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The processing and integration of map elements during a recognition memory task is mirrored in eye-movement patterns

Lars Kuchinke [a, b, *], Frank Dickmann [c], Dennis Edler [c], Martin Bordewieck [b], Anne-Kathrin Bestgen [b, c]

[a] International Psychoanalytic University Berlin, Germany
[b] Department of Psychology, Ruhr-University Bochum, Bochum, Germany
[c] Department of Geography, Ruhr-University Bochum, Bochum, Germany

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ABSTRACT

Grid lines and visual detail in topographic maps support the encoding and recognition of object locations. Perception-based and knowledge-based functions are discussed to contribute to these effects, but little is known about how participants process such map elements. An eye-tracking study was conducted where participants were asked to learn object locations in topographic maps. The behavioural data of this recognition memory paradigm support the assumption of memory-enhancing functions of grids and topographic detail. Eye-movement data reveal that during encoding, grids and topographic detail trigger attentional shifts towards to-be-learned object locations. These eye-movement patterns are likely one factor contributing to an improved memory performance. Moreover, already the first fixations on a map are affected by the experimental manipulations. This result is particularly visible in the recognition phase and apparently indicates that grids and topographic detail get integrated into the mental representation of the map.

1. Introduction

Reading spatial information from maps and in particular from maps displaying topographic information of spatial conditions (so called 'topographic maps') is a rather complex human ability. Different map elements from simple objects or landmarks to complex survey knowledge (Downs & Stea, 1973; Siegel & White, 1975) need to be integrated to build a mental representation of the spatial environment. Perceptual and knowledge-driven processes interact to help the map reader in building these mental representations. The results of these processes are mental models that include information about spatial objects, the relations and distances between them in form of cognitive maps (Barkowsky, 2002; Mark, Freksa, Hirtle, Lloyd, & Tversky, 1999). The resulting cognitive maps are incomplete and distorted systematically (Golledge, 1978; Tversky, 1981, 1993). It is commonly assumed that during the process of spatial memory acquisition different frames of references at different levels of spatial information are combined into "more complex hierarchically organized representations" (McNamara, 2013, p.176; Tversky, 1993). The category adjustment model by Huttenlocher, Hedges, and Duncan (1991) predicts that most distortion errors for object locations arise from a mismatch between fine-grained spatial information and information at superordinate spatial categories.

Such spatial categories used as frames of reference in spatial processing consist of salient features, such as large-scale structures visible on a map or highlighted landmarks. As to topographic maps, examples of such frames of reference are regional boundaries (see Hurts, 2005; Stevens & Coupe, 1978) or square grids (Edler, Bestgen, Kuchinke, & Dickmann, 2014a; McNamara, 1986). Maps overlaid with squared grids and topographic details include both types of spatial information: fine-grained spatial information and information at superordinate spatial categories. Therefore, they are effective stimulus material that can be used to test how a map-reader transfers these different types of spatial information into a cognitive map.

Of interest is that in the Huttenlocher et al. (1991) study cited above, the use of category information improved the accuracy of remembered object locations. Similarly, a series of recent examinations emphasized that hierarchical processing does not

* Corresponding author. Methods and Evaluation, Psychoanalytic University Berlin, Stromstr. 3, 10555, Berlin, Germany.
E-mail address: lars.kuchinke@ipu-berlin.de (L. Kuchinke).

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necessarily lead to spatial memory distortions. For example, the accentuation of map-immanent visual details like streets (Edler & Dickmann, 2015; Edler, Bestgen, Kuchinke, & Dickmann, 2015) or the addition of square grids to topographic maps (Bestgen et al., accepted; Edler et al., 2014a; 2014b) improve memory performance compared to maps without these elements. The results of these studies point to memory advantages due to hierarchical coding of spatial information based on such large-scale space-referencing map elements (e.g. Edler et al., 2014a). Similar effects are known from vision research and scene perception when space-structuring elements like visible and invisible squared grids enhance memory for object locations (Martin, Houssemand, Schiltz, Burnod, & Alexandre, 2008; Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2002).

This effect is however not unequivocal. If participants are asked to learn object locations on a map, the maps complexity also contributes to the accuracy of recall memory. An increase in map complexity from low to mid- or high complex maps (e.g. urban map scenarios that depict a huge amount of topographic detail) results in improved object location memory (Edler et al. 2014a). At first glance, such results seem to represent hat any visible element on a map improves spatial memory. This is not the case: In general, adding topographic detail enhances memory performance. Secondly, the effects of space-referencing map elements (like square grids) and topographic detail interact. This leads to the observation that if a high amount of fine-grained visual detail is displayed on a topographic map the grid effect decreases. Bestgen and colleagues (accepted) basically confirmed the above observations. By using a recognition memory paradigm instead of a recall, these authors were able to identify dissociable effects on the underlying memory processes by applying a signal detection theory analysis (Green & Swets, 1966): Grids enhance memory performance, whereas topographic detail triggers differences in strategic processing as indicated by higher, more conservative response bias measures. Such conservative response strategies seem indicative of more thorough decisions or a refined decision process under higher visual complexity conditions. These results so far mainly relied on behavioural examinations. So far, it is not known how these map elements are perceived and processed by the map-reader to build a mental representation of the environment. We suggest that eye-tracking is an appropriate method to examine this question. By using the eye-tracking method, it is possible to examine map reading during the encoding phase, i.e. the time during which the map-reader selects and learns the spatial information needed to later on retrieve the correct object locations. The proposed differences between grids and topographic detail might well apply to a distinction between a perceptually-driven visual structuring of a map display and the memory effects of visual anchors. Any visual object (like a grid or topographic detail) may act as an anchor point for local reference (Couclelis et al., 1987) that gets integrated into the cognitive map. Regarding the perceptual function of map elements, vision science provides further propositions: It is discussed that global image features trigger gist-like processing (Greene & Oliva, 2009; Oliva & Torralba, 2006). Processing the global structure of a scene is assumed to be automatic, likely starting with the first gaze (i.e. the first fixation) on a scene (Rayner, 2009). A gist, i.e. the conceptual category and the spatial layout of a scene, is processed within the first 100 ms of presentation, i.e. within or even before the first fixation occurs (Potter, 1976; Renninger & Malik, 2004). Acquiring gist-like spatial layouts of a scene or a map might therefore precede the processing of local detail information. Gist processing is guided by structuring map elements that regionalize the map surface. Thus, grids, with their function as space-referencing map elements, likely support gist-like perceptual processing. The results of this regionalization of the spatial layout constrains local analysis (Torralba, Oliva, Castelhano, & Henderson, 2006) linking its function back to the distinction between fine-grained spatial information and category information in the category adjustment model (Huttenlocher et al., 1991).

The present study aims to examine these assumptions by an analysis of gaze patterns while map readers learn and retrieve object locations in a recognition memory paradigm. If the distinction between the processing of large-scale map elements and fine-grained visual detail in object location memory mirrors differences in the underlying memory processes, such differences should be visible in the gaze patterns. Examinations of object location memory have revealed that the gaze patterns for encoding object location differ from "those underpinning memory for global spatial layout" (Shih, Meadmore, & Liversedge, 2012). In general, average number of fixations and the average fixation durations on a particular object or Area-of-Interest (AOI) correlate with the depth of cognitive processing (Rayner, 2009). In case of the encoding of object location information, this effect is narrowed down to the number of fixations on an object (Shih et al., 2012; Tatler, Gilchrist, & Land, 2005). Tatler and colleagues assume that object location information is accumulated across different fixations. Similarly, during memory retrieval, the number of fixations predicts successful memory retrieval. The amount of re-fixations during retrieval reflects the reinstatement of encoding operations, as it would be predicted to be functional for the perceptual reconstruction of the object (Holm & Mäntylä, 2007; Johannson & Johannson, 2014; Mäntylä & Holm, 2006).

Translating these effects to the modulation of object location memory in topographic maps, it can be predicted that the addition of square grids or visual detail affects eye-movements during encoding and retrieval. As far as we are aware, this relationship has not been examined to date. Moreover, relatively little is known about how these map elements affect object location memory. The examination of pure behavioral outcome measures provides only little insights. In contrast, the analysis of eye-movements during encoding and during memory retrieval will likely help to differentiate the functions these map elements have. Based on what is known from vision research, with memory improvement, a higher number of fixations on the to-be-learned objects would be expected during both encoding and retrieval. A higher number of fixations would point to a causal role of these fixations for the processing of visual anchors during encoding and their reinstatement during retrieval. An object may act as an anchor point of its proximal reference region (Couclelis, Golledge, Gale, & Tobler, 1987; Montello, 2003). In addition, complex maps provide more detail, and thus more anchor points, which should lead to an enhanced number of fixations that are causal for better memory performance. A different assumption can be derived regarding the effects of square grids. Their proposed primary function is to structure the map and to constrain local analysis. If square grids visually structure the map surface, the global image features and, thus, the perceptual processing of the spatial layout should be altered. As a consequence of gist-like spatial layout processing no particular fixation pattern on the grid lines themselves would be observed. Instead, shifted attention to the to-be-learned objects and their close neighborhood were expected (cf. Hollingworth & Henderson, 2002).

2. Methods

2.1. Participants

Thirty-one Students from Ruhr-University Bochum (aged between 18 and 34 years, m = 24.3 years, 8 female) participated in the study. The study was conducted in accordance with the Declaration