Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 33(33)

ISSN

1069-7977

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Publication Date

2011

Peer reviewed

The Number, Type, and Configuration of Landmarks Distort Distance Estimates

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Abstract

In phase 1, participants memorized two two-dimensional maps consisting of routes with concrete landmark features and two maps consisting of routes with abstract landmark features and then made distance estimates and mental walks for the routes on each map. Participants estimated significantly longer lengths for routes with concrete features versus abstract features, for routes with four versus two features, and for routes with linear sequences of features versus clustered features. In phase 2, a feature recognition task indicated that participants had significantly greater accuracy and faster response times for concrete features versus abstract features and for features that had appeared in linear arrangements versus clustered arrangements. Our results suggest that the number, type, and configuration of landmark features can distort humans' memories of path lengths, even when the paths are originally viewed on a simple two-dimensional map rather than encountered through embodied experience.

Keywords: Cognitive maps, survey knowledge, visual landmarks

Introduction

When we walk down a bustling city street, we are likely to notice an assortment of sights and sounds, and this variety may lead us to remember the street as being longer than a walk of equal distance through a barren or monotonous landscape. Byrne (1979) showed that participants who were familiar with the local environment overestimated lengths for routes that were near the local town center and routes that included more major bends. In both cases, an increase in the number or saliency of features apparently led to distance overestimations.

Thorndyke (1981) conducted a series of experiments to test his "clutter hypothesis" that participants would remember paths on a map as longer if there were more intervening cities. His results showed that participants overestimate distances for cluttered paths from maps of fictitious regions as well as from maps of familiar regions in the United States. Moreover, participants still exaggerated these distances, albeit to a lesser extent, when the maps were in front of them while making the perceptual estimates. In order to explain these results, Thorndyke proposed an analog timing model in which participants initiate an internal timer as they scan the route (whether the scanning is perceptual or from memory), and intervening cities cause participants to temporarily stop scanning and retrieve relevant information before continuing to scan the route towards the destination.

Other studies have found distance distortions that suggest the hierarchical arrangement of cognitive maps. For instance, participants distort spatial relationships to conform to superordinate organization, (Stevens & Coupe, 1978), e.g. Reno is incorrectly believed to be east of San Diego because participants focus on the geographical arrangement of the respective states, Nevada and California, and participants use a heuristic with this superordinate structure. Similarly, participants underestimate the distance between related landmarks and overestimate the distance between unrelated landmarks or organizations (Hirtle & Jonides, 1985).

The current study tests distance distortion for memorized maps as a function of the number, type, and configuration of landmark features. We hypothesized that more features on a path memorized from a map would lead to longer distance estimates, and this result would essentially replicate Thorndyke's (1981) findings. In addition to those previous findings, we hypothesized that the configuration of those features would also be critical, with a linear, sequential arrangement of features drawing additional attention and therefore promoting longer path estimates than a path with features clustered together in one location. Similarly, we hypothesized that the type of features is also key and that representations of concrete, real world features would lead to longer path estimates than representations of abstract features, because participants would treat each concrete feature distinctly but may group together the abstract features. The latter hypotheses would not be explained by Thorndyke's analog timing model (1981), because that model would suggest that each additional feature temporarily stops the scanner regardless of the feature type or how the features are configured. However, such results could be accommodated by a combination of Thorndyke's model and the categorical considerations of Stevens and Coupe (1978) and Hirtle and Jonides (1985).

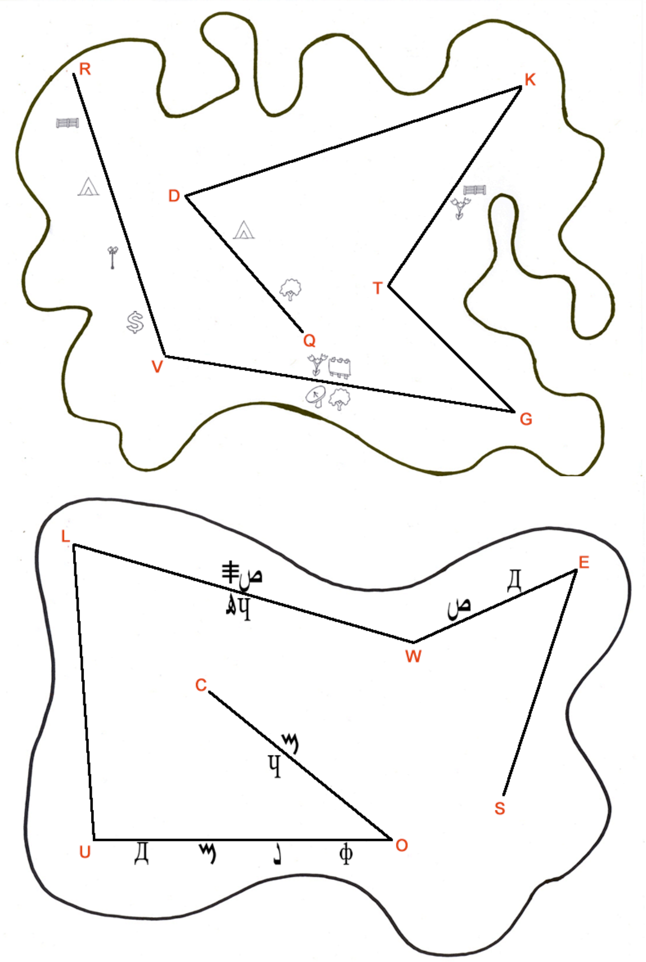

Figure 1: Concrete feature map (top) and abstract (bottom)

Methods

Participants

Sixty-nine undergraduate students at DePauw University chose course credit or a $10 gift certificate for approximately two hours of participation. Data from 19 students were excluded from the behavioral analyses. Of these, nine were excluded due to experimental failure, and ten were excluded due to missing or extreme values (described in the results section) for specific conditions. The phase 2 results included 31 participants (38 were excluded due to missing or extreme values from phase 1, technical errors with the ERP equipment, and due to not being right-handed.

Materials

Eight two-dimensional 792 X 612 pixel maps were constructed as bitmap images using Macromedia Fireworks software, and each map consisted of seven destinations connected by six lines (routes) in a non-cyclical arrangement. An alphabetical letter designated each of the route intersections so particular routes could later be referenced, e.g. “route A-E.” Four route lengths (3, 4, 5, and 6 inches) were used for each map. Two of the routes contained two and four features, respectively, arranged in a linear sequence along the entire route (so a traveler using the map would expect to encounter the first feature, then the second, etc.). On a given map, these route lengths were either 3 and 5 inches, or 4 and 6 inches. The other two lengths were used for two routes with two and four features, respectively, that were clustered together in the middle of the routes (so a traveler would encounter a group of features in an area). The remaining two routes duplicated two of the route lengths (either 3 and 5 inches or 4 and 6 inches), and these routes did not contain features. The route lengths for the respective conditions were balanced across maps for each participant so that all four lengths were used for zero-feature routes, linear routes, and clustered routes for each map type. Thus, we could assess distortion caused by the number of features and the arrangement of features without a confound of actual path length.

Features were also constructed using Macromedia Fireworks software and arranged on the maps as detailed above. Four of the maps contained concrete features (e.g. drawings of flowers, trees, stop signs, buildings, etc.) along the routes, and four maps contained abstract features (e.g. Cyrillic, Greek, and Arabic letters). The four-feature routes contained two unique features that did not occur elsewhere on the map, along with two features that occurred on one of the two-feature routes. The concrete and abstract features were balanced across the eight maps (which, in turn, were balanced across participants) so that each feature appeared in each route condition. Each map was surrounded by an outline in order to provide a boundary. Figure 1 shows an example of one concrete feature map and one abstract feature map.

Procedure

The experiment consisted of two phases. For phase 1, participants memorized the maps and then provided distance estimates and mental walk response times by using a mental image of the routes. For phase 2, participants completed a feature recognition task during which we recorded brain activity for an ERP study. The details of the ERP methods, analyses, and results are quite extensive and beyond the scope of this paper, so we are only presenting the behavioral results from the two phases of the experiment here.

In phase 1, each participant was sequentially presented with four maps on a computer monitor. The maps alternated between concrete features and abstract features, with order balanced across participants. For each map, participants were instructed to memorize the map so they would be capable of redrawing the map from memory. The participants were told that no particular beginning or end point was necessary for memorizing the map, but they should try to memorize the letter that designated each point, the features that were encountered along each route in the map, and the scale of the map so route lengths could be

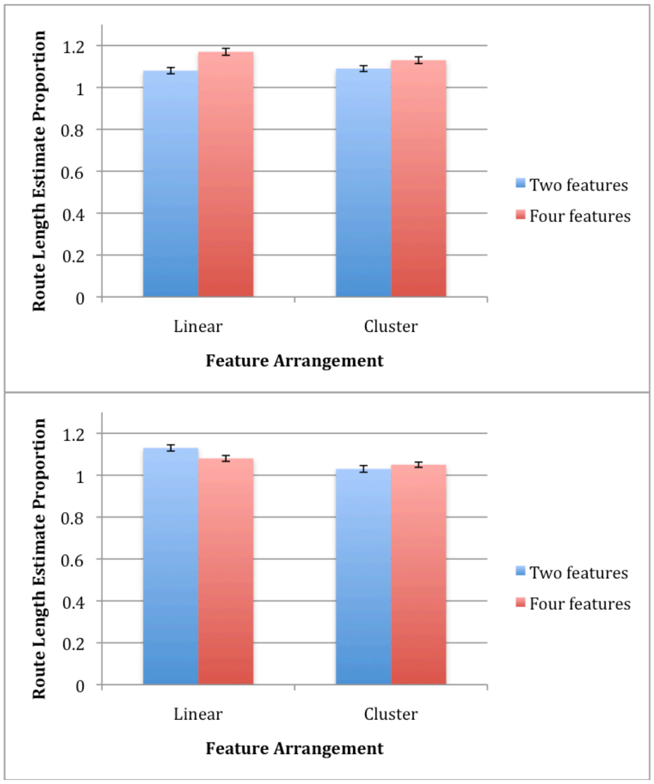

Figure 2: Mean (and standard error) distance estimate proportions for routes with concrete features (top) and abstract features (bottom)

accurately reported. Participants were told that they would need to memorize four different maps, and for each map, they would have five minutes for memorization before subsequently answering questions about the estimated distance and mental walk times for particular routes. Finally, participants were told that they would be asked questions about features on the maps during the second phase of the experiment.

We used E-Prime experiment design software in phase 1 for accurate timing of stimuli presentation and collection of response times. After memorizing a specific map, the participants answered questions about the six routes in a random order. The map disappeared from the screen, and for each route, the participant was asked to use a mental image of the route in order to estimate the route's length and perform a mental walk task. For the distance estimate, the participant was told to give a numeric estimate of the route length (e.g. route "B-D") compared to a standard two-inch line that we labeled as "20 units." For the mental walk task, the participant pressed the space bar to begin the walk at one point and pressed the space bar again to end the walk. Walks always consisted of a single line, i.e. we did not test longer routes that incorporated multiple lines.

Phase 2 consisted of a feature recognition task that used previously seen concrete and abstract features and novel foils. E-prime was used for stimulus presentation and for recording responses and reaction time. Each trial consisted of a fixation point (+) that varied randomly from 1000ms to 2000ms, followed by a feature image that was shown for up to 2500ms or until the participant responded. Participants were instructed to press one button on a response pad to indicate they had seen a feature during phase 1 of the experiment and another button if they had not seen the feature. The button associated with the response type was counterbalanced across participants. For each of the four memorized maps, a participant was tested on the two unique and two duplicate features from four-feature linear paths, the two unique and two duplicate features from four-feature cluster paths, and four foils that had not been seen on the maps. The unique and duplicate features were counterbalanced across participants during the learning in phase 1, and the foils were counter-balanced across participants in phase 2. Participants completed a total of 480 trials for the four maps, with 15 trials per feature in order to provide sufficient data for ERP analyses.

Results

Phase 1

In order to analyze the route length estimates, we divided a participant's estimate for a route by the true length of the route. For example, the two-inch comparison line was labeled "20 units," so the participant would make a perfect estimate if he or she labeled a three-inch route as 30 units. It is possible that participants remembered the wrong routes in some trials (e.g. if the trial concerned "A-E" and the participant mistakenly confused that with a different route). Therefore, we set arbitrary proportion cut-offs of .5 and 2.0 for each trial, and data for a trial were excluded if the proportion was outside these extremes. We averaged the proportions for all of the participants' trials in each of the eight respective conditions of map type (real or concrete features), number of features (two or four), and feature arrangement (linear or clustered). Thus, an average of .90 for two-feature linear paths may indicate consistent underestimation of route length, while an average of 1.10 may indicate consistent overestimation. Nine participants were excluded from the ANOVA analyses because all of their proportions were outliers for at least one condition. The final sample consisted of 50 participants (36 women and 14 men).

Figure 2 shows the mean and standard error for each condition. A 2 (Map type: concrete features or abstract features) X 2 (Number of features: 2 or 4) X 2 (Arrangement of features: linear or clustered) repeated measures ANOVA using the averaged proportions revealed significant main effects for map type, number of features, and arrangement of features and one significant interaction between map type and number of features. Participants overestimated the lengths for routes with concrete features (M=1.11) by significantly more than the routes with abstract features (M=1.06), $F(1,49) = 4.23$, $p < .05$, $\eta^2_p = .08$. Participants overestimated the lengths for routes with four

Table 1: Mean (standard deviation) recognition accuracy

	Linear	Cluster
Concrete	.80 (.18)	.77 (.23)
Abstract	.71 (.23)	.62 (.28)

features (M=1.10) by significantly more than the routes with two features (M=1.07), $F(1,49) = 4.59$, $p < .05$, $\eta^2_p = .09$. However, there was a significant interaction between map type and number of features, $F(1,49) = 4.52$, $p < .05$, $\eta^2_p = .09$, and pairwise comparisons only indicated significant differences between two and four-feature paths when the features were concrete. Participants overestimated the lengths for routes with a linear arrangement of features (M=1.10) by significantly more than the routes with a cluster of features (M=1.06), $F(1,49) = 4.14$, $p < .05$, $\eta^2_p = .08$

An additional repeated measures ANOVA with gender as a between groups factor did not reveal any significant effects. When examining the individual conditions, only the concrete, four-feature condition was significantly overestimated with respect to the true proportion of 1.0, $t(54) = 2.41$, $p < .05$.

For each condition of the mental walk task, we divided the mental walk time by the same participant's mental walk time for a zero-feature route of the same length. Thus, path length was controlled, and we could comparatively assess changes in mental walk time based on the map type, number of features, and arrangement of features. Unfortunately, the mental walk data showed an enormous amount of variability. Many of the participants' data (n=19) were excluded because the average proportion for at least one condition was less than .5 or greater than 2.0. Four additional participants were excluded because their data revealed them as significant outliers for at least one condition. A 2 (Map type: concrete features or abstract features) X 2 (Number of features: 2 or 4) X 2 (Arrangement of features: linear or clustered) repeated measures ANOVA only showed a significant main effect for map type, $F(1,27) = 5.00$, $p < .05$, $\eta^2_p = .16$, as mental walks for routes with concrete features (M=1.08) took significantly longer, in proportion to zero-feature paths, than routes with abstract features (M=1.00).

Phase 2

We analyzed accuracy and response times according to map type and arrangement of features for the feature recognition task in phase 2 of the experiment. For recognition accuracy, a 2 (Map type: concrete features or abstract features) X 2 (Arrangement of features: linear or clustered) repeated measures ANOVA showed significant main effects for map type and feature arrangement with no interaction between these two variables (see Table 1 for means and standard deviations). Participants showed significantly more accurate recognition for concrete features than abstract features, $F(1,30) = 14.55$, $p < .01$, $\eta^2_p = .33$. Participants showed significantly more accurate recognition for features that had appeared in a linear arrangement than features that had appeared in a cluster, $F(1,30) = 4.61$, $p < .05$, $\eta^2_p = .13$. Consistent with these results, a 2 (Map type: concrete features or abstract features) X 3 (Stimulus type: duplicate, foil, or unique feature) repeated measures ANOVA showed a significant main effect for map type, $F(1,30) = 5.90$, $p < .05$, $\eta^2_p = .16$, with significantly more accurate recognition for concrete features.

Table 2: Mean (standard deviation) recognition response times in milliseconds

	Linear	Cluster
Concrete	488.79 (139.68)	669.82 (104.66)
Abstract	672.12 (123.18)	692.08 (117.57)

Table 3: Mean (standard deviation) recognition response times in milliseconds

	Unique	Duplicate	Foil
Concrete	579.29 (90.64)	655.28 (124.13)	686.61 (176.80)
Abstract	682.10 (113.66)	661.83 (120.78)	730.45 (111.03)

For response times, a 2 (Map type: concrete features or abstract features) X 2 (Arrangement of features: linear or clustered) repeated measures ANOVA showed significant main effects for map type and feature arrangement, but the significant interaction, $F(1,30) = 19.76$, $p < .001$, $\eta^2_p = .40$, was clearly driven by the extremely fast responses to concrete features that had appeared in a linear arrangement on the original maps (see Table 2 for means and standard deviations). Finally, a 2 (Map type: concrete features or abstract features) X 3 (Stimulus type: duplicate, foil, or unique feature) repeated measures ANOVA showed significant main effects for map type, $F(1,30) = 9.45$, $p < .01$, $\eta^2_p = .24$, and stimulus type, $F(1,30) = 13.63$, $p < .001$, $\eta^2_p = .31$, as well as a significant interaction, $F(1,30) = 6.37$, $p < .01$, $\eta^2_p = .18$ (see Table 3 for means and standard deviations). For abstract stimuli, unique and duplicate features were significantly faster than foils but not significantly different from each other. However, for concrete stimuli, unique features were significantly faster than duplicate features, which were in turn significantly faster than foils.

Discussion

Previous research has shown that people distort spatial lengths when remembering paths with multiple landmark features (Byrne, 1979), and the distortion even occurs for paths simply memorized from maps (Thorndyke, 1981). We hypothesized that the number, arrangement, and type of features would influence the extent to which participants distort remembered map distances. The phase 1 results indicate that each of these factors is important. Participants overestimated route lengths significantly more when the route contained more features, a linear arrangement of features, and concrete, recognizable features. The mental walk results were limited due to a great deal of variability across participants, but mental walks were longer for routes that had concrete features than routes with abstract features.

In regards to the distance estimation results, participants may treat clustered features as one group and pay less attention to the individual features. These results seem to be consistent with previous findings that categorization influences distance estimates (Stevens and Coupe, 1978; Hirtle and Jonides, 1985). Similarly, the statistical interaction showed that overestimation of four-feature versus two-feature routes only occurred for concrete landmark features. Participants may attend to recognizable features more closely, and, in turn, an increase in these features leads to increased distance estimates. In contrast, participants may treat abstract symbols as belonging to one general category, so the symbols may not be independently studied in detail. Thornydyke's (1981) analog timing model could potentially be adapted to incorporate these categorical considerations, but without such modifications, the model would be unable to account for the effects of map type and arrangement of features.

For the conditions that promote overestimation, it is unclear whether participants attend more closely to each feature while learning the map and thereby distort the route length in memory, or whether participants remember more features during memory retrieval for the distance estimate, and these retrieval processes may lead to distorted distance estimates. Thorndyke (1981) found distance distortions for both perceived and remembered paths, but the distortions were significantly smaller for perceived paths. Our phase 2 results suggest that the distortions occur because some features are recognized better than others. Features that had appeared in a linear sequence on a route were recognized more accurately than features that had appeared in a cluster. Response times indicate that this effect is particularly pronounced for concrete features that had appeared in a sequence.

It is possible that the magnitude of our results would change if the map was scaled or if we emphasized a particular internal or external reference point to the participants, as previous research has shown that distances between landmarks are stretched if the reference point is nearby rather than distant (Holyoak & Mah, 1982). Nonetheless, our results clearly demonstrate that the number, type, and configuration of landmark features lead humans to distort distance estimates even when simply viewing a map. Thus, when a person is new to a city (or any novel location), he or she is likely creating a distorted cognitive map simply by looking at noteworthy features on a map. Presumably, once the person begins navigating the environment, these distortions can be rectified (Thorndyke & Hayes-Roth, 1982), but previous navigation findings indicate that the distortions may be sustained or even enhanced (Byrne, 1979).

Humans clearly rely on simple landmark navigation in many situations (Foo, Warren, Duchon, & Tarr, 2005), so the number or saliency of landmarks in real or virtual worlds may also lead to distance distortion. Previous research indicates clear differences in cognitive maps according to how the knowledge was acquired. For instance, Thorndyke and Hayes-Roth (1982) compared map learning and navigation learning for routes with multiple legs and found that map learning led to better Euclidean (i.e. straight-line, potentially moving through an obstacle to reach a target destination) estimates of distance, but navigation learning led to better distance estimates of the actual routes (i.e. unable to move through an obstacle). However, Thorndyke and Hayes-Roth did not examine influences from the number of features along each route. The current research could be extended to examine route navigation through multiple legs of a journey for both survey knowledge and procedural knowledge, with particular combinations of route legs controlled for number and configuration of landmark features.

Furthermore, a future direction may compare distance estimates in real world or virtual world situations in which people are actively walking to situations in which people are going to locations with relatively passive movement, such as driving in a car or taking a subway. In the current experiment, there was clearly no movement, but recent studies on embodied perception have shown that participants overestimate distance in some conditions, such as when they are carrying a heavy backpack and gauging the distance to the top of a hill (Proffitt, Stefanucci, Banton, and Epstein, 2003). Such embodied perception effects could be independent effects, or they could potentially interact with the number and configuration of features, e.g. leading to even greater distance distortions when approaching a daunting hill in San Francisco with many noteworthy attractions on both sides of the street. In the much more constrained context of survey knowledge in the current experiment, the results could indicate that humans unconsciously distort distances whenever they view maps, or the distortion may only occur when humans make effortful mental walks along the depicted routes.

Acknowledgments

The authors are very grateful to Heng Li and Neil Wright for their help in collecting data, and to Amber Goode for her technical assistance with the ERP and computer equipment.

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