Perceptually Induced Distortions in Cognitive Maps

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Abstract. Cities on a map that are directly connected by a route are judged closer than unconnected cities. This route effect has been attributed to memory distortions induced by the integration of map information with high-level knowledge about implications of route connections. However, depicted routes also connect cities visually, thereby creating a single visual object—which implies a perceptual basis of the route effect. In this article we show that the effect does not depend on whether a map is presented as a map or as a meaningless pattern of symbols and lines (Experiment 1), and that the effect occurs even if spatial judgments are made vis-à-vis a permanently visible configuration (Experiment 2). These findings suggest that the distorted spatial representation is a by-product of perceptual organization, not of the integration of abstract knowledge in memory by given organization principles.

1 Introduction

When people use or try to remember knowledge from spatial representations of the environment, such as geographic maps, they produce systematic errors. This suggests that their cognitive representations of those maps and the represented knowledge, respectively, are systematically distorted. A well-known demonstration of such a distortion is what we will refer to as the route effect, reported by McNamara et al. (1984). These authors had participants estimate distances between cities whose locations were previously memorized from a map. When comparing estimates for location pairs of equal Euclidean distance, they found those estimates to depend on whether or not a given pair was directly connected by a route: Connected cities were judged closer than unconnected (or not directly connected) cities.

These and related observations have been taken to suggest two types of conclusions (for overviews, see McNamara, 1991; Tversky, 1991). First, cognitive representations of spatial layouts do not seem to be mere mental copies or pictures of the represented arrays but, rather, integrated and highly organized knowledge structures, i.e. processed according to cognitive principles (e.g., McNamara, 1986; Stevens &

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Coupe, 1978). Second, in the process of being integrated and organized the represented information is merged with, enriched and sometimes even modified by (pre) knowledge of the representing individual (e.g., Merrill & Baird, 1987; Tversky & Schiano, 1989). The route effect, for instance, is commonly attributed to the interaction of information about spatial distance with knowledge about the functional implications of route connections (e.g., McNamara et al., 1984). These conclusions receive considerable support from available findings. Indeed, judgments of spatial relations are not only affected by route distance but also by geographical (Stevens & Coupe, 1978), political (Maki, 1981), and semantic (Hirtle & Mascolo, 1986) relations between locations, suggesting that spatial information is integrated with both nonspatial and nonperceptual information (but see our conclusions for a possible perceptual interpretation).

However, evidence of information integration and of knowledge-based effects does not mean that all distortions of map representations result from background knowledge. Given that visual maps are often rather complex configurations, the way they are perceived and perceptually organized may shape the emerging cognitive representation some time before processes of memory storage or retrieval come into play. Accordingly, Tversky (1981) has argued that at least some distortions of cognitive maps may reflect principles of perceptual organization, i.e., Gestalt laws (e.g., Coren & Girgus, 1980). Indeed, spatial memories and relation judgments have been found to be affected by manipulating Gestalt factors, such as grouping by proximity (Tversky, 1981), closure (McNamara, 1986), symmetry (Tversky & Schiano, 1989), and similarity (Hommel et al., 2000). As to be expected from perceptually based effects, the impact of Gestalt factors do not only show up in memory tasks but in perceptual tasks as well, that is, in judgments of spatial relations between currently perceived locations (Baylis & Driver, 1993; Hommel et al., 2000). Thus, at least some demonstrations of distorted spatial memories may reveal rather the influence of perceptual organization on memory than effects of memory processes as such.

In the present study, we asked whether the same logic may apply to McNamara et al.'s (1984) route effect, hence, whether even this standard spatial-memory effect might be of perceptual origin. Consider our slightly simplified version of the map used by McNamara et al. in Figure 1. Take pair E-F as an example of a connected pair and M-N as one of a distance-matched unconnected pair. If the visual configuration is taken to represent a road map, it is obvious that E and F are, in a sense, "closer together" because the direct route makes it easier to get from E to F, or vice versa, than from M to N. However, not only are E and F functionally linked—someone can travel directly with no other stop from E to F, they also have a perceivable visual connection. Connecting visual elements is likely to affect their perceptual organization in creating a single perceptual object to which these elements then belong (Baylis & Driver, 1993; Humphreys & Riddoch, 1992)—the Gestalt law of connectedness. If so, judging a relation between E and F would represent a within-object judgment and judging M and N a between-object judgment, which is known to be more difficult (Baylis & Driver, 1993). In other words, the finding of McNamara et al. (1984) may be better explained by a (perceptually based) line effect rather than by a (memory based) route effect.

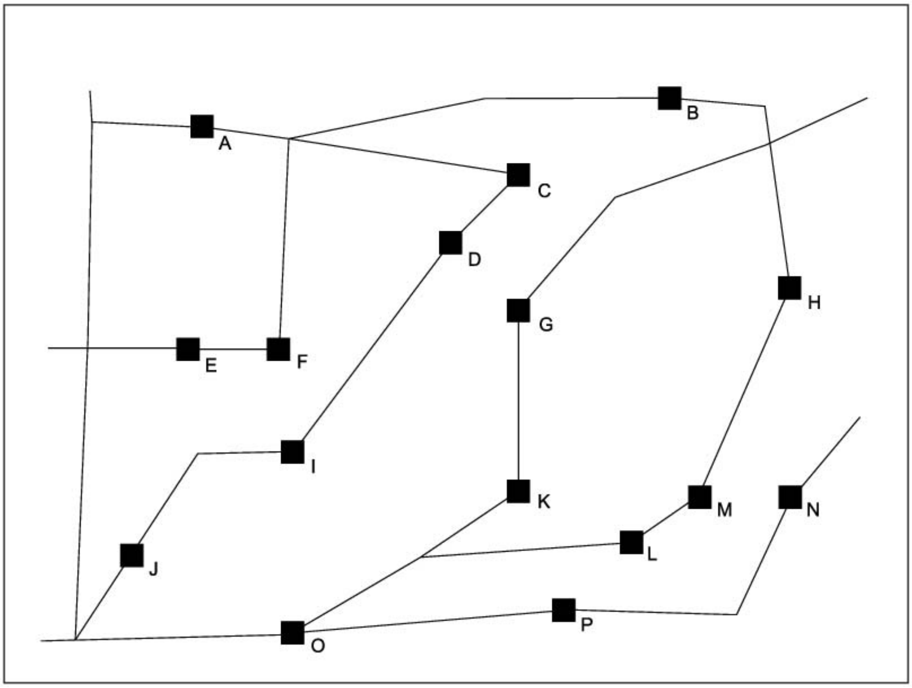

Fig. 1. Stimulus layout used in Experiments 1 and 2. The letters indicating locations were not presented; instead each location was identified by a nonsense name appearing at the bottom right corner of the corresponding square. The layout was presented in two orientations (rotation angle 0 and 180), balanced between participants

2 Experiment 1

Attributing the route effect to the knowledge-based (re-)organization of spatial information presupposes that respective knowledge (here: about implications of route connections) is not only available but is also actually used. That is, to produce a route effect participants would not only have to know about the fact that roads "bring cities together"; they also would need to interpret a particular layout as a road map. Otherwise it would be hard to see why road-related knowledge should come into play.

Experiment 1 tests this idea by introducing the stimulus layout shown in Figure 1 as either a road map or a meaningless visual pattern. Like in the study of McNamara et al. (1984) participants performed a memory task, i.e., they estimated distances between locations of the previously acquired layout. Under map instruction we expected a normal route effect, that is, estimated distances should be shorter for connected than unconnected locations. Under pattern instruction, however, a knowledge-based account would predict no route effect, whereas a perceptual account would expect the same effect as with map instruction. Hence, if the route effect is really a route rather than a line effect, it should depend on interpreting the stimulus as a map (rather than an arbitrary graph).

2.1 Method

Participants

Thirty-two paid adults (mean age 24.5 years, 24 female) participated in single sessions of about 90 minutes; they were unaware of the purpose of the study and reported having normal or corrected-to-normal vision. Sixteen of the participants received the map instruction and 16 the pattern instruction (see below).

Procedure and Design

Data acquisition was controlled by a standard PC. Stimuli were projected via a video projector (BARCODATA 800) onto a vertical 144 x 110 cm surface, about 200 cm in front of the seated participants. The stimulus layout was a visual black-on-white configuration of lines and squares (see Fig. 1), which was introduced as either a map showing cities and connecting roads (map instruction) or a meaningless graphical layout of squares and lines (pattern instruction). In the pattern group any hint to the semantics of the pattern or its elements was carefully avoided. Indeed, when asked after the experiment, none of the participants of this group reported to have recognized or imagined a map. As Figure 1 shows, the map/pattern consisted of partially connected square symbols (representing the cities under map instruction) of 34 x 34 mm, each individually named by a consonant-vocal-consonant nonsense syllable chosen to avoid any obvious phonological, semantic, or functional similarities. Names appeared at the bottom right corner of the squares. Two versions of the configuration were balanced between participants: the one shown in Figure 1 and a copy rotated by 180 degrees.

Eight location pairs were chosen for distance estimation. Half of them were composed of squares directly connected with a line (E-F, D-C, G-K, O-P) and the other half consisted of squares that were not (directly) connected (M-N, P-L, I-O, G-H). As can be taken from Figure 1, for each of the connected location pairs there was a corresponding unconnected pair with an identical Euclidean distance and orientation: item1 = E-F vs. M-N (135 mm); item2 = D-C vs. P-L (145 mm); item3 = G-K vs. I-O (260 mm); item4 = O-P vs. G-H (400 mm). A small set of vertical and diagonal pairs was used as fillers. On basis of the critical items a set of 160 judgments was composed, consisting of eight repetitions for each location pair and two orderings of presentation within the pair (A—B, B—A), plus 32 judgments on filler pairs that were not further analyzed.

At the beginning each session, participants were shown the display and were asked to memorize the locations of the "cities" or "squares", respectively. After a 2-minute study period, the display was replaced by a "road" or "line" grid that no longer showed squares and their locations (a procedure also used by McNamara et al., 1984). In each of 16 randomly ordered trials, an empty frame of a square's size then appeared in the upper center of the display, together with the "name" of a display element. Using a computer mouse, participants were then to move the frame to the correct position of the square with that name and to confirm their choice by pressing the left mouse button. After completing 16 trials, correct locations were superposed on the judged locations and the experimenter pointed out any errors the subject may have made. If in a sequence a square was misplaced by more than 15 mm, the whole procedure was repeated until a participant positioned an entire sequence correctly.

Following this acquisition phase, participants judged distances between pairs of labeled squares. The 160 pairs were displayed, one pair at a time, in the upper center of a projection surface. Labels were displayed in adjacent positions, separated by a hyphen. A horizontal line of 110 cm in length was shown above the names and participants were explained that this line would represent a line of 70 cm (half of the width of the whole projection surface). Thus, a scaling factor of 11:7 was applied to the represented length. A vertical pointer of 5 cm in length crossed the horizontal line. This pointer could be moved to the left or right by pressing a left or a right response key, respectively. For each pair of squares, participants were required to estimate the distance between the corresponding squares (center to center) by adjusting the location of the pointer accordingly. Then the participants had to verify their estimation by pressing a central response key. They were instructed to take as much time as they needed for their decisions, but not longer. The latencies of distance estimations were recorded as well.

2.2 Results

Over all conditions, the real average distance of 235 mm was overestimated (328 mm), with the relative magnitude of overestimation decreasing with actual distance between location pairs: item1 = 201 mm; item2 = 215 mm; item3 = 410 mm; item4 = 485 mm (actual distances were 135, 145, 260 and 400 mm, respectively).

Table 1. Mean estimated Euclidean distances (in millimeters) between symbol pairs in Experiments 1 and 2 as a function of symbol relation (judged pairs connected or unconnected), instruction (Experiment 1: road map or pattern), and actual connectedness (Experiment 2: pairs actually connected by lines or not). Real mean distance was 235 millimeters

	Pairs		
	Connected	Unconnected	Δ
Experiment 1			
Map Instruction	328	359	31
Pattern Instruction	292	336	44
Experiment 2			
Symbols & Lines	356	376	20
Symbols Only	371	372	1

Mean estimated distances (in mm) were computed for each participant and condition by collapsing across the four distances used (see Table 1), so that comparisons could be made between the pooled estimates of the connected location pairs E-F, D-C, G-K, and O-P and the pooled estimates of the unconnected location pairs M-N, P-L, I-O, and G-H. A three-way mixed ANOVA (analysis of variance) was run with the within-participants factor symbol relation (connected/unconnected) and the between-participants factors stimulus display (original/rotated) and instruction (map/pattern). The analysis revealed only a significant main effect of symbol relation, F(1,28) = 15.872, MSE = 1227.124, $p < .001$, whereas the interaction of instruction and symbol relation was far from significant ($p > .3$). Thus, distances were judged shorter between connected pairs than unconnected pairs under either instruction. If anything, the connectedness effect was stronger under pattern than under map instruction (η^2's = .499 and .223, respectively).

The latencies of distance estimations were also analyzed. A three-way mixed ANOVA revealed a significant main effect of symbol relation, F(1,28) = 30.827, MSE = 456072, $p < .001$, indicating that the participants spent less time estimating connected than unconnected pairs (7.667 vs. 8.604 s), this paralleling the estimation results.

2.3 Discussion

The results show a clear route effect: Distances between directly connected location pairs were estimated shorter than between unconnected pairs, and the estimation latencies, likewise, were shorter for connected pairs than for unconnected pairs. Both the estimation and latency patterns fully replicate the findings of McNamara et al. (1984) and demonstrate the robustness of the route effect. However, the effect also occurred if the stimulus display was introduced as a meaningless pattern of lines and symbols, i.e. under conditions that made the employment of route- or map-related knowledge at least less likely. Moreover, there was no indication that the pattern interpretation might have weakened the effect; on the contrary, the effect was even stronger in the pattern group. Thus, Experiment 1 provides first evidence that the route effect might have a perceptual origin.

3 Experiment 2

Although the outcome of Experiment 1 is consistent with a perceptual account of the route effect, there are two reasons to search for further, converging evidence. First, there was no way to check to which degree our instruction manipulation really worked. True, none of the participants in the pattern group reported about perceiving the pattern as a map. But even if some of the participants did perceive the pattern as a map, the route effect should have been at least somewhat reduced. Nevertheless, we do not know whether the self-reports were correct and we do not know whether members of the map group might have failed to actually perceive the layout as a map.

Second, taking evidence from a memory task to conclude on a perceptual effect is still rather indirect. Indeed, if connecting lines do affect the perception of location arrays we should be able to demonstrate such effects in a perceptual task, that is, in a task performed vis-à-vis the stimulus array. This is what we did in Experiment 2. Here we presented one group of participants (the symbols-and-line group) with the pattern condition of Experiment 1, except that distance estimations were performed in front of the permanently visible stimulus configuration. To control for possible perceptual Gestalt effects apart from the connecting lines we further investigated another group (the symbols-only group). This group worked with a display version where all lines were omitted. According to a perceptual account, a route effect was expected in the symbols-and-line group but not in the symbols-only group.

3.1 Method

Participants

Thirty-two new paid adults (mean age 24.5 years, 22 female) were recruited, 16 in each of the two groups.

Procedure and Design

The method was as in the pattern group of Experiment 1, except that the acquisition phase was omitted and participants performed the distance-estimation task in front of the constantly visible stimulus display. In the symbols-and-line group the same stimulus layout as in Experiment 1 was used, whereas in the symbols-only group all lines were omitted.

3.2 Results

On average, distances again were overestimated in both the symbols-and-line group (366 mm) and the symbols-only group (372 mm). Pooled estimates were entered into a three-way ANOVA including one within-participants factor, symbol relation, and two between-participants factors, connectedness and stimulus display (for means, see Table 1). Although treated as an orthogonal factor, connectedness had a different meaning in the two groups: In the symbols-and-line group it distinguished locations that were directly connected by a line from those that were not (i.e., E-F, D-C, G-K, and O-P vs. M-N, P-L, I-O, and G-H). In the symbols-only group the location pairs were sorted in exactly the same way, even though there were no actual lines.

The main effect of symbol relation was highly significant, $F(1,28) = 11.015$, $MSE = 164.618$, $p < .001$, as was the symbol relation x connectedness interaction, $F(1,28) = 8.192$, $MSE = 164.618$, $p < .01$. Planned paired comparisons showed a highly significant effect of symbol relation in the symbols-and-line group, $t(15) = 3.627$, $p < .001$, but not in the symbols-only group, ($p > .4$; always one-tailed). Comparable patterns were observed in estimation latencies. A reliable interaction of symbol relation and connectedness, $F(1,28) = 5.502$, $MSE = 275043$, $p < .05$, and corresponding t-tests indicated that actually connected pairs were estimated faster than unconnected pairs (8.877 vs. 9.294 s), $t(15) = 2.431$, $p < .05$, whereas the same pairs produced the same results when not actually connected (10.482 vs. 10.250 s, n.s.).

3.3 Discussion

As predicted by a perceptual account, the symbol-and-line group replicated the findings from Experiment 1 in all detail, even though here participants estimated in front of a visible display: Distances between connected location pairs were estimated shorter than between unconnected pairs, and a comparable pattern showed up in the estimation latencies. In contrast, no effects were obtained in the symbol-only group, demonstrating that the connecting lines, not the configuration were responsible. That is, a "route" effect can be obtained even in the absence of any routes and even in a perceptual task, implying that the route effect is actually an effect of connectedness.

4 Conclusions

Altogether, our findings demonstrate that spatial distortions are not only present in the memory representation of map-like configurations but in their perceptual representation as well. In principle, distortions in perception and memory—as well as their underlying causes—may be independent and may co-exist. However, it seems more reasonable and parsimonious to assume that the latter simply reflects the former, hence, memory distortions may be a by-product of perceptual organization (Hommel et al., 2000).

On one hand, this raises the question of whether other phenomena attributed to post-perceptual integration are actually of perceptual origin. For instance, take another classical finding of Maki (1981) that judging spatial relations between cities of the same country (e.g., Alamo and Burlington, North Dakota) takes less time than comparing cities of different countries (e.g., Jamestown, North Dakota, and Albertville, Minnesota). It may well be that effects of this sort reflect the (apparently hierarchical) way spatial information is organized in memory as proposed by McNamara (1986) and others. Nevertheless, this very organization may not be a memory-specific characteristic but it may merely mirror the way this information has been perceptually organized in the acquisition process, i.e., in map-reading (Tversky, 1981). Indeed, the same logic applies to other classical findings, as those of Stevens and Coupe (1978), Thorndyke (1981), or Wilton (1979). So, the structure of (parts of) our spatial memory may be perceptually derived.

On the other hand, though, it may be farfetched to attribute all effects on spatial memory to processes of perceptual organization. For instance, Hirtle and Mascolo (1986) had participants memorize map locations falling in two functional clusters, recreational facilities and city buildings. When later judging inter-location distances, participants showed a tendency to underestimate distances between places belonging to the same functional cluster as compared to pairs belonging to different clusters. Again, this is an indication of hierarchical memory organization—but in this case without an obvious perceptual basis. Similarly, Hommel and Knuf (2003) found that participants are faster in verifying spatial relations between objects that previously had been associated with the same action than between objects associated with different actions. As the authors argue, cognitive codes of the actions may be integrated into object representations, thereby functionally linking the codes of objects belonging to the same action (Hommel & Knuf, 2000; Hommel et al., 2001). This leads us to conclude that perceptual organization is only one of perhaps several types of processes shaping the structure, and in part even the content, of spatial memory. However, the present findings suggest that perceptual organization plays a powerful role.

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