Grid or no grid: Distance distortion in recognizing spatial information from complex cartographic maps

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Abstract

Mental representations of environments are embodied in cognitive maps. Cognitive maps enclose spatial and distance distortions, which appear due to transcription errors based on processing of map information. Participants processed complex cartographical maps of varying amounts of visual details like topography, boundaries and grid to examine their effects on recall and orientation performance. The results indicate that the presentation of boundaries, topographies and a square grid significantly reduced distortion errors compared to a blank map, whereas a presentation of more than one visual element did not further reduce the distortions.

Keywords: Cognitive Maps; Complexity; Visual Boundaries; Square Grid; Distance Distortions; Spatial Cognition

Introduction

A map, as a symbolic two-dimensional image of spatial relations, is a complex display of different kinds of stimuli, like object names, shapes, colors, spatial relationships and distances (Thorndyke & Stasz, 1980). Orientation on a map, thus, must be seen as a complex skill, which involves encoding a broad set of verbal and spatial information as well as combining and constructing a mental representation of the visual stimulus. Furthermore, all information is given simultaneously, which forces the map reader to evaluate and process the information in procedures running parallel.

The mental representations of environments are embodied in cognitive maps (Tversky, 1993). In a cognitive map, elements are structured and can be mentally inspected (Tversky, 1992). However, cognitive maps are not miniaturized models of the reality, but rather a derivation of the reality (Barkowsky, 2002). Examining the mental representation of knowledge acquired from simple maps, it can be shown that these representations are systematically distorted affecting both the participants' recognition and orientation performance (McNamara, 1986). Such distortions have been shown to follow the principles of perceptual grouping. For example, cities that are connected by lines are found to be recalled as lying closer together (Klippel, Knuf, Hommel & Freska, 2004; McNamara, Ratcliff, & McKoon, 1984). Moreover, omissions and additions that cannot be retrieved in the reality are present (Mark et al., 1999). To examine the representation of cognitive maps and distortions of real maps, previous research has focused on subsets of cartographical tools. Okabayashi and Glynn (1984), for instance, analyzed straight and curved boundaries on simple white maps and came to the conclusion that participants who studied the curved boundary maps made more distortion errors than those who studied the straight boundary maps and no-boundary maps. Furthermore, Sadalla and Magel (1980) showed that landmarks also distort the space around them. The hierarchical organization of landmarks was examined by Hirtle and Jonides (1985), who found a clustering of landmarks on the basis of non-spatial attributes. Moreover, they were able to point out that the clusters have consequences for participants' performance in distance estimations. In addition, Hommel, Gehrke and Knuf (2000) and Hurts (2005) showed a clustering due to boundaries or rivers.

As introduced above, previous research mainly focused on the examination of simple maps, and it still remains open whether such distortions are also observed when using higher complex cartographic material. Moreover, based on cognitive principles, square grids are commonly used in cartography as an artificial tool to guide a map reader´s attention and to reduce spatial distortions, but this hypotheses has not been tested empirically yet. Therefore, the maps presented in this study were created at different levels of visual complexity, varying in the amount of visual details displayed at three dimensions: (1) territorial boundaries: no boundaries vs. boundaries, (2) topography: no topographic details vs. maps containing topographic information (e.g., mountains), (3) grid: no grid vs. overlaid square grid. The goal is to evaluate the orientation and memory performance when participants learn the location of unknown cities at the different types of cartographic maps.

Methods

Participants

Sixty-two participants (30 male, 32 female) aged between 19 to 34 years [*M* = 23,1; *SD* = 3,4] participated voluntarily in the study. All participants gave written informed consent before inclusion in the study.

Materials

Eight different maps (680 px x 510 px) were created as study material. The first map was a blank white map, the second map included a network of red boundaries and the third included a colored topography. The fourth map comprised both the topography and boundary lines. Maps 5-8 copied these maps but additionally were overlaid by an artificial square grid (170 px x 170 px) (see Figure 1). The other design parameters of the grid, such as the color and width of the grid line, are based on the map grids standardly used in printed German topographic maps (scale 1:25,000). In addition, a pool of 28 newly created city names of eight-letter-length was established. Based on this pool, seven cities were pseudorandomly overlaid on each of these maps illustrated as red dots (so that no city was presented twice for any participant).

Design

The study consisted of a three-factorial 2*2*2 mixed design comprising the within-subjects factors boundaries and topography, and the between-subjects factor grid (see Figure 1). Participants were randomly divided into two groups. Both groups received the same maps with the same arrangement of cities, boundaries and topography, but one group with an overlaid square grid and the other without. All participants were told to study the seven cities on each map. For each city they had to remember the localization on the map as well as the name.

Each trial began with a study phase of two minutes, which was followed by a two minute interval with filler tasks. After the interval participants had to recall the seven cities on the same map, which now only included the background but not the red dotted cities. Participants were instructed to complete the task as accurate and as fast as possible by placing the cities on the map, using the cursor. After the placement of each city, participants had to type in the city-name. The trial was confined to three minutes. Furthermore, the presentation order of the different map types was randomized for each participant. The cartographic visualization of the maps was made with Adobe® Illustrator® CS5. The final maps (RGB color model) were exported as vector data sets and, in a further step, imported into Adobe® Flash® CS5. Here, based on the object-oriented language ActionScript 3.0, the maps were imbedded into an animated application used to execute the computer-based trial.

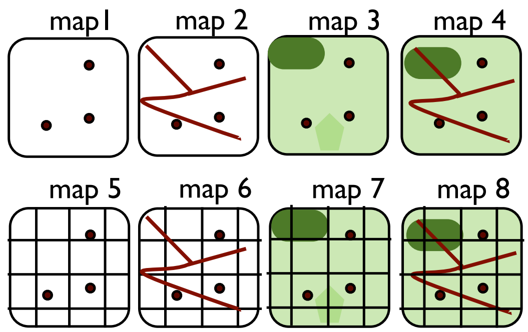

Figure 1: Schematic visualization of the four maps of the paradigm. Maps 2, 6, 4 and 8 include boundary lines. Maps 3, 7, 4 and 8 include a colored topography. Maps in the second row are overlaid by an artificial square grid.

Statistics

The orientation and memory performance was assessed by measuring the distance between the recalled place location compared to the original location of the city from the study-phase map. The Euclidian distance was measured in pixels. A city was rated correct in case the recalled location fell within a distance smaller than 28,4 px (= 1cm) from the study location (Okabayashi & Glynn, 1984). A mixed three-way 2*2*2 ANOVA comprising the within-subjects factors boundaries and topography and the between-subjects factor grid was computed for the number of correctly recalled cities and the mean distances of correctly positioned cities within the 1cm radius at a given significance threshold of $p = .05$.

Results

The repeated measures ANOVA for mean distances of correct placements with grid versus no-grid as a between subject factor revealed a significant main effect of grid [$F(1,60) = 6.359$, $p = .014$, $\eta_p^2 = .096$], but no significant main effects of topography ($p = .69$) and boundaries ($p = .21$). Moreover, a significant interaction between topography and grid was observed [$F(1,60) = 6.464$, $p = .014$, $\eta_p^2 = .097$]. Post-hoc *t*-tests showed that distances significantly decreased with the presentation of grids when no topography was present [$t(122) = 3.631$, $p < .001$].Distances for maps without topography and without grids are higher compared to those with topography and either without or with grids [$t(122) = 2.069$, $p < .043$; $t(122) = 2.287$, $p < .024$] whereas the presentation of the grid has

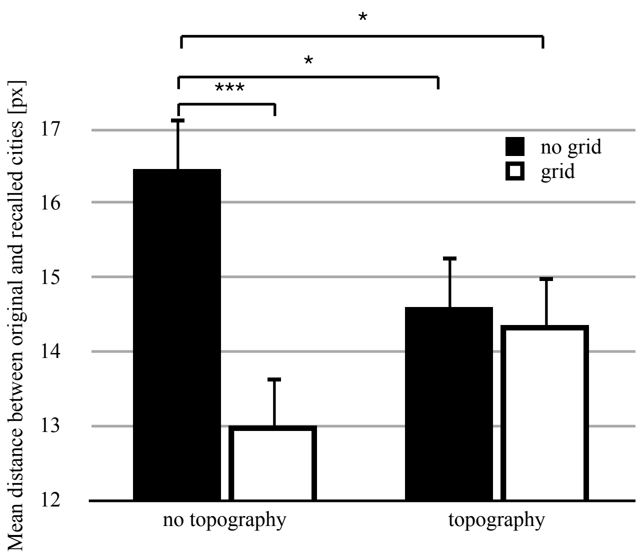

Figure 2: Mean distances between original and correctly recalled cities (a city was rated correct, when the recalled location fell within a distance smaller than 28,4 px) on maps with topography or no topography and overlaid with a square grid or without. * = $p < .05$; *** = $p < .001$

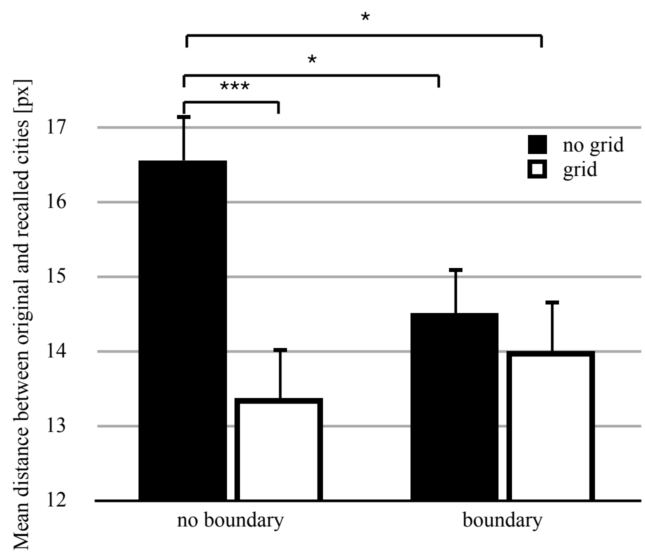

Figure 3: Mean distances between original and correctly recalled cities (a city was rated correct, when the recalled location fell within a distance smaller than 28,4 px) on maps including boundaries or without and overlaid with a square grid or without. * = $p < .05$; *** = $p < .001$

no effect when a topography is present ($p = .770$) (Figure 2).

The ANOVA on distances also revealed a significant interaction between boundaries and grid [$F(1,60) = 5.821$, $p = .019$, $\eta_p^2 = .088$]. The results of the post-hoc *t*-tests indicate that distances significantly decrease with the presentation of grids when no boundary is present [$t(122) = 3.676$, $p < .001$] and distances are higher compared to maps with boundaries and either without or with grids [$t(63) = 2.471$, $p < .016$; $t(122) = 2.874$, $p < .005$], whereas the presentation of the grid has no effect when boundaries are present ($p = .560$) (Figure 3). The interactions between topography and boundary ($p = .40$) and between grid, topography and boundary ($p = .21$) were not significant (for means and standard deviations see Table 1).

Table 1: Distances in pixels between original and correctly recalled cities [mean (*SD*)] for the different map types.

	no topography		topography	
	no boundary	boundary	no boundary	boundary
no grid	18.1 (5.0)	14.8 (5.8)	15.0 (4.6)	14.2 (4.6)
grid	12.6 (4.6)	13.4 (5.3)	14.2 (4.7)	14.6 (4.5)

The repeated measures ANOVA for mean percentages of correctly recalled cities with grid versus no-grid as a between subject factor revealed a significant main effect of topography [$F(1,60) = 4.976$, $p = .029$, $\eta_p^2 = .077$]. No other main effect reached significance (grid, $p = .12$; boundaries, $p = .06$). Moreover, significant interactions between grid and topography [$F(1,60) = 10.762$, $p = .002$, $\eta_p^2 = .152$], and between grid, topography and boundary[$F(1,60) = 10.245$, $p = .002$, $\eta_p^2 = .146$] were observed. Although the presentation of a grid did not show any effect if a topography was present, the recall of city-locations was significantly better among maps without topography if a grid was present [$F(1,60) = 8.717$ $p = .004$, $\eta_p^2 = .127$] (Table 2). The interactions between grid and boundaries ($p = .17$), and between topography and boundaries ($p = .44$) were not significant (for means and standard deviations see Table 2).

Table 2: Percent of correctly recalled cities [mean (*SD*)] on the different map types.

	no topography		topography	
	no boundary	boundary	no boundary	boundary
no grid	38.8 (24.1)	42.9 (25.1)	57.1 (24.3)	49.6 (29.5)
grid	63.8 (23.6)	44.3 (25.3)	51.9 (22.0)	51.4 (21.7)

Discussion

The inclusion of visual boundaries, topographic information and of a square grid significantly modulate distance distortions and recall performance of complex cartographic maps, probably due to altered cognitive representations of the spatial relations. Following the analysis of the distance distortions a clear picture emerges in that adding of visual elements significantly reduces distances relative to the original locations. Of particular note is that no further additive effects of these visual elements were observed. For example, no further advantage of boundaries or the displayed topography is visible in orientation performance when a square grid is already present – but also no disadvantage. Participants seem to set different additional visual information apart from an other to enhance their orientation performance and thus to reduce distortions (Figures 2 and 3), but the transfer to combination of visual information is missing.

In general these result support the notion of structured cognitive maps derived from environmental (visual) information – as the present paradigm rules out effects of previous knowledge (Barkowsky, 2002; Tversky, 1992). A likely way to use such complex visual information is to build visual hierarchies (Eastman, 1985; Hirtle & Jonides, 1985) forming frames of representation that clusters the visual elements. Thus, cartographic details seem, in accordance with our initial hypothesis to guide the processes of cognitive map formation. It will be a question of future research to examine why no additive effects of the visual elements were visible, a first hypothesis would need to consider a kind of visual overkill, which if it can be replicated would affect the designing of cartographic material.

Regarding the recall performance of cities, topography had an overall effect, whereas grids again only improved the orientation on simple maps. This matches the results of the distance distortion analyses. Future studies should include different grid types to examine this result and to improve the use of grids, but also the presentation of topographic details and boundary information as assistant cartographic elements. Topographic details and boundaries should be modified in density and spacing to receive an impression of the degree in which the adding of visual elements effects distance distortion. Additionally, different grid types in combination with the assistant cartographic elements should be analyzed in terms of a coordination of cartographic elements to support the map reader. Furthermore, general investigations in navigation performances should be pursued based on these results.

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