, the learning order, accounting for chance (Pellegrino, 1971). An ARC′ score of 1 represents perfect recall according to the predefined order, whereas ARC′ scores close to 0 represent chance recall according the predefined order. Although this possibility is unlikely because of the high degree of spatial organisation that was observed, subjects may have combined a temporal organisation with the spatial organisation in their recalls. However the recall data do not reflect this. No subject had an ARC′ score higher than .03, and 8 of the 12 subjects had the lowest ARC′ score possible for the number of objects they recalled.

These results clearly show that spatial information, such as the room in which an object is located, is available from subjects' mental maps when needed. Subjects showed a high degree of spatial organisation when they were explicitly instructed to organise their recalls according to the map's spatial categories. The temporal priming observed in recognition does not necessarily indicate that spatial information is not available from a mental map.

GENERAL DISCUSSION

Readers draw information from long-term memory to augment a text and guide the creation of a coherent situation model. The use of spatial information to create and update situation models has been observed in a number of studies, and is consistent with the idea that spatial information is an important aspect of situations. Although spatial effects have been observed in comprehension, the results of long-term memory retrieval studies suggest that mental maps are temporally organised. This study considered a number of explanations for this difference. The results of Experiment 1 indicate that when spatial and temporal information are deconfounded during learning, temporal effects are observed in memory retrieval and spatial effects are observed in comprehension. The temporal priming effect replicates findings of previous long-term memory studies (Clayton & Habibi, 1991; Curiel & Radvansky, 1998) and the spatial gradient and spatial shift effects replicate findings of previous narrative comprehension studies (Rinck & Bower, 1995, Zwaan et al., 1998). This suggests that these effects do not reflect characteristics of the maps that were used in these experiments or how they were learned.

A temporal priming effect was observed in recognition. This effect has been interpreted as reflecting the organisation of the mental map. The nature of this organisation is thought to consist, at least partially, of associative relations that provide links between the map objects (Anderson, 1983; Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara et al., 1992). Priming reflects the automatic activation of concepts. A link based on temporal proximity is only one of a number of associative relations that may be formed between objects. The fact that the temporal priming effect was observed gives more weight to the idea that associations between temporally close objects are likely formed under the learning circumstances used in the present study.

Although the priming effect suggests a temporal organisation, the results of Experiment 2 indicate that spatial information is available from a mental map. Subjects were able to recall map objects by spatial categories when explicitly instructed. These findings are not surprising given that another study (Curiel, 1997) showed that people who learn a map in a manner similar to that of these studies are relatively accurate when asked to estimate distances and judge directions between objects, tasks that by their very nature are prone to strategic retrieval. The temporal priming observed in recognition indicates that use of spatial information to organise recall likewise involves more effortful retrieval processes. Employing such retrieval strategies may be an aspect of memory retrieval that is also found in other cognitive tasks, such as narrative comprehension.

In contrast to the results of the primed recognition task, the use of spatial organisation was observed in the narrative comprehension task. This occurred despite the fact that spatial information was not explicitly required to perform the task. Rinck and Bower (1995) deconfounded spatial and temporal proximity at the level of the map room, whereas we deconfounded spatial and temporal proximity at the level of the map object. The results of this study indicate that it is unlikely that the spatial effects previously observed in narrative comprehension studies are due to the confounding of spatial and temporal information during learning. If this were so, no spatial effects would be observed when spatial and temporal information were deconfounded. Although the spatial gradient for the anaphor sentences did not show a linear increase, as has been previously observed, other spatial effects were generally replicated. Specifically, reading times for anaphor sentences were fastest when the sentence referred to an object that was in the same room as the protagonist, and a shift in spatial location was a reliable predictor of sentence reading times. This suggests that readers used prior knowledge of the map to guide comprehension.

Because the anaphor sentences did not show the linear increase previously observed by Rinck and Bower (1995), one might wonder whether this pattern of results was due to the complete deconfounding of spatial and temporal information or whether it reflected carry-over effects of doing the recognition task prior to story reading. A pilot study that was identical to Experiment 1, except that only the narrative comprehension task was given, showed a similar pattern of reading times. This suggests that any influence of the recognition task is negligible.

In conclusion, this study explored the differences in the availability of spatial information observed in long-term memory retrieval and narrative comprehension. Completely deconfounding spatial and temporal information during learning led to a temporal organisation in memory retrieval and a spatial availability in narrative comprehension. These differences reflect differences in the task goals involved in recognition and narrative comprehension.

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REFERENCES

Anderson, J.R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Clayton, K., & Habibi, A. (1991). Contribution of temporal contiguity to the spatial priming effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 263–271.

Curiel, J.M. (1997) *The use of identity and location information in mental map organization*. Unpublished Master's thesis. University of Notre Dame, IN.

Curiel, J.M., & Radvansky, G.A. (1998). Mental organization of maps. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 202–214.

Francis, W.N., & Kucera, H. (1982). *Frequency analysis of English usage*. Boston, MA: Houghton Mifflin.

Glenberg, A.M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during test comprehension. *Journal of Memory and Language*, *26*, 69–83.

Gray Wilson, S., Rinck, M., McNamara, T.P., Bower, G.H., & Morrow, D.G. (1993). Mental models and narrative comprehension: Some qualifications. *Journal of Memory and Language*, *32*, 141–154.

Johnson-Laird, P.N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge MA: Harvard University Press.

Johnson-Laird, P.N. (1989). Mental models. In M.I. Posner (Ed.), *Foundations of cognitive science*. Cambridge, MA: Harvard University Press.

McNamara, T.P. (1986). Mental representations of spatial relations. *Cognitive Psychology*, *18*, 87–121.

McNamara, T.P., Altarriba, J., Bendele, M., Johnson, S.C., & Clayton, K.N. (1989). Constraints on priming in spatial memory: Naturally learned versus experimentally learned environments. *Memory & Cognition*, *17*, 444–453.

McNamara, T.P., Halpin, J.A., & Hardy, J.K. (1992). Spatial and temporal contributions to the structure of spatial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 555–564.

McNamara, T.P., & LeSueur, L.L. (1989). Mental representations of spatial and nonspatial relations. *The Quarterly Journal of Experimental Psychology*, *41A*, 215–233.

McNamara, T.P., Ratcliff, R., & McKoon, G. (1984). The mental representation of knowledge acquired from maps. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 723–732.

Merrill, A., & Baird, J.C. (1987). Semantic and spatial factors in memory. *Memory & Cognition*, *15*, 101–108.

Morrow, D.G., Bower, G.H., & Greenspan, S.L. (1989). Updating situation models during narrative comprehension. *Journal of Memory and Language*, *28*, 292–312.

Morrow, D.G., Greenspan, S.L., & Bower, G.H. (1987). Accessibility and situation models in narrative comprehension. *Journal of Memory and Language*, *26*, 165–187.

Pellegrino, J. (1971). A general measure of organization in free recall for variable unit size and internal sequential consistency. *Behavioral Research Methods, Instruments and Computers*, *3*, 241–246.

Presson, C.C., & Hazelrigg, M.D. (1984). Building spatial representations through primary and secondary learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 716–722.

Rinck, M., & Bower, G.H. (1995). Anaphora resolution and the focus of attention in situation models. *Journal of Memory and Language*, *34*, 110–131.

Rinck, M., Hähnel, A., Bower, G.H., & Glowalla, U. (1997). The metrics of spatial situation models. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 622–637.

Roenker, D.L., Thompson, C.P., & Brown, S.C. (1971). Comparison of measures for the estimation of clustering in free recall. *Psychological Bulletin*, *76*, 45–48.

Sherman, R.C., & Lim, K.M. (1991). Determinants of spatial priming in environmental memory. *Memory & Cognition*, *19*, 283–292.

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology*, *10*, 422–437.

van Dijk, T.A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.

Zwaan, R.A., & Radvansky, G.A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, *123*, 162–185.

Zwaan, R.A., Radvansky, G.A., Hilliard, A., & Curiel, J.M. (1998). Constructing multidimensional situation models during reading. *Scientific Studies of Reading*, *2*, 199–220.

APPENDIX A

Example of story used in experiment 1

Roy was in charge of a crew hired to clean the research building. He walked around the conference room with an assistant, examining the woodwork at the base of the walls. Suddenly he let out a yell and jumped back in disgust. He pointed to a huge rat poking its head out of a hole in the woodwork. Wondering how much of the building the beasts had infested, he told his assistant they should split up and check other rooms for any signs of rats. Roy checked in the library, but didn't find a trace of the rodents. Then he walked from the library into the storage room. There, he stopped and imagined all the dark corners of the research center where rats might be hiding.

He thought the corner behind the closet in the storage room would be a nice place for rats. *(Goal)*

He thought the corner behind the microscope in the laboratory would be a nice place for rats. *(Path)*

He thought the corner behind the copier in the library would be a nice hiding place for rats. *(Source)*

He thought the corner behind the projector in the conference room would be a nice place for rats. *(Other)*

But he didn't find anything, so he went into the wash room where he thought he heard a sound. He saw a rat scurrying toward a hole and gave chase, but he slipped on a puddle of water, cursing as he fell. Next he walked from the wash room into the lounge.

He imagined that even more rats might be hiding under the bed in the lounge. *(Goal)*

He imagined that even more rats might be hiding under the cart in the repair shop. *(Path)*

He imagined even more rats might be hiding under the sink in the wash room. *(Source)*

He imagined even more rats might hide under the lifter in the storage room. *(Other)*

Looking around the storage room, he thought that if the rats were anywhere in the room, they would be among the storage boxes, lurking in the corners. In the lounge, he sat down and rubbed his knee, then he heard a rustling sound from the far side of the room. He looked toward the repair shop and saw a misplaced rat cage under the pool table, but noticed that the cage was secure and the lab animal inside was cute and white, not ugly and black. Suddenly he realized the rats could be chewing up electrical wiring, and he got to his feet and walked inside the experiment room, but fortunately no rats were among the wires. Then he walked from the experiment room into the office. He paused for a moment to ask himself if he had really checked every possible hiding place in the building.

Suddenly he remembered that he hadn't checked the dark corner behind the plant in the office. *(Goal)*

Suddenly he remembered that he hadn't checked the corner behind the magazine rack in the reception room. *(Path)*

Suddenly he remembered that he hadn't checked the dark corner behind the clock in the experiment room. *(Source)*

Suddenly he remembered that he hadn't checked the corner behind the television in the lounge. *(Other)*

However, he was already pretty sure that the rats had infested the whole building. When Roy met up with his assistant in the office, he grabbed a memo pad from the desk and wrote out a note informing the director of the bad news.

APPENDIX B

Studied and nonstudied object names used in Experiment 1.

Studied		*Nonstudied*	
radio	desk	stereo	file cabinet
rug	plant	carpet	waste basket
magazine rack	water fountain	camera	flowers
lamp	picture	fan	sculpture
clock	coffee machine	telephone	microwave
blackboard	table	bulletin board	mailbox
speakers	projector	lights	screen
booths	chair	intercom	shredder
bed	shelves	centrifuge	cabinet
television	catalogue	VCR	cupboard
pool table	couch	dartboard	futon
refrigerator	copier	freezer	fax machine
plywood	work counter	bricks	chamber
cart	scales	display case	thermometer
tools	microscope	toolbox	oscilloscope
furnace	computer	water heater	printer
toilet	closet	shower	fire extinguisher
lockers	loading dock	drain	poster
mirror	crates	soap dispenser	air conditioner
sink	lifter	paint	pallets