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The Mental Representation of Knowledge Acquired From Maps

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Recognition priming and distance estimation were used to investigate the mental representation of knowledge acquired from maps. In Experiment 1, recognition priming showed that cities close in route distance primed each other more than cities far in route distance, even when Euclidean distance was equated. Experiment 2 showed that this finding was robust and not an artifact of the way subjects learned the maps. Distance estimations in Experiment 1 supported the priming results. These results indicated that psychological distance in cognitive maps is primarily dependent on route distance rather than Euclidean distance.

The experiments reported here tested how knowledge acquired from simple maps is mentally represented and processed. These experiments also tested a new methodology for examining spatial representations. The main question addressed in this research was how route and distance information are represented in cognitive maps. In particular, the experiments examined the relative contributions of route and Euclidean distance on a map to determining the psychological distance between locations in the mental representation of that map. For example, in Figure 1, the cities Sedona and Emmet are equidistant from Nesmith in terms of Euclidean distance. However, Sedona is much closer to Nesmith than is Emmet in terms of route distance. In Experiments 1 and 2, we attempted to determine if the psychological distance between cities in a cognitive map would be primarily dependent on the route distance or the Euclidean distance between those cities on the real map.

The second goal of this research was to test a new methodology for examining the mental representation of spatial knowledge. Many tasks have been used to study spatial representations. Some of the more common ones have been distance estimation (e.g., Baird, Merrill, & Tannenbaum, 1979; Kosslyn, Pick, & Fariello, 1974; Newcombe & Liben, 1982; Thorndyke, 1981); orientation judgments (e.g., Hintzman, O'Dell, & Arndt, 1981; Stevens & Coupe, 1978); direct mapping, in which subjects draw maps from memory (e.g., Baird et al., 1979; Tversky, 1981); and navigation (e.g., Arcedelo, Pick, & Olsen, 1975; Thorndyke & Goldin, 1983). All of these tasks are potentially informative about various aspects of spatial cognition and behavior. However, some authors have questioned whether these tasks are informative about the mental representation of spatial knowledge (e.g., Liben, 1981, 1982; Siegel, 1981). Siegel (1981) has suggested that experiments testing spatial representations should use tasks that minimize performance demands so that the contents of spatial representations can be assessed more accurately. A paradigm that might meet this requirement is priming in spatial memory. The priming task used in our experiments was based on priming in item recognition (for another priming task, see Clayton & Chatten, 1981). This task has been used previously with textual materials. Typically, subjects read paragraphs of text and then are given a recognition test in which they distinguish words in the text from words not in the text. It has been found that subjects recognize a target word faster when it is immediately preceded in the recognition list

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by a word from the same sentence as the target than when it is preceded by a word from a different sentence. Recognition priming has proven to be effective for examining the relative distances between propositions in memory for text (e.g., McKoon & Ratcliff, 1980; Ratcliff & McKoon, 1978). The priming technique has also been used successfully to examine how the relations among parts of pictures are mentally represented (McKoon, 1981). A difference between recognition priming and many other tasks is that priming does not seem to be influenced by retrieval strategies. Ratcliff and McKoon (1981) have shown that recognition priming in memory for sentences is insensitive to the probability of a priming event and has a very fast onset. These qualities indicate that priming is primarily an automatic process (as defined by Posner & Snyder, 1975a, 1975b).

Applying recognition priming to the study of spatial representations was straightforward. In our experiments, subjects first learned the locations of several cities on a map and then were given a recognition test in which they distinguished names of cities on the map from names of cities not on the map. We were interested in the extent to which subjects would recognize a target city faster if, on the immediately previous trial, they had just recognized a city close to the target on the map. By varying both route and Euclidean

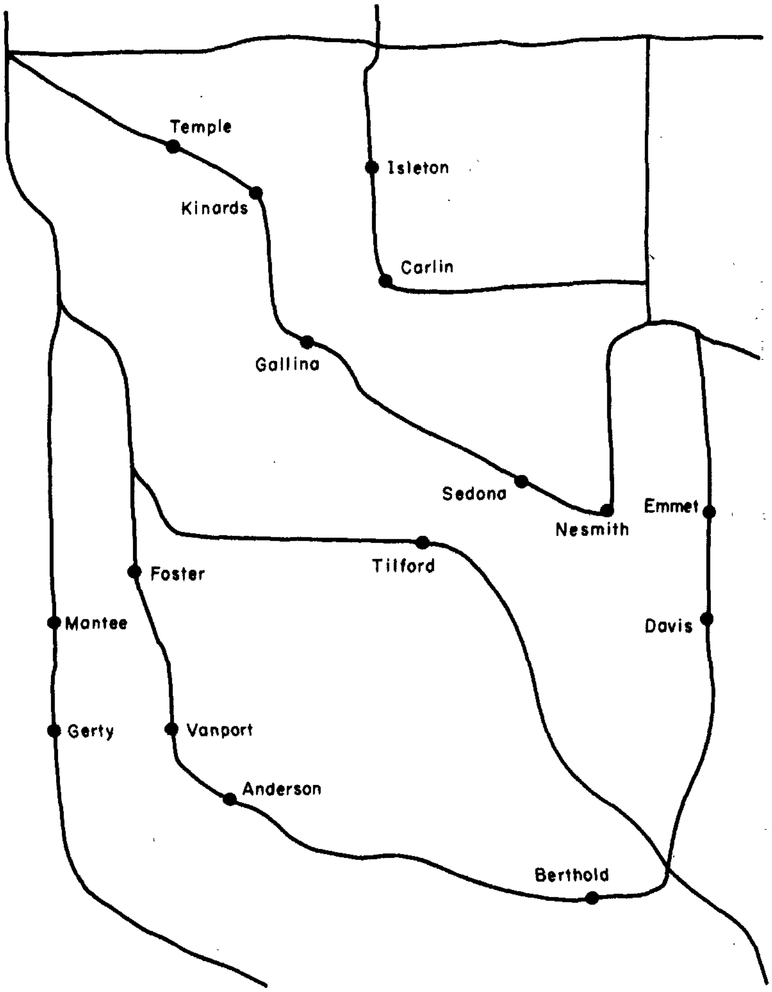

Figure 1. An example of one of the maps used in the experiments.

distances on the maps, we hoped to assess the relative contributions of these variables to determining psychological distance in cognitive maps.

Experiment 1

In Experiment 1 subjects learned artificial road maps like the one illustrated in Figure 1. Critical pairs of cities on the maps could be close in Euclidean distance and close in route distance (e.g., Temple–Kinards), close in Euclidean distance but far in route distance (e.g., Gallina–Carlin), or far in Euclidean distance and far in route distance (e.g., Temple–Mantee). (A fourth condition, far in Euclidean distance but close in route distance, was impossible because Euclidean distance is always less than or equal to route distance.) If psychological distance in cognitive maps is primarily determined by route distance, locations near each other in route distance should prime each other more than locations far apart in route distance (even if they were close together in Euclidean distance). However, if psychological distance is primarily determined by Euclidean distance, locations near each other in Euclidean distance (even if they were far apart in route distance) should prime each other more than locations far apart in Euclidean distance.

Another goal of the first experiment was to examine the relation between distance estimations and the time to produce those estimates. We thought that the relation between these variables might distinguish among models of distance estimation from cognitive maps.

Method

Subjects

The subjects were 18 Yale University undergraduates. Subjects were compensated for their participation with course credit.

Materials and Design

Three artificial road maps were constructed. One of the maps has been reproduced in Figure 1. Each map contained 16 cities, one of which was a filler that was not used in any of the experimental conditions. The remaining 15 cities could be divided into 6 targets and 9 primes. Each target could be paired with 3 primes to form city pairs falling into three conditions: (a) close in Euclidean distance and close in route distance (CE–CR); (b) close in Euclidean distance but far in route distance (CE–FR); and (c) far in Euclidean distance and far in route distance (FE–FR). For example, Nesmith–Sedona was in the CE–CR condition; Tilford–Sedona was in the CE–FR condition; and Anderson–Sedona was in the FE–FR condition.

Maps occupied most of the area on 8.5 × 11 in. sheets of paper. The Euclidean distance between close cities ranged from 0.9 to 1.3 in. The mean intercity Euclidean distance was 1.1 in. for pairs in both the CE–CR and the CE–FR conditions. Far cities were between 4.0 and 8.3 in. apart in Euclidean distance, with a mean distance of 5.3 in. Route distance between pairs in the CE–FR and FE–FR conditions was not explicitly controlled. However, we attempted to make the route distances comparable in the two conditions.

City names were selected from the index of a current road atlas with the constraints that they were not names of famous cities in the United States and that the initial letters of city names were fairly evenly distributed across the alphabet. Seventy-two city names were so selected. Forty-eight of these names were randomly selected to serve as names of locations on the maps (16 per map). The remaining 24 names (8 per map) were used as foils in the recognition task. City names were randomly assigned to locations on the maps with the constraint that no more than 2 city names on a map begin with the same letter of the alphabet.

Three lists of cities were constructed initially for each map to be used in the recognition test. Each list contained 24 names; 16 were positive items (cities on a map) and 8 were foils. The same 8 foils appeared on all three of the lists constructed for a given map. Six pairs of cities on a list were involved in priming relations, two in each of the three conditions (CE–CR, CE–FR, and FE–FR). The prime–target pairs were assigned to the three lists so that (a) each city appeared only once on a list, (b) each target appeared in each condition across lists, and (c) each prime was paired with two targets across lists. City names were assigned to positions on a list (i.e., the first serial position, the second serial position, etc.) with the following constraints: (a) Targets appeared no earlier than the fourth position; and (b) priming pairs from the same condition did not appear sequentially in a list, or when this was impossible to avoid, they were separated by at least three trials. Two such orderings of cities were constructed for each of the three initial lists, producing a total of six stimulus lists per map. Each of these lists was seen by three subjects. Each subject saw three lists (one per map) over the course of the experiment. Lists were assigned to subjects according to a fixed rotation determined by the order in which subjects participated in the experiment.

Procedure

Subjects first learned the locations of the cities on a given map and then participated in a recognition test. This sequence was repeated for each of three maps. The order in which maps were learned was varied in a Latin square rotation, such that each map was tested equally often in each serial position across subjects. After learning the maps and participating in the recognition test for each map, subjects estimated the distances between pairs of cities on one of the maps (the map in Figure 1).

Map learning. Subjects were given a map and asked to learn the locations of the cities. After a 2-min study period, the map was removed and subjects were given a list of the cities in random order and a road grid for the map, minus the cities and the locations of the cities. Subjects were asked to place all of the cities on their correct locations. When a subject completed placing the cities, the experimenter checked the subject's work and pointed out any errors the subject may have made. This study-test sequence was repeated until the subject could place all of the cities within about 0.25 in. of their correct locations.

Recognition. Twenty-four practice trials (in which subjects discriminated names of U.S. states from names of foreign countries) preceded the first recognition test. For the remaining maps, the recognition test immediately followed map learning.

City names were presented one at a time on a computer terminal screen. The subjects' task was to decide whether or not the city name was on the map just learned. Subjects pressed the "/" key to respond *yes* and the "z" key to respond *no*. Subjects were asked to respond carefully and accurately but also quickly. Two hundred and fifty milliseconds ellapsed between a response and the presentation of the next city name.

Distance estimation. When subjects completed the map learning and recognition tests for all three maps, they participated in a distance-estimation task. Subjects were given the map in Figure 1 and allowed to review it for 1 min. After reviewing the map but before starting the distance estimation, subjects were told that the distance between Gallina and Sedona was 30 miles. This distance corresponded to a scale of approximately 1 in. to 11 miles. Subjects were then shown all possible pairs of the 15 critical cities on the map (105 pairs) and were asked to estimate the Euclidean distance in miles between the cities, using the example distance as a scale. The exact procedures were as follows.

On each trial, one pair of cities was presented on the terminal screen. Subjects were instructed to press the "enter" key on the terminal keyboard when they had estimated the distance between the cities. Subjects were told to take as much time as they needed, but no more, to make their decisions. The experimenter emphasized that subjects should press the "enter" key only when they had "a number in mind." After the "enter" key was pressed, the word "Distance:" appeared on the same line as the pair of cities. At this point, subjects typed in the distance using a numeric keypad on the right-hand side of the terminal keyboard. Subjects were given a rest period after the 53rd item. Most subjects completed the distance estimations in 30 min, but there was no time limit imposed. Each city appeared as the left member of a pair as many times as it appeared as the right member of a pair. The ordering of pairs was random and different for each subject.

Results

Map Learning

The mean numbers of trials to reproduce each of the three maps correctly were 2.9, 2.6, and 2.8, $F(2, 34) = 1.11$. These means indicate that the maps were about equally difficult to learn.

Table 1
Mean Response Times and Error Rates in Experiment 1

Condition	RT (in ms)	Errors (%)
CE–CR	627	1.9
CE–FR	682	0.0
FE–FR	677	2.8

Note. RT = response time. CE–CR = close in Euclidean distance, close in route distance. CE–FR = close in Euclidean distance, far in route distance. FE–FR = far in Euclidean distance, far in route distance.

Recognition

Analyses of response latencies were conducted on the mean correct response latencies to the targets in each condition. Only correct responses preceded by correct responses were included in the analyses to ensure that both the prime and the target were in memory at time of test. Finally, response latencies outside the "outer, upper fence" (Tukey, 1977) for each condition were classified as outliers and excluded from the analyses of response latencies.[1] The outer, upper fences were 1,226 ms for the CE–CR condition, 1,445 ms for the CE–FR condition, and 1,296 ms for the FE–FR condition. Eight outliers were identified out of the 307 responses meeting the condition above. The mean response latencies and the error rates in each condition are presented in Table 1.

Analyses of variance performed on the mean latencies computed for each condition revealed a reliable effect of condition across subjects, $F(2, 34) = 4.54$, $MS_e = 3{,}621.30$, $p < .025$, and across items, $F(2, 34) = 7.35$, $MS_e = 2{,}644.58$, $p < .005$. Pairwise comparisons showed that responses to items in the CE–CR condition were significantly faster than responses to items in either of the other conditions, which did not differ significantly. Analyses of the error rates revealed no significant effects ($F < 1$).

The mean correct response latency and

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[1] The outer, upper fence is equal to the 75th percentile + [3 × (75th percentile − 25th percentile)].

error rate for foils were 738 ± 14 ms and 3.2 ± 0.9%; means for primes and fillers (taken together) were 707 ± 12 ms and 3.1 ± 0.8%. The overall mean latency for errors was 1,012 ± 164 ms.

Distance Estimation

Mean estimated distances in miles were computed for each subject and each condition.[2] Means across subjects were 14.2 for the CE–CR condition, 18.9 for the CE–FR condition, and 47.1 for the FE–FR condition. The actual mean distances in these conditions were 12.3, 12.8, and 54.3 miles, respectively. (The difference of 0.5 miles between the first two conditions corresponds to a distance of less than 0.05 in. on the map.) The important comparison in these data is between distance estimations in the CE–CR and CE–FR conditions, because Euclidean distance was the same in these two conditions. A t test between the CE–CR and the CE–FR conditions showed distance estimates were significantly smaller in the former than in the latter condition, $t(17) = 3.24$, $p < .005$.

The mean estimation latencies were 8.065 s for the CE–CR condition, 8.682 s for the CE–FR condition, and 9.972 s for the FE–FR condition. In contrast to distance estimations, there was no reliable difference between estimation latencies in the CE–CR condition and estimation latencies in the CE–FR condition ($t < 1$).

The intercorrelations between mean estimated distances, mean estimation latencies, and actual distances are presented in Table 2. The high correlation between estimated distances and actual distances shows that subjects were quite accurate at estimating distances, to within a linear transformation. A regression of estimated distances on actual distances produced an intercept of 8.81 and a slope of 0.71. These parameter values show that subjects tended to overestimate small distances and underestimate large distances, a finding that is consistent with the results of previous research (e.g., Newcombe & Liben, 1982).

Table 2
Intercorrelations Between Estimated Distances, Estimation Latencies, and Actual Distances in Experiment 1

Variable	1	2	3
1. Estimated Distances	—	.54	.97
2. Estimation Latencies		—	.50
3. Actual Distances			—

Note. $n = 105$. All correlations are significant at the .001 level or better.

Certain models of distance estimation from cognitive maps propose that subjects estimate distances on the basis of how long it takes to scan from one point to another on a mental image of a map. In particular, some models propose that distance estimations are a linear function of image scan time (e.g., Thorndyke, 1981). This relation can be indirectly tested if we assume that estimation latency is a linear function of image scan time. Under these assumptions, there is a linear function from estimation latencies to scan time, and so, from estimation latencies to distance estimations. In fact, the correlation between distance estimations and estimation latencies (0.54) was significant ($p < .001$). However, this correlation corresponds to only 29% shared variance between these variables, which is not very high if the theoretical relations are proposed to be linear.

A stronger test of linear scanning models can be made by examining the distributions of distance estimations and estimation latencies for each experimental condition. We computed the first, second, and third quartiles of the distance estimations and estimation latencies for each subject and each condition and then averaged these quartiles across subjects. This Vincentizing procedure guarantees that the combined distribution will be representative of individual subject's distributions

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[2] A few subjects reported that they forgot to press the "enter" key on some trials before typing a distance estimation. When this omission occurred, the computer ignored the first digit pressed, recording only the second digit as the distance estimation. We analyzed the data in three ways: (a) including all of the data, (b) including all data except for zero values, and (c) including only values greater than or equal to 10 (the smallest actual distance on the map was 11 miles). These analyses yielded *identical* patterns of results, including the statistical significance of the various effects. For simplicity, we presented findings from the second analysis, in which all zero values (and their associated estimation latencies) were excluded.

(Ratcliff, 1979). The resulting mean quartiles for each condition are plotted in Figure 2. The plots in Figure 2 are pseudo-bivariate distributions. These data are plotted on a distance-latency plane to emphasize their bivariate relation, but the actual values plotted correspond to the marginal distributions (the projections of the bivariate distributions onto the distance and latency dimensions). For each experimental condition, we first located the point formed by the median of the distance estimations and the median of the estimation latencies in that condition. We then plotted the 25th and 75th percentiles of latencies on a horizontal line through the medial point and the 25th and 75th percentiles of distances on a vertical line through the medial point. These plots accurately depict the locations of the bivariate distributions. They also provide some information about shape, but they provide no information about eccentricity (slant).

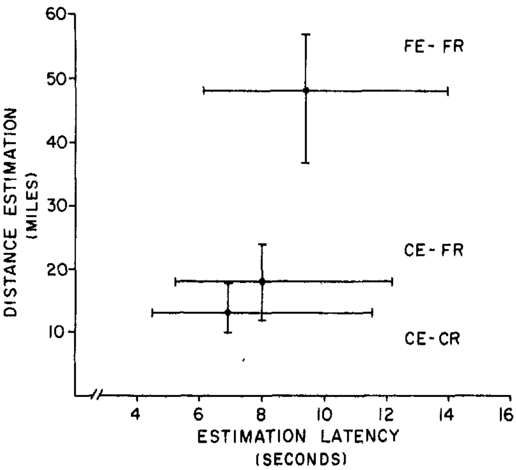

Figure 2. Bivariate distribution summaries for estimation latencies and distance estimations in each experimental condition. (These plots are only approximate because they are based on the marginal distributions of latencies and distances. For each condition, the horizontal line summarizes the marginal distribution of estimation latencies: the left-most hash mark is the 25th percentile, the midpoint is the median, and the right-most hash mark is the 75th percentile. Similarly, the vertical line summarizes the marginal distribution of distance estimations: the lower hash mark is the 25th percentile, the midpoint is the median, and the upper hash mark is the 75th percentile. CE–CR = close in Euclidean distance, close in route distance; CE–FR = close in Euclidean distance, far in route distance; and FE–FR = far in Euclidean distance, far in route distance.)

If we imagine mapping latencies onto distances using a linear function, then latencies between 7 and 11 s pose serious problems. In some cases, these values get mapped onto distances between 10 and 22 miles (CE–CR and CE–FR), but in other cases, the same values get mapped onto distances between 36 and 56 miles (FE–FR)! This indeterminacy shows that there cannot be a monotonically increasing function from latencies to distances, let alone a linear function.[3] These results make any model assuming linear relations between scan times and distance estimations and between scan times and estimation latencies extremely suspect.

Discussion

The results from Experiment 1 suggest that locations on a simple map that were close together in Euclidean and route distance were encoded closer in the mental representation than locations that were close together in Euclidean but not in route distance. This conclusion is supported by the recognition priming results and the distance estimations. However, there may be a problem with this conclusion. It is possible that the priming technique was tapping connections between city names in a retrieval structure separate from the cognitive map. Suppose, for example, that subjects learned the maps by learning the locations of cities on the same route. If this was the case, it would be highly likely that cities that were close together in route and Euclidean distance also would have been close together in subjects' rehearsal protocols. And if the city names were near one another in the rehearsal protocols, the priming results might have been indexing verbal associations

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[3] A model could be developed in which most of the variability in estimation latencies was due to factors other than scan time variability. In such a model, a nonlinear transformation of scan time could produce distance estimations. This model is implausible, however, because the standard deviations of scan times would have to be less than 300 ms to allow accurate mapping from scan times to distance estimations, leaving a huge component of estimation latency (3–4 s *SD*) to be accounted for by other processes. Further, if scan times were available to distance estimation, then one must question why it would not be equally available to estimation latency (leading to small standard deviations).

developed during the map learning phase rather than the spatial structure of the cognitive map. We tested this hypothesis in Experiment 2 by controlling how subjects learned the maps.

Experiment 2

In Experiment 2, we forced subjects to learn the maps in ways that ensured that the distance in the learning protocol was the same for cities in the CE–CR condition and cities in the CE–FR condition. If a reliable priming effect is still obtained for cities that are close together in both route and Euclidean distance relative to cities close only in Euclidean distance, there will be strong evidence that priming effects in Experiment 1 were not an artifact of how subjects learned the maps.

Method

Subjects

The subjects were 12 Yale University undergraduates. Subjects were compensated for their participation with monetary payment.

Materials and Design

The three maps from Experiment 1 were also used in Experiment 2. The only changes in the maps were that the cities were numbered from 1 to 16 with red numerals indicating the order in which the locations of the cities were to be learned. The 16th city in a learning protocol was always the filler city. Because different subjects saw different targets (as well as different primes) in the three experimental conditions and because we wanted to ensure that the order of a prime and target in the recognition test corresponded to the order of the cities in the learning protocol, we constructed three versions of each map differing only in the order in which cities were to be learned. Each subject learned one of the three versions of each map. One of the orderings used for the map in Figure 1 was: Tilford, Sedona, Nesmith, Emmet, Davis, Gallina, Carlin, Isleton, Kinards, Temple, Anderson, Vanport, Gerty, Mantee, Foster, Berthold. Thus, the distance between Tilford and Sedona (CE–FR) is the same as the distance between Anderson and Vanport (CE–CR) in the learning protocol. Note, however, that the distance between FE–FR cities was not controlled using this procedure. Versions of the maps were assigned to subjects in a fixed rotation determined by the order in which subjects participated in the experiment. The materials for the recognition test were identical to those used in Experiment 1.

Procedure

The procedures were the same as those in Experiment 1, except that subjects were required to learn the locations of the cities in the order specified by the red numerals. Subjects were told not to rehearse cities in any other order including working backwards through the learning protocol. After a 2-min study period, subjects were given a road grid, minus the cities, and a list of the cities. The experimenter was present during this test phase to ensure that subjects placed the cities in the order specified by the red numbers. If subjects deviated from the ordering, they were immediately informed of the error and asked to try again. If subjects were stumped at some point, either because they could not remember the name of the next city or the location of the next city, the experimenter would provide the name or location, as the case required. When subjects indicated that they had no idea how to continue, they were shown the map, errors were pointed out, and they were allowed to study the map for another 2 min. Subjects were not allowed to advance to the recognition test until they could place all of the cities within about 0.25 in. of their correct location, in the order specified by the numbering on the map, and with no help from the experimenter.

When subjects finished the map-learning phase, they participated in the recognition test. The procedures were identical to those in Experiment 1. Immediately after each recognition test, subjects were asked to recall all of the cities on the map that they had just learned. This sequence—map learning, recognition, and recall—was repeated for each of the three maps.

Results and Discussion

Map Learning

The mean numbers of trials to reproduce each of the three maps correctly were 2.9, 3.2, and 3.2 ($F < 1$).

Recognition

Analyses of response latencies were performed on the mean correct response latencies for each condition. Responses for which there was an error on the previous trial were excluded, as were response latencies that exceeded the outer, upper fence for each condition. The outer, upper fences were 1,166 ms for the CE–CR condition, 1,189 ms for the CE–FR condition, and 1,314 ms for the FE–FR condition. Five of the 200 response latencies meeting the first condition were identified as outliers. The mean response latencies and error percentages for each condition are presented in Table 3.

The critical comparison in Experiment 2 is between the CE–CR condition and the CE–FR condition, because distance in sub-

Table 3
Mean Response Times and Error Rates in Experiment 2

Condition	RT (in ms)	Errors (%)
CE–CR	620	2.8
CE–FR	658	4.2
FE–FR	668	4.2

Note. RT = response time. CE–CR = close in Euclidean distance, close in route distance. CE–FR = close in Euclidean distance, far in route distance. FE–FR = far in Euclidean distance, far in route distance.

jects' learning protocols was controlled for these two conditions but not for the FE–FR condition. The 38-ms difference in response latencies between these conditions was significant, $t(11) = 2.02$, $p < .05$ (one-tailed). Moreover, the difference was significant at the 2% level with a sign test: One subject had a shorter mean latency in the CE–FR than in the CE–CR condition; 1 subject had identical means in the two conditions; and 10 subjects had longer mean latencies in the CE–FR than in the CE–CR condition. This result shows that the priming results were not artifacts of how subjects learned the maps. An analysis of error rates revealed no significant effects of condition ($F < 1$).

The mean correct response latency and error rate for foils were 695 ± 17 ms and 1.4 ± 0.7%; means for primes and fillers (together) were 707 ± 14 ms and 4.4 ± 1.1%. The overall mean latency for errors was 896 ± 129 ms.

Recall

Recall protocols were scored to verify that subjects were learning the locations of the cities in the orders specified. Seven subjects recalled all of the city names in the correct order for all three maps; an eighth subject got the order correct for each map but failed to recall 1 city on one map. The mean distances between primes and targets in the recall protocols (where a value of 1 means that the cities were next to each other) were 1.18 for the CE–CR condition, 1.34 for the CE–FR condition, and 6.46 for the FE–FR condition. The difference between the means for the CE–CR and CE–FR conditions can be attributed to three subjects, because for eight subjects the means were 1.0 in both conditions and a ninth had a slightly higher mean for the CE–CR condition (1.07) than for the CE–FR condition (1.00). The overall mean number of cities recalled per map was 15.6 out of 16.

General Discussion

Overall, the results from Experiments 1 and 2 converge on the conclusion that route information has a special status in mental representations of maps. Results from the two experiments suggest that locations on simple maps were encoded as "closer" together in cognitive maps if those locations were on the same route than if those locations are on different routes. Two findings support this conclusion: First, locations that were close together in both route distance and Euclidean distance primed each other in a recognition test significantly more than locations close together only in Euclidean distance. Experiment 2 shows that this finding was robust and not an artifact of verbal associations derived from the way in which subjects learned the maps. Second, subjects underestimated the distance between locations that were near each other in both Euclidean and route distance relative to locations that were near each other only in Euclidean distance.

Although there are many possible explanations of these findings, two immediately come to mind. The first assumes that spatial knowledge is mentally represented in some kind of analog representation with continuously varying properties (e.g., Kosslyn, Ball, & Reiser, 1978; Levine, Jankovic, & Palij, 1982; Thorndyke, 1981). Under this view, the results could be explained by assuming that distances in the cognitive map were distorted; that is, the psychological distance between locations that were near one another in both Euclidean and route distances was actually less than the psychological distance between locations that were near one another only in Euclidean distance. This explanation in conjunction with some version of a spreading activation theory of memory retrieval could account for the priming results. The distortions in distance estimations could be explained easily because distances in the mental representation would be distorted.

A second explanation assumes that spatial knowledge is mentally represented in some kind of propositional format (e.g., Kuipers, 1978; Stevens & Coupe, 1978). Under this view, the results could be explained by assuming that locations near one another in both route and Euclidean distances shared a connecting proposition that locations near one another only in Euclidean distance did not share, namely that the two locations were on the same route. This additional proposition might have facilitated the activation of a location when the name of a neighboring location was retrieved. How this explanation could account for distortions in distance estimations is not entirely clear. One possibility is that distance estimations between locations were an increasing function of the real distance and a decreasing function of the strength of association (as measured by the number of connecting propositions) between the locations.

Our experiments do not have much to say about whether spatial knowledge is represented in an analog or a propositional format. However, it is worthwhile to consider the kinds of information that the mental representation must *contain* to account for our findings. First, to account for the priming results, locations that are near each other in route and Euclidean distances would have to be "closer" in the mental representation than locations near each other only in Euclidean distance. How one chooses to implement "closer" is, at this point, largely a matter of taste. Second, to account for the fact that subjects could estimate distances, the representation must contain metric information of some kind. Third, to account for the fact that the priming task, which used verbal test items, was sensitive to spatial properties of cognitive maps (as Experiment 2 demonstrated), the representation would have to contain both name codes and spatial codes stored in such a way that these codes could not be retrieved independently.

In closing, we want to emphasize that although priming seems to be informative about certain aspects of spatial knowledge, it is only one of many tasks that might be used to study spatial cognition. We believe that research on spatial representations and processing should use several tasks as converging operations (Garner, Hake, & Eriksen, 1956). This strategy is especially well suited to research on spatial cognition because there are so many tasks available (priming, distance estimation, and orientation judgments, to name a few) offering complementary perspectives on the mental representation and processing of spatial knowledge.

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