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Mental Organization of Maps

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Previous studies deconfounding spatial and temporal proximity during map learning have found a temporal influence on mental map organization. The authors explored whether this observed priming effect reflected the manner in which a map was learned by having people either name objects or point to them during learning. Naming objects resulted in temporal organization but pointing to objects resulted in spatial organization, suggesting that mental map organization is sensitive to emphasizing different types of map information during learning. The authors also explored whether the temporal organization observed in the naming group was influenced by the ease of using spatial information during learning, such as when the expectancy to use spatial information was made explicit or when a consistent temporal order was absent. When naming map objects, evidence for a spatial organization was weak, whereas a temporal organization was observed when a consistent temporal order was present.

Knowledge of how objects are organized in space is necessary to understand the information conveyed by a map. Intuitively, it seems that a map's spatial structure should be reflected in its mental representation. However, theories differ in the extent to which spatial information is incorporated into the mental map. Some researchers have argued that the structure of the memory representation is primarily influenced by spatial information (e.g., Kosslyn, Ball, & Reiser, 1978; McNamara, 1986; McNamara, Ratcliff, & McKoon, 1984; Stevens & Coupe, 1978; Tolman, 1948), whereas others have attributed map organization to nonspatial properties present during map learning, such as temporal order (e.g., Clayton & Habibi, 1991; Sherman & Lim, 1991) or a combination of spatial and temporal information (McNamara, Halpin, & Hardy, 1992). This study was aimed at examining the separate influence of spatial and temporal information on the mental organization of experimentally learned maps.

Although some spatial views consider mental maps to be structured in an analog fashion (e.g., Kosslyn et al., 1978; Levine, Jankovic, & Palij, 1982; Presson & Hazelrigg, 1984; Sheperd & Chipman, 1970), more recent views have specified a hierarchical component (McNamara, 1986; McNamara, Hardy, & Hirtle, 1989). For example, according to the partially hierarchical view developed by McNamara (1986), a map is mentally parsed into major areas or regions. Each region is represented as a different "branch" in a hierarchy that denotes the relations of regions to one another. Spatial relations among locations are more likely to be directly represented within regions and are more likely to be inferred across regions. The strongest evidence for the partially hierarchical theory came from the observation that spatial priming was greater within the same region than across regions. *Spatial priming* refers to a faster response time on a recognition test trial that is preceded by a map item that was spatially close relative to one that is preceded by a map item that was spatially far. This pattern of spatial priming has been reported both when the map is perceptually divided into regions (McNamara, 1986) and when regions are subjectively determined (McNamara, Hardy, & Hirtle, 1989).

More recent research has questioned the use of spatial information in organizing mental maps. Studies of naturally learned environments, such as a college campus, have not consistently yielded observations of spatial priming independent of nonspatial relations on a recognition test of building names (e.g., McNamara, Altarriba, Bendele, Johnson, & Clayton, 1989; Merrill & Baird, 1987). However, spatial priming was observed when the retrieval task involved the explicit use of spatial information, such as deciding whether two buildings were from the same college, and when people learned a map of novel building names in the same configuration as the campus buildings. Thus, these studies indicate that the use of spatial information on mental maps is limited.

Other research has further limited the extent to which spatial information is used in mental map organization. For example, Clayton and Habibi (1991) did not find spatial priming when spatial and temporal proximity were deconfounded during learning. That is, spatial priming was not observed when map item names were presented during learning one at a time in a temporal order such that spatially

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close map items were not temporally close. However, they did find temporal priming, suggesting that mental maps are organized by using temporal information. McNamara et al. (1992) followed up on this finding by examining the joint contribution of spatial and temporal information in mental map organization and reported that spatial organization depended on the temporal proximity, such that temporal proximity affected the probability of forming spatial relations.

Although McNamara et al.'s (1992) article focused on the joint use of spatial and temporal proximity, the present article focuses on the separate use of spatial and temporal information in the organization of mental maps. These dimensions were selected because of their seemingly basic nature and because previous studies have indicated that temporal information may serve as a basis for structuring mental maps, either independent from or in conjunction with spatial information.

As in previous studies, this article focuses primarily on how mental organization may be revealed through primed recognition. Unlike tasks that explicitly require the use of spatial information, such as distance estimation, "because priming is primarily automatic, it should be informative about the kinds of knowledge encoded in memory and how that knowledge is organized" (McNamara, 1986, p. 93). Thus, the observed organization should be less contaminated by the necessarily spatial demands of a spatial task. In the following sections, we consider in detail two studies that bear most directly on the use of spatial and temporal information in mental map organization: one by Clayton and Habibi (1991) and another by McNamara et al. (1992).

Clayton and Habibi (1991)

Clayton and Habibi (1991; see also Sherman & Lim, 1991) questioned whether the spatial priming effects reported in studies of experimentally learned maps actually reflected the use of spatial information. They argued that spatial and temporal proximity had been confounded in studies reporting a spatial priming effect. Many of those studies either had not mentioned how map items were presented during learning or had presented all of the map at once. Because learning order was not controlled, people probably studied items together such that spatial location was confounded with the temporal order of the studied map locations. Clayton and Habibi eliminated this confound by presenting the map items one at a time in an order that did not correspond to the configuration of locations. This resulted in an absence of spatial priming, both when the prime–target pairs were temporally close and when they were temporally far. However, *temporal priming* was observed, as indicated by faster response times to target items following temporally close primes relative to temporally far primes. Clayton and Habibi interpreted these results as showing that temporal proximity affects the probability that locations will be associated together in a mental map.

These results are consistent with a view that places a greater emphasis on temporal information. This is surprising when one considers a map's fundamentally spatial nature. Moreover, this emphasis on temporal information further limits the degree to which previously observed spatial priming effects can be attributed to the use of spatial information.

McNamara, Halpin, and Hardy (1992)

The use of spatial and temporal information in mental map organization was further explored in a study by McNamara et al. (1992). These researchers detailed several aspects of the Clayton and Habibi (1991) study that restricted how these data are interpreted. Specifically, they argued that the Clayton and Habibi study (a) did not include tasks that explicitly required the use of spatial information, such as distance estimation, (b) used a relatively small number of map locations, and (c) had the map items distributed in a linear fashion. McNamara et al. altered each of these characteristics (a) by including explicit spatial tasks after the recognition test, (b) by increasing the number of map locations from 18 to 30, and (c) by having map items distributed more homogenously in the map. It should be noted that McNamara et al. also differed from Clayton and Habibi in that the maps had two regions, rather than one, and that the comparison of spatial and temporal effects was done within subjects, rather than in separate experiments.

In McNamara et al.'s (1992) study, spatial and temporal proximity were factorially combined yielding prime probes that could be (a) spatially and temporally close, (b) spatially close and temporally far, (c) spatially far and temporally close, or (d) spatially and temporally far to the target. This was done because they were interested in the joint contribution of the spatial and temporal dimensions. McNamara et al. reported a spatial priming effect when map locations were temporally close but not when they were temporally far. Also, they reported not observing a temporal priming effect for spatially far map locations.

In addition to primed recognition, McNamara et al. (1992) included two spatial tasks: a location judgment task, where people decided in which of the two map regions an item was located, and a distance estimation task, where people estimated the distance between map locations. For the location judgment task, spatial priming was observed at both temporal distances, and temporal priming was observed at both spatial distances. For the distance estimation task, people tended to underestimate spatial distance. Distance estimates were found to be unaffected by temporal distance in one experiment but were affected by temporal distance in another experiment, such that distance estimates of short spatial distances were greater when map items were temporally far.

These results led McNamara et al. (1992) to propose a dual-representation hypothesis. In this view, map information is stored in two representations: a nonmetric code, in which spatial information, such as the adjacency of two locations, is propositionally represented, and a metric code, in which information, such as Euclidean distance and temporal order, is stored in an analog form. According to McNamara et al., spatial nonmetric relations (such as "next to") are more likely to be encoded when map items are temporally close, presumably because temporal proximity increases the likelihood that the two items will be in working memory at the same time, thus allowing a spatial association to be formed. In contrast, both spatial and temporal information are stored in the metric representation. McNamara et al. further argued that recognition tapped the nonmetric representation because neither purely spatial nor temporal effects were observed. In contrast, location judgments tapped the metric representation because both spatial and temporal effects were observed. However, neither representation could accommodate the distance estimation results because, although this task presumably tapped the metric representation, a temporal effect was only observed in one experiment at the spatially close distance.

This dual-representation theory in some ways parallels Huttenlocher, Hedges, and Duncan's (1991) model. This view explains biases in spatial memory in terms of the differential use of representation at two levels of detail: a fine grain value (analogous to the metric structure) and a category value (analogous to the nonmetric structure). However, Huttenlocher et al. do not commit to the type of information stored in the representation, only the level of granularity of information used in subsequent decisions.

Comparison of Clayton and Habibi (1991) and McNamara et al. (1992)

Based on this research, it seems that both temporal and spatial information are involved in the organization of a mental map. However, the degree of influence each has is unclear because there are some inconsistencies. Specifically, greater temporal effects were reported in Clayton and Habibi (1991), whereas greater spatial effects were reported by McNamara et al. (1992). Because determining the nature of these discrepancies is relevant to our study, we consider each of the conditions in the primed recognition test used by these researchers.

Spatial Priming in Temporally Close Pairs

McNamara et al. (1992) reported significant spatial priming effects of 62 and 39 ms when map locations were temporally close. In contrast, Clayton and Habibi (1991) reported only a 4-ms effect, which was not significant. McNamara et al. (as mentioned earlier) appealed to the differences in methodology to account for this difference. However, the dependency of spatial priming on these methodological factors lessens the importance of spatial relations.

Temporal Priming in Spatially Close Pairs

Although not mentioned by McNamara et al. (1992), when map locations were spatially close there were significant temporal priming effects of 74 and 50 ms. The Clayton and Habibi (1991) study did not allow for this comparison. The fact that the temporal priming effects are numerically larger than the spatial priming effects may suggest that temporal structure is more fundamental.

Assessing spatial and temporal priming by using conditions where map locations are both spatially and temporally close (we refer to the conditions where map items are both spatially and temporally close as *aligned conditions*), as was the case in the above comparisons, indicates that the joint contribution of spatial and temporal information provides a large degree of priming benefit. However, it is unclear whether having map locations both spatially and temporally close provides this benefit because spatial information is added to an existing temporal structure, temporal information is added to an existing spatial structure, or both are combined equivalently. Because the aligned trials involve a confounding of spatial and temporal information, it is not possible to assess the separate contribution of each of these dimensions. For this reason, considering conditions where items are far on the other dimension provides a better means of assessing the separate influence of spatial and temporal information on the organization of mental maps than when aligned conditions are involved.

Spatial Priming in Temporally Far Pairs

Both Clayton and Habibi (1991) and McNamara et al. (1992) agreed that spatial priming is not observed when prime–target pairs are temporally far from one another. The size of the spatial priming effect under these conditions in both studies ranged from 3 to 5 ms. The explanation offered by McNamara et al. was that temporal proximity allows a person to notice the spatial relation between the map locations and to encode that information into memory. When map items are temporally far, it is unlikely that a person will notice the spatial relations. As such, temporal information is important to the structure of a mental map.

Temporal Priming in Spatially Far Pairs

When temporal priming is assessed at spatially far map locations, Clayton and Habibi (1991) and McNamara et al. (1992) disagreed as to whether such an effect is observed. Clayton and Habibi reported a significant 20-ms effect. However, McNamara et al. reported effects of 15 and 16 ms that were not statistically significant, even in a combined analysis of two experiments. However, three things should be noted when considering the results of the McNamara et al. study. First, although not significant, the magnitude of the temporal priming effects in these studies is similar. Second, because their interaction was significant, McNamara et al. used the standard error of the differences for the error term in all comparisons, including this one. This error term includes not only the trials from the conditions of interest, but also trials from the aligned condition. As such, this potentially inflated error term may make it difficult to detect a difference. As stated above, this joint influence of spatial and temporal information does not allow for an assessment of the separate influences of spatial and temporal information. A comparison that involves only the conditions of interest here may result in a significant difference. Such a statistical test cannot be performed on the basis of the data reported by McNamara et al. Third, the device used to collect the response time data was a PC computer keyboard. Response times collected in this manner are known to vary by 7 ms (Segalowitz & Graves, 1990), which increases the variability of the data, making it more difficult to detect actual differences.

The Influence of the Learning Task

Although there are some differences between the pattern of results reported by Clayton and Habibi (1991) and McNamara et al. (1992), both have reported effects of temporal information on mental map organization. A factor that may have contributed to the observed organization in both studies was the manner of testing map information. In both studies, people were tested for map information by identifying the name of the map item at a given location cue. They were never asked to demonstrate learning of location information in a similar fashion. Because learning only required identifying object names, people may have relied on the temporal order to learn the map.

In Experiment 1, we explored the possibility that the observed organization reflects this manner of testing map information during learning. In previous studies that deconfounded spatial and temporal proximity (Clayton & Habibi, 1991; McNamara et al., 1992), people were required to produce an item in response to a location cue during learning. Information about map locations was not directly tested; it was always given as a cue to name a map item. Instead, people were required to focus on learning object identities. Temporal information may have then been linked to object identities. This seems particularly likely given that identity information in these experiments was a verbal label, and a temporal structure is important when processing verbal information, such as when constructing sentences or rehearsing verbal information in working memory. Thus, a greater temporal influence than spatial influence observed in the previous studies may reflect encoding strategies and processes adopted in response to being directly tested for identity information.

We conducted a series of experiments to clarify the separate roles of spatial and temporal information on the organization of mental maps. In our experiments, after learning a map, people were given a primed recognition test that separately assessed temporal and spatial priming. These experiments sought to reproduce and clarify the results of previous studies that deconfounded spatial and temporal information (e.g., Clayton & Habibi, 1991; McNamara et al., 1992) and to see whether the nature of the learning task affected the observed organization. The map used in these experiments was similar to those used by McNamara et al. (1992). People were also given four free-recall tests as an additional test of mental map organization.

Experiment 1

In Experiment 1, we examined whether differences in how a map was learned would lead to differences in the mental organization of the map. Two groups of people learned a map of objects either by naming an object at a cued location (referred to as the naming group) or by pointing to a location of a cued object name (referred to as the pointing group). After memorizing the map, both groups were given a primed recognition test and free-recall tests. If the organization of the mental map is affected by how the map information is learned, then differences in the organization should be observed between the two groups. Specifically, it was expected that temporal organization, that is, temporal priming in recognition and a greater temporal organization in recall, would be observed when identity information was emphasized (naming group), whereas spatial organization, that is, spatial priming in recognition and a greater spatial organization in recall, would be observed when location information was emphasized (pointing group).

Such a difference between naming and pointing groups would be consistent with findings in other domains in cognitive psychology observing a dissociation between identity and location information, including neuropsychology (e.g., Goodale & Milner, 1992; Ungerleider & Haxby, 1994), attention (e.g., Connelly & Hasher, 1993; Egly, Driver, & Rafal, 1994), working memory (e.g., Baddeley, 1986; Shah & Miyake, 1996), and language (Jackendoff & Landau, 1992). For example, an organizational difference has been recently reported such that pointing out directions leads to a different pattern of the availability of reference frame axes than the pattern observed when naming directions (e.g., De Vega, Rodrigo, & Zimmer, 1996).

Method

Participants. The participants were 128 people, recruited from the University of Notre Dame's undergraduate psychology pool, who were given partial course credit or monetary compensation for their participation. Of the participants, 64 were randomly assigned to the naming group and 64 were assigned to the pointing group. An additional 16 participants were replaced: 4 for failing to complete the experiment (2 from the naming group and 2 from the pointing group); 9 for having an error rate greater than 10% or an error rate greater than 20% in one of the experimental conditions (4 from the naming group and 5 from the pointing group); and 3 for having a mean in an experimental condition greater than 3 standard deviations above the group mean (2 from the naming group and 1 from the pointing group). The participants were tested in groups of 1 to 4.

Materials. The map used in learning consisted of a 12 cm × 12 cm array consisting of four map quadrants of equal dimensions (6 cm × 6 cm). The map and subsequent learning and memory tasks were presented on a Gateway 2000 486DX computer. Twenty-eight dots were placed within this map, 7 in each region. The map used in Experiment 1 and the subsequent experiments is presented in Figure 1. The dots represented the location of map items. Within each region, a pair of dots was defined as *spatially close* (0.55 cm). These items were separated by an average of 11.5 items in the learning order. A pair of dots was also defined as *spatially far* (6.05 cm). These items were separated by an average of 9.5 items in the learning order. As a further test of spatial organization, four pairs of dots were identified as *across-region* pairs, which were separated by an average of 10.0 items in the learning order. The spatial distance between the across-region pairs was the same as in the spatially far condition. The primary difference was that the dots were in different map regions, rather than within the same region.

Object names referred to common objects small enough to be

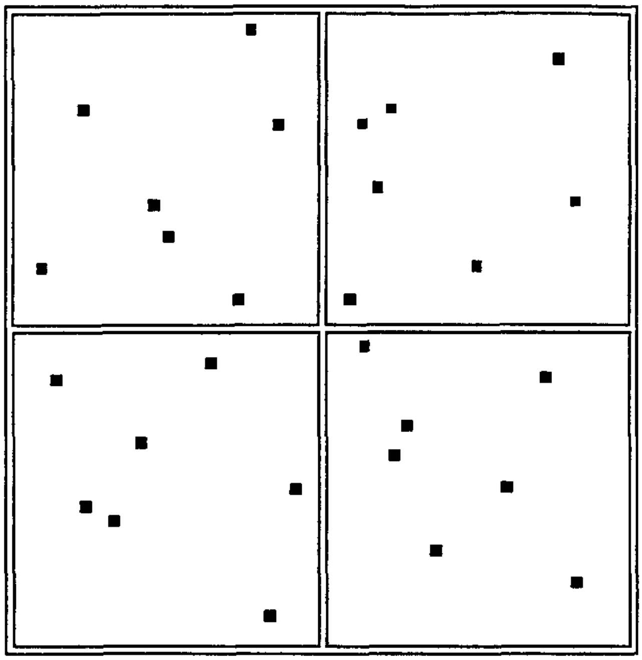

Figure 1. Map used in all experiments.

placed on a table. These names ranged from three to seven letters long and were one or two syllables in length (e.g., *cup* or *wallet*), with word frequencies ranging from 1 to 260 ($M = 40$; Francis & Kučera, 1982). For each participant, the location names were a set of 28 object names that were randomly selected from a pool of 56 object names.

The order of presentation was constant during learning. This temporal order was designed such that it did not correspond to the spatial position of the objects. In general, objects next to one another in the learning order were located in different spatial regions. There were four pairs of objects next to one another in the learning order that were located in the same region. Four pairs of objects were designated as temporally close, and four pairs were designated as temporally far. *Temporally close* pairs were adjacent in the temporal order and were an average of 11.6 cm apart. *Temporally far* pairs were separated by four items in the temporal order and were an average of 5.6 cm apart. This difference in the spatial distances between these two conditions works against our finding a temporal priming effect. The temporal distances were the same as those used in the McNamara et al. (1992) study.

Design and procedure. Participants completely memorized the map before taking the memory tests. Memorization was conducted by using a study–test procedure. During the study portion, object names were presented one at a time next to the corresponding dot for 2 s each until all objects had been displayed. All 28 dots were always present on the map. After studying the object names, participants were given a cued-recall test. The two groups differed in the type of cue given and the form of their response. People in the naming group were cued with the location of an object by having a dot on the map blink for 3 s and turn red. Below the map, the question, *What is the name of this object?* was presented. Participants typed their response into the keyboard and then pressed the enter key, which recorded it to a file.

Participants in the pointing group were cued with the name of the object. This cue was given in the form of a question, *Where is the object*?, in which *object* was replaced with an object name. This question was presented below the map and served to prompt participants to recall the location of the object. Participants used a computer mouse to move a cursor on the computer screen to the location of the object and pressed the left mouse button to record the response location.

After a participant had given an answer, the correct object name was displayed next to the dot and either the word *Correct* or *Incorrect* was displayed below the map for 2 s. After all of the objects had been identified or located, feedback about the number of correct and incorrect responses was given. Participants then returned to the study portion. This study–test cycle continued until a person could perfectly recall all 28 object names for two cycles.

After learning, participants were given a primed recognition test, in which object names were presented on the computer screen. The recognition test consisted of 336 trials and was preceded by 18 practice trials. The interstimulus interval was 200 ms for both the practice and experimental trials. The practice trials served to familiarize a person with the structure of the recognition test and on the use of the mouse buttons to respond. The left mouse button was marked with a *Y* and corresponded to "Yes, this item was on the map," and the right mouse button was marked with an *N* and corresponded to "No, this item was not on the map." During practice, participants pressed the left mouse button in response to those trials when the phrase *OBJECT STUDIED* was presented and pressed the right mouse button in response to those trials when the phrase *OBJECT NOT STUDIED* was presented. No feedback was given during the experimental trials.

Of the recognition trials, 168 were studied objects. Of these, 80 were primes or targets from one of the experimental conditions and 88 were fillers. The other 168 trials involved equal occurrences of the 28 nonstudied object names from the pool of 56 object names. The 80 experimental trials consisted of 40 prime trials and 40 target trials. Target trials were immediately preceded by primes that were spatially close, spatially far, across regions, temporally close, or temporally far to the target during map learning. Participants were not informed of the prime–target relation and responded to both primes and targets. For each experimental condition, there were four prime–target trial pairs. Each pair was presented twice. The same objects served as the target under two experimental conditions. Specifically, an object used as a target for the spatially close condition was also used as a target for the temporally far condition, and an object used as a target for the spatially far condition was also used as a target for the temporally close condition.

For the statistical tests, the mean response time for each condition was calculated. For each group, three critical comparisons were planned: spatially close with spatially far (to assess spatial priming), spatially far with across regions (to assess an influence of region information), and temporally close with temporally far (to assess temporal priming). The recognition-tested data were trimmed such that response times (RTs) less than 200 ms or greater than 3,000 ms were excluded from the RT analysis as anticipations or lapses of attention, respectively, but were not counted as errors. Furthermore, trials on which the prime was incorrectly identified were also trimmed from the RT analysis. These trimming procedures excluded 4% of the data in Experiment 1.

After the recognition test, participants were given four free-recall tests as another measure of mental map organization. The participants recalled as many of the entire set of object names from the map as they could. The recall tests occurred in immediate succession. Responses were recorded into the computer by having each person type the object name and then press the enter key. Pressing the enter key erased the response so that the person was less able to use previous items as memory aids. To end a recall trial, the person typed in the word *done*. No feedback was given during recall.

To assess the extent to which recall was spatially or temporally organized, we analyzed the recall trials by using ARC (adjusted ratio of clustering) and ARC′ scores. An ARC score represented the proportion of observed categorical clustering, relative to chance (Roenker, Thompson, & Brown, 1971). Here spatial region was used to define the categories. An ARC score could range from a negative number to 1, with a negative number indicating less than chance spatial organization, 0 indicating chance organization, and 1 indicating perfect spatial clustering. An ARC′ score represented the consistency of the recall order with a previous comparison order, again accounting for chance performance (Pellegrino, 1971). In the present experiments, the uniform learning order was used to define the comparison order. An ARC′ score could also range from a negative number indicating less than chance occurrence of the presentation order, 0 indicating chance organization, and 1 indicating perfect recall of the presentation order.

Results

The results of Experiment 1 showed that the degree of temporal and spatial organization observed was affected by how the map was learned. People in the naming group showed a greater influence of temporal order on both recognition and recall tests. In contrast, people in the pointing group showed a greater influence of the map's spatial structure.

Learning. Participants took an average of 5.6 ($SD = 1.4$) cycles to memorize the map. The naming group took fewer cycles ($M = 5.5$; $SD = 1.2$) than did the pointing group ($M = 5.7$; $SD = 1.6$), but this difference was not significant ($t < 1$).

Recognition. Because the mean error rate was low (less than 3%), the error rate data are not considered further. The RT data are presented in Table 1.

To assess temporal organization, we submitted the mean RTs for the temporal-close and temporal-far conditions to a 2 (group) × 2 (distance) mixed analysis of variance (ANOVA), with group as a between-subjects variable. Neither the main effect of group, $F(1, 126) = 1.73$, $MSE = 59{,}140$, $p = .19$, nor the main effect of distance, $F(1, 126) = 2.51$, $MSE = 20{,}467$, $p = .12$, was significant. However, the Group × Distance interaction was marginally significant, $F(1, 126) = 3.48$, $MSE = 29{,}864$, $p = .06$. Planned simple effects tests showed a significant effect of temporal distance for the naming group, $F(1, 63) = 3.92$, $MSE = 49{,}889$ (unless otherwise mentioned, $p < .05$ was assumed), but not for the pointing group ($F < 1$). Thus, reliable temporal priming was observed for the naming group but not for the pointing group. This is consistent with the idea that emphasizing identity information during learning encourages the use of temporal information and results in temporal priming.

Table 1

Mean Response Time (RT, in Milliseconds) for Spatial and Temporal Conditions for the Naming and Pointing Learning Groups in Experiment 1

	Naming		Pointing	
Condition	RT	*SD*	RT	*SD*
Spatial				
Close	690	132	681	136
Far	714	149	730	133
Priming[a]	24		49*	
Across regions	696	192	748	165
Priming[b]	−18		18	
Temporal				
Close	669	148	721	137
Far	709	176	718	137
Priming[c]	40*		3	

[a] Priming = spatially far − spatially close; [b] priming = spatially across regions − spatially far; [c] priming = temporally far − temporally close.

*$p < .05$.

To assess spatial organization, we submitted the mean RTs for the spatial-close and spatial-far conditions to a 2 (group) × 2 (distance) mixed ANOVA, with group as a between-subjects variable. The main effect of group was not significant ($F < 1$). However, there was a significant main effect of spatial distance, $F(1, 126) = 9.00$, $MSE = 105{,}340$. People were faster to respond to a target trial when it was preceded by a spatially close than by a spatially far prime. Although the Group × Distance interaction was not significant ($F < 1$), planned simple effects tests showed a significant spatial priming effect for the pointing group, $F(1, 63) = 8.60$, $MSE = 74{,}305$, but not for the naming group, $F(1, 63) = 1.56$, $MSE = 18{,}121$, $p = .22$. This is consistent with the idea that directly testing object locations during learning results in spatial priming.

A separate analysis was conducted for the spatial-far and across-regions conditions. Because spatial organization was observed in the pointing group, such that spatially close items were represented closer together in the representation, it is possible that there may be a hierarchical region component to the organization. The RT data for the spatially far conditions (within and across regions) were submitted to a 2 (group) × 2 (region) mixed ANOVA, with group as a between-subjects variable. Neither the main effect of group, $F(1, 126) = 2.04$, $MSE = 73{,}001$, $p = .16$; the main effect of region, $F < 1$; nor the Group × Region interaction, $F(1, 126) = 1.55$, $MSE = 20{,}395$, $p = .22$, was significant. Planned simple effects tests showed no effect of region for either group (both Fs < 1). These results do not provide strong evidence for the use of region information on the organization of a mental map.

Overall, the recognition test data indicated that priming in recognition is sensitive to differences in how map information is memorized. When object locations were directly tested, a spatial priming effect was observed, but when object identities were directly tested, a temporal priming effect was observed. In addition, no strong evidence for an influence of spatial region was observed, which is surprising given the results of previous studies observing a hierarchical influence of spatial region (e.g., McNamara, 1986; McNamara, Hardy, & Hirtle, 1989).

Recall. An average of 89% of the map object names were recalled ($SD = 10$). Participants in the naming group recalled more words ($M = 91\%$, $SD = 10$) than did those in the pointing group ($M = 86\%$, $SD = 10$), which is not surprising given the nature of the learning task in the naming group, $t(126) = 2.60$.

For the naming group, the mean ARC score was .32 (*SD* = .41) and the mean ARC′ score was .40 (*SD* = .36). However, an inspection of the data of both scores revealed bimodal distributions. These distributions can be seen in Figure 2 (A and B). As can be seen from the figures, use of both spatial and temporal information was observed during recall.

For the pointing group, the mean ARC score was .60 (*SD* = .37) and the mean ARC′ score was .12 (*SD* = .16). An inspection of the data revealed a bimodal distribution for the ARC scores and a unimodal distribution for the ARC′ scores. The distributions can be seen in Figure 3 (A and B). Seventy percent of the people had ARC scores greater than .5 (mode at 1.0) and the rest were less than .5 (mode at 0), which indicated a tendency to organize spatially. This pattern of recalls points to a prominent use of spatial information. Moreover, there was virtually no use of temporal information.

When the two learning groups were directly compared, the mean ARC score for the pointing group was significantly greater than for the naming group, $t(126) = 4.07$. Thus, the recalls for people in the pointing group were more spatially organized than for the naming group. In addition, the mean ARC′ score for the naming group was significantly greater than for the pointing group, $t(126) = 5.85$. Thus, the recalls for participants in the naming group were more temporally organized than the recalls for the pointing group.

Discussion

The main finding of this experiment is that the way a map is learned affects the observed map organization. The temporal organization observed in the naming group replicates previous studies that deconfounded spatial and temporal proximity by using a learning procedure similar to the naming group (e.g., Clayton & Habibi, 1991; McNamara et al., 1992). However, the spatial organization observed in the pointing group does not. This pattern of results suggests that the differences in the nature of the map-learning task can lead to differences in a map's mental organization. When identity information was emphasized, temporal effects in recognition and recall were observed. When location infor-

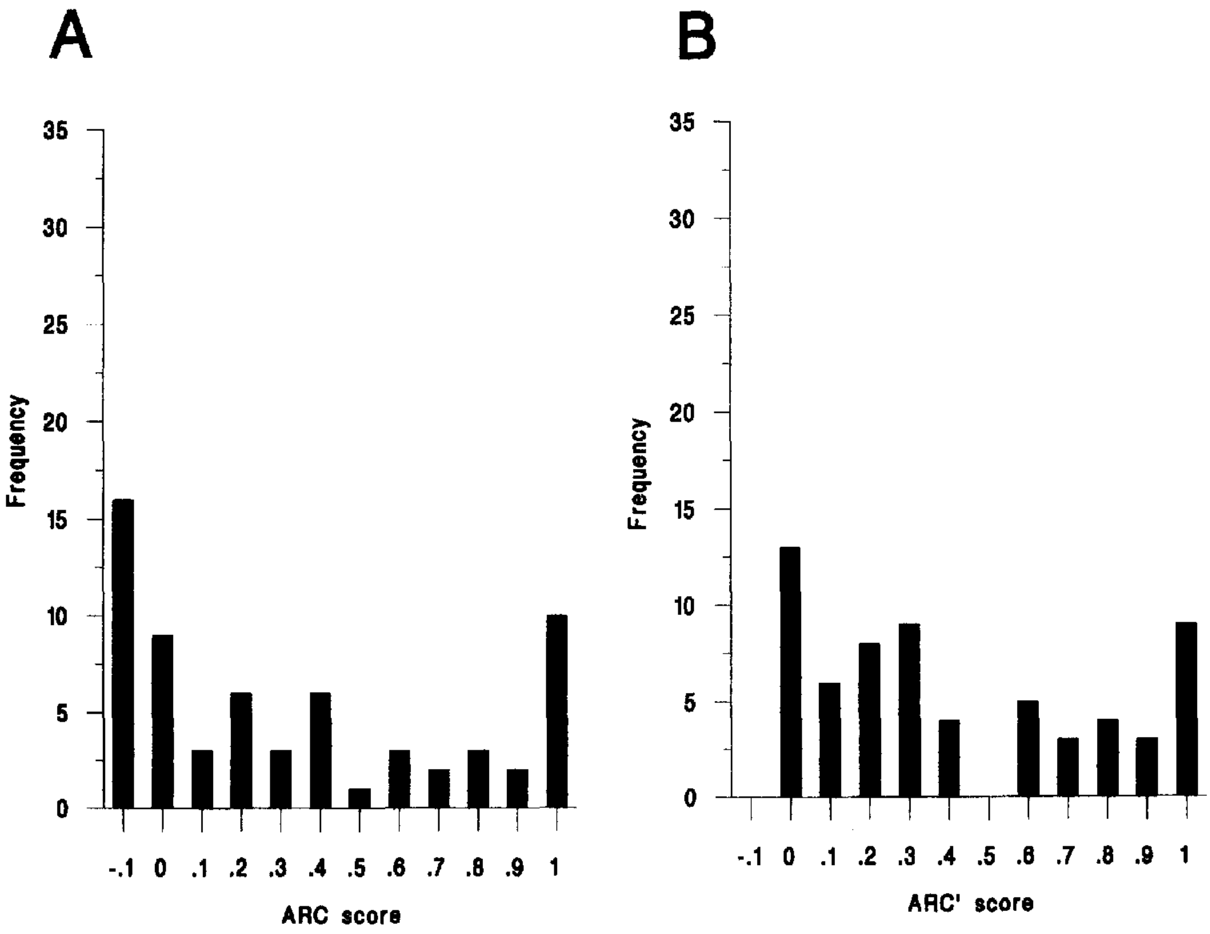

Figure 2. (A) ARC (adjusted ratio of clustering) and (B) ARC′ score distributions for the Experiment 1 naming group. ARC is an index of recall organization by spatial category; ARC′ is an index of recall organization by temporal order.

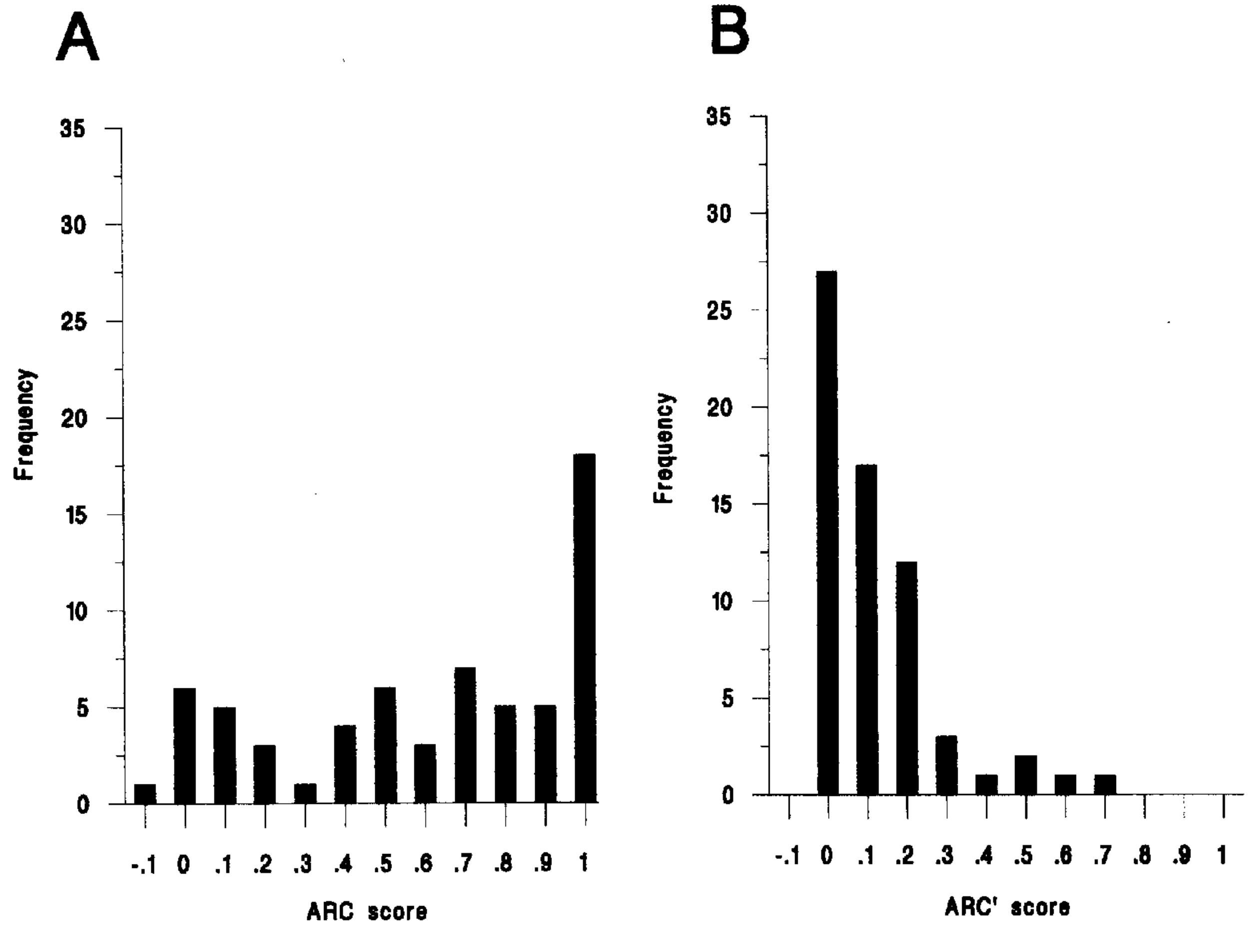

Figure 3. (A) ARC (adjusted ratio of clustering) and (B) ARC′ score distributions for the Experiment 1 pointing group. ARC is an index of recall organization by spatial category; ARC′ is an index of recall organization by temporal order.

mation was emphasized, spatial effects in recognition and recall were observed.

Experiment 2

In Experiment 1, the nature of the learning task influenced the organization observed in primed recognition. Experiments 2 and 3 were designed to see whether spatial priming would be observed in the naming group, when the salience of spatial information was increased. Introducing an explicit expectation to be tested for spatial information should serve to increase the prominence of spatial proximity information during learning. This was done in Experiment 2 by telling people that they would be given a distance estimation test after memorizing the map. Although the primary point of interest of this experiment was whether this expectancy had an influence on the observed priming effects, the distance estimation task was given anyway. This was done more to confirm the participants' expectations and to decrease the likelihood that later participants would have been informed of our method and disregard the expectancy instruction. So, although the distance estimation task was given, the primary data of interest were the recognition test data.

Method

Participants. The participants were 64 undergraduates from the University of Notre Dame subject pool who received partial course credit in exchange for their participation. None had participated in the previous experiments. Six additional people were replaced, 2 for having error rates exceeding 10% on the recognition test and 4 for not following directions in the distance estimation task.

Materials and procedure. The map and object names used in this experiment were the same as those used in Experiment 1, as were the spatial and temporal priming conditions. The memorization procedure used during learning was the same as that for the naming group in Experiment 1. Following memorization, participants were given a primed recognition test. The trimming procedure eliminated 1% of the recognition data in Experiment 2.

After the recognition test, participants were given the distance estimation task. For this test, 80 trials consisting of pairs of object names were presented one pair at a time in the lower left corner of the computer screen. Between these pairs was a horizontal line 3

Table 2
Mean Response Time (RT, in Milliseconds) For Spatial and Temporal Conditions for Experiments 2 and 3

	Experiment 2		Experiment 3	
Condition	RT	*SD*	RT	*SD*
Spatial				
Close	727	160	713	134
Far	700	130	756	199
Priming[a]	−27		43†	
Across regions	742	153	727	142
Priming[b]	42*		−29	
Temporal				
Close	673	123		
Far	718	159		
Priming[c]	45*			

[a]Priming = spatially far − spatially close; [b]priming = spatially across regions − spatially far; [c]priming = temporally far − temporally close.
$^*p < .05$. $^\dagger p = .08$.

mm long. Each critical spatial (close, far, and across regions) and temporal (close and far) prime–target pair from the recognition test was presented twice so that each object of the pair occurred on both the left and the right. The rest of the trials consisted of pairs of randomly selected objects, with the restriction that each object occurred on the right and left an equal number of times. Participants were instructed to estimate the distance between the objects by adjusting the length of the line. This was done by pressing the *M* key to increase the length of the line and by pressing the *Z* key to decrease its length. When satisfied with the estimate, the participant pressed the enter key.

Results

Learning. Participants took an average of 5.8 ($SD = 1.4$) cycles to memorize the map.

Recognition. The mean error rate was low (2%), and so the error rate data are not considered further. The mean RTs for each condition are presented in Table 2. No spatial priming effect was observed between the spatially close and spatially far target trials, $t(63) = 1.24, p = .22$. There was a significant difference between the spatially far and the across-regions target trials, $t(63) = 2.23$. However, the lack of spatial priming between the close and far conditions (which is in the opposite direction) suggests that this is not strong support for a spatial organization. Once again, there was a significant temporal priming effect, $t(63) = 2.13$. Thus, even when there was an expectancy to use spatial information, it appears that temporal information was the primary source used in mental map organization.[1]

Distance estimation. Although the data from the distance estimation task were not of central interest, we analyzed the data to assess the degree of distortion of people's estimates. Because the spatial distances involved varied in the different conditions, we conducted regression analyses to obtain the exponents of the best fitting psychophysical function (e.g., Radvansky, Carlson-Radvansky, & Irwin, 1995; Stevens & Galanter, 1957; Wiest & Bell, 1985). Separate analyses were done for the temporally close and temporally far conditions, because they each involved a number of spatial distances. In addition, the spatially close and spatially far conditions were combined for a third analysis. The mean exponent across all of these conditions was .702. On the basis of previous research (e.g., Radvansky et al., 1995; Wiest & Bell, 1985), this is within the range expected when estimates are made from inference processes rather than being directly retrieved from memory, suggesting that this information is not directly stored in memory. For the individual conditions, the mean exponents were .622 for the temporal-close condition, .732 for the temporal-far condition, and .752 for the spatial condition. The only significant difference was between the temporal-close condition and the spatial exponents, $t(63) = 2.79$, with the rest being nonsignificant (all $ts < 1$). As a reminder, the temporal distance between the spatial pairs was greater than even our temporally long conditions. Thus, the degree to which people's distance estimates were distorted seemed to vary as a function of how far apart the two objects were temporally: The closer they were temporally, the more the distance was underestimated.

In addition, because the same spatial distance was involved in the spatially far and across-region conditions, these two conditions were directly compared to see whether there was an effect of region. The actual distance involved was 6.05 cm. The estimated distance for the within-region spatially far condition was smaller (6.0 cm, $SD = 1.4$) than for the across-region condition (6.5 cm, $SD = 1.7$), $t(63) = 3.57$. This suggests that regions may influence judgments when people are explicitly asked to use spatial information. This is consistent with Huttenlocher et al.'s (1991) theory that states that distance estimation judgments such as these are influenced by both detail information and categorical information. In this case, the map regions would correspond to categorical information. Knowing that two items are in different categories could lead people to overestimate the distance between them.

Discussion

Increasing expectations to use spatial information after memorization did not have an appreciable effect in the pattern of priming. Although a significant spatial priming

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[1] It should be noted that the data from two additional experiments also showed temporal priming in the absence of spatial priming. One experiment was like the naming group. The results of this experiment showed temporal priming (37 ms), $F(1, 47) = 4.16$, but neither spatial priming (5 ms), $F < 1$, nor across-regions spatial priming (−35 ms), $F(1, 47) = 1.96$. The recall data showed a slightly greater preference for temporal organization ($ARC' = .5$) than for spatial organization ($ARC = .3$). The other experiment differed in that the map was divided into two regions, rather than four, which is more similar to the map used by the McNamara et al. (1992) study. Again, there was temporal priming (64 ms), $F(1, 63) = 5.86$, but neither spatial priming (33 ms), $F(1, 63) = 1.35$, nor across-regions spatial priming (−7 ms), $F < 1$. The recall data also showed a greater preference for temporal organization ($ARC' = .5$) than for spatial organization ($ARC' = .1$).

effect was observed in comparing within- and across-regions conditions, the difference between spatially close and spatially far conditions was not significant and was numerically in the opposite direction. This leads us to conclude that it was unlikely that people were using spatial information to organize mental maps. However, a reliable temporal priming effect was observed as in the naming group of the previous experiments. So, it appears that when maps are learned by identifying object names, temporal information provides a strong basis for organizing a mental map, whereas spatial information provides only a weak basis.

As for the distance estimations, people tended to underestimate the actual distance, and this distortion seemed to be systematically influenced by temporal distance. That is, the smaller the temporal distance, the greater the underestimation of spatial distance. In addition, consistent with Huttenlocher et al.'s (1991) theory, region information seems to have some influence on distance estimates, with within-region estimates being more underestimated than between-region estimates.

Experiment 3

In the naming group of Experiment 1 and in Experiment 2, consistent temporal and spatial proximity information were both available during map learning; however, consistent spatial priming was not observed. Despite an effort to increase the likelihood that spatial information would be used in organizing map information in Experiment 2, little evidence of spatial priming was observed, suggesting that spatial information does not play a strong role in organizing mental maps when they are learned by naming objects. Experiment 3 was an extreme attempt using the learning method of the naming group to get people to organize their mental maps spatially. During learning, rather than presenting the study and test trials in a consistent temporal order, a different random order was used on each presentation. Thus, not only were spatial and temporal proximity deconfounded, but a uniform temporal structure was completely absent. As such, spatial information was the only stable source of proximity information available.

Method

Participants. The participants were 74 undergraduates from the University of Notre Dame subject pool who received partial course credit in exchange for their participation. None had participated in the previous experiments. Ten additional participants were replaced, 7 for failing to finish the experiment and 3 for recognition-test error rates that were greater than 10%.

Materials and procedure. The maps and object names used in Experiment 3 were the same as those used in the previous experiments. Map presentation varied during learning by having the computer randomly select a different temporal order for each study–test learning cycle. Thus, there was no consistent temporal order. After memorization, people were given primed recognition and recall tests. Obviously, no temporal effects could be assessed. The trimming procedure eliminated 1% of the recognition test in Experiment 3.

Results

Learning. Participants took an average of 6.2 (SD = 1.5) cycles to memorize the map.

Recognition. The mean error rate was low (2%), and so the error rate data are not considered further. The mean RTs for each condition are presented in Table 2. A marginally significant spatial priming effect was observed, with responses to targets following spatially close primes being faster than those following spatially far primes, $t(73)$ = 1.79, p = .08. However, a closer inspection of the data revealed a participant whose mean RT (1,096 ms) was 3 standard deviations greater than the group mean RT (753 ms, SD = 114).[2] The spatial priming effect for this person was 949 ms, more than 4 standard deviations larger than the group mean. A reanalysis of the data excluding this person resulted in a nonsignificant spatial priming effect, $t(72)$ = 1.46, p = .15.

There was no evidence of spatial priming when the spatially far trials were compared with the across-regions trials, $t(73)$ = 1.40, p = .17. Furthermore, difference between the long and across-regions conditions was in the direction opposite of what would be expected for spatial organization. Thus, these data provide very weak evidence for a spatial organization.

Recall. People recalled an average of 97% of the object names. Unlike the results of Experiments 1 and 2, the ARC scores were unimodally distributed (see Figure 4). The mean ARC score was −.01 (SD = .1), indicating only chance spatial organization. Thus, whatever strategy people were using to organize their recalls, it was not spatial. This result is surprising given that spatial information was the only constant and stable source of information throughout learning.

Discussion

Although there was no consistent temporal order during map learning, the data from Experiment 3 failed to reveal a strong spatial organization. The spatial priming effect that was observed in the recognition-test data was only marginally significant in spite of the fact that more people were tested in this experiment with this learning method than in the previous experiments. Furthermore, spatial organization was completely absent in the recall data. Thus, this experiment did not provide compelling evidence that spatial information is used as a major means of organizing mental maps when identity information is emphasized during learning.

General Discussion

Previous research on how people organize mental maps has suggested that people use processes that lead to a temporal organization (Clayton & Habibi, 1991; Sherman & Lim, 1991), with the possibility that this organization may in

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[2] An exceptionally slow participant was also identified in a reconsideration of the data from Experiment 2. An analysis that excluded this participant did not change the pattern of results.

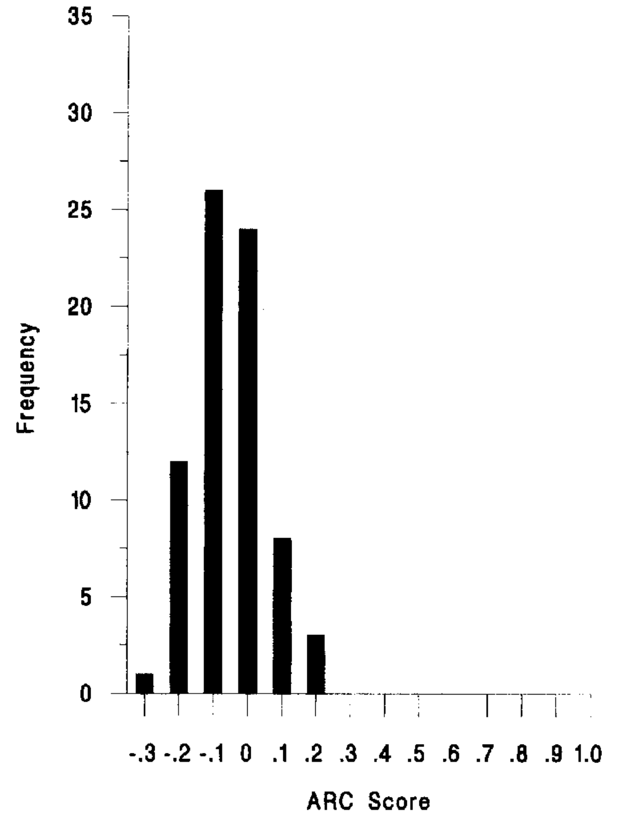

Figure 4. ARC (adjusted ratio of clustering) score distribution for Experiment 3. ARC is an index of recall organization by spatial category.

some way be modified by spatial characteristics when spatial and temporal proximity are confounded (McNamara et al., 1992). The purpose of the present experiments was to further explore the separate contributions of spatial and temporal information on the organization of mental maps when spatial and temporal proximity are deconfounded.

In Experiment 1, we explored the possibility that the pattern of results observed by other researchers was related to the nature of the map-learning task. Consistent with this idea, a pointing group showed a spatial organization, both in recognition and recall, whereas a naming group showed a temporal organization. This organization reflects the actual use of spatial information, rather than intended use, because expectancies to use spatial information alone (Experiment 2) did not result in spatial organization. The results of Experiments 2 and 3 indicate that spatial information does not play a prominent organizational role when a map is learned by naming objects, even when the salience of spatial information is increased. Temporal priming was observed when expectancies to use spatial information were increased (Experiment 2). In contrast, no compelling spatial priming effects were observed. Together, the results of the experiments suggest that an emphasis on identity information during learning results in a temporal organization.

One potential criticism of our study is that the maps in our experiments conveyed an impoverished amount of information in comparison to "real world" maps that convey additional detailed information, such as symbols that resemble the items they represented (e.g., jagged lines to represent mountain ranges). Our maps simply consisted of a number of objects placed in a square area that was divided into smaller regions. Thus, the results may not reflect the use of map representations that contain more richly detailed information.

However, data from another study conducted in our lab suggest that this is not the case (Curiel, Radvansky, & Wolters, 1997). This study was modeled after a series of experiments by Morrow, Bower, and colleagues (e.g., Morrow, Bower, & Greenspan, 1989; Morrow, Greenspan, & Bower, 1987; Rinck & Bower, 1995) that investigated the use of spatial information in narrative comprehension. In this paradigm, people memorize a map of a building, such as a research center. The map typically contains 10 rooms with four objects located in each room. These maps are fairly detailed with symbols denoting objects that are physically similar to the objects themselves and doorways in room walls to allow passage to the next room. Semantic information is also present in that the objects are semantically related to the rooms in which they are located (e.g., the shelves and the copier are located in the library) and are not randomly placed. After memorizing the map, participants read short stories, which take place in the research center.

The focus of the Curiel et al. (1997) study was on how knowledge of a memorized map affects later processing in both narrative comprehension and long-term memory retrieval. For now, we only consider the set of data from the memory-retrieval task because it is directly related to the current experiments. In this study, as in Experiment 1, people memorized a map, with spatial and temporal proximity deconfounded, either by naming objects or by pointing to them. It should also be noted that map objects were presented during learning in a consistent temporal order that was different for each participant. As in the current experiments, temporally close items were defined as objects that were next to each other in the temporal order and temporally far objects were defined as items that were separated by four objects in the temporal order. Spatially close objects were defined as objects that were located in the same room and spatially far objects were defined as objects that were located in different rooms.

As in the experiments reported here, when the map was learned by naming objects, a significant 45-ms temporal priming effect was observed. This occurred even though (a) the map used was more complex and realistic, (b) the objects were semantically related to the rooms in which they were located, (c) the names of the rooms were related to each other in that they could be part of a research building, and (d) the room names were presented along with the object names during learning. Moreover, as in Experiment 1, when participants learned the map by pointing to object locations, a significant 38-ms spatial priming effect was observed. Thus, spatial priming is not observed unless spatial information is emphasized during learning, even with a map that provides more detailed information.

Although it is unclear from the present data what is the precise nature of a long-term mental map, some conclusions can be drawn. First, it is clear that previously proposed theories of mental map organization would have difficulty accommodating the present results. Spatial theories, such as the partially hierarchical theory (e.g., McNamara, 1986), cannot account for the data. They would have trouble with the constant temporal priming effects observed in the naming group of Experiment 1 and in Experiment 2. Furthermore, according to the partially hierarchical theory, region information is used to organize mental maps. However, across three experiments (see also footnote 2), only one showed a significant regions effect, although in that experiment the basic spatial priming effect was in the wrong direction. The present data also discount temporally based theories (Clayton & Habibi, 1991) in that, although consistent temporal priming effects were observed in the naming group of Experiment 1 and in Experiment 2, no temporal priming was observed in the pointing group of Experiment 1. Thus, a purely spatial or temporal theory is insufficient to account for these results.

A hybrid theory that considers both spatial and temporal information to be used in organizing map information may more adequately explain the results. As described earlier, McNamara et al. (1992) proposed a hybrid model in the form of a dual-representation hypothesis. As a reminder, according to this view, map information is stored in two representations, a nonmetric representation that captures spatial relations in a propositional format and a metric representation that captures spatial and temporal relations in an analog format. Furthermore, they claimed that the nonmetric representation is what is accessed during recognition. Although they argued at length for why the nonmetric representation reflected spatial relations, this contention hinged on the nonsignificant temporal priming effect when items were spatially far. However, this idea that spatial information is important for the nonmetric representation is at odds with the temporal priming effects at spatially far distances observed in the naming group of Experiment 1 and in Experiment 2, whereas the only compelling spatial priming effect was observed in the pointing group in Experiment 1.

The present data can be accounted for by assuming that associative relations between objects are represented in the mental map. Such a claim is not new. For example, Clayton and Habibi (1991) viewed the primacy of temporal order to underlie the creation of associations among items in a mental map. Similarly, McNamara et al. (1992) viewed primed recognition to reflect the creation of spatial propositions. However, the results of Experiment 1 point to a more flexible use of spatial and temporal information in creating associations in that neither the use of spatial nor temporal information consistently plays a primary role in mental map organization. Rather, the use of spatial and temporal information is related to the nature of the learning task. This explanation is consistent with the fact that region effects were not observed and would lead to the prediction that an emphasis on learning region information would lead to across-regions priming.

As such, we suggest that the organization of a mental map is based on a number of possible associative relations. Two of these relations are spatial and temporal proximity. As mentioned above, it is possible that region-based relations may also be involved. Although we found no consistent evidence of the influence of such information, other researchers using different tasks have found effects of region information (e.g., Stevens & Coupe, 1978). Finally, on the basis of other research (e.g., McNamara, Altarriba, et al., 1989; McNamara & LeSueur, 1989), semantic relations may also affect mental map organization.

One admittedly ad hoc way to conceptualize how a mental map might be represented is in terms of some sort of associative network in which the nodes of the network would correspond to the map locations. Importantly, the links among nodes would vary in terms of the type of relation they represent (e.g., spatial or temporal). This is consistent with other theories that suggest that links can vary in terms of the types of relations they convey (e.g., Anderson, 1983). When information is encoded into such a structure, what guides the use of various types of links among location nodes is not merely the presence of that information in the environment, but what aspect(s) of the map that the learning situation emphasizes. This emphasis serves to focus the learner's attention on various subsets of relations among map locations. Thus, the creation of mental maps seems to be a very flexible process from which spatial organization may or may not be observed. A mental map is most likely to convey more spatial characteristics when the encoding situation focuses attention on the spatial relations among map locations. When attention is focused on other aspects, the presence of spatial relations in the structure of the mental map will be attenuated or absent. Instead, the organizational structure of the map locations will be more likely to reflect those dimensions on which attention has been focused. In this way, mental maps may not be spatially organized but may be based on some other type of organization, such as the apparent temporal organization in the naming group of Experiment 1 and in Experiment 2.

The goal of future research will be to more clearly define the nature of the learning-based influences and the effect they have on other ways of using information from mental maps, such as distance estimation or direction judgment. In the current experiments, we relied mostly on tasks that did not explicitly require the use of certain types of relation information. At this point, it is unclear to what extent the sorts of learning differences observed here will generalize to circumstances in which specific types of relational information (e.g., spatial, temporal, semantic) are explicitly required during memory retrieval.

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