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The Salience of Landmark Representations in Maps and its Effects on Spatial Memory

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Declaration of Authorship

This thesis is subdivided into seven chapters. The chapters 1 and 2 contain a general introduction into landmarks, salience and spatial memory. The chapters 3, 4, 5 and 6 contain papers published in international peer reviewed journals as part of the priority programme "Volunteered Geographic Information: Interpretation, Visualisation and Social Computing" (SPP 1894, project number 314977345, funding numbers DI 771/11-1 and KU 2872/6-1) financed by the German Research Foundation (DFG). Chapter 7 consists of a general discussion of the research findings reported in the previous chapters and suggestions for potential future research and practical applications of the findings. The included papers and the respective author contributions are listed below.

1. Keil, J., Edler, D., Dickmann, F., & Kuchinke, L. (2019). Meaningfulness of landmark pictograms reduces visual salience and recognition performance. *Applied Ergonomics*, 75, 214–220. **https://doi.org/10.1016/j.apergo.2018.10.008**

   Julian Keil planned, designed, and carried out the experiment, analyzed and visualized the data, and wrote the paper. Feedback concerning the study design was provided by Dennis Edler, Frank Dickmann and Lars Kuchinke. Comments and suggestions of all authors and anonymous reviewers were integrated into the final version of the paper by Julian Keil.

2. Keil, J., Mocnik, F.-B., Edler, D., Dickmann, F., & Kuchinke, L. (2018). Reduction of Map Information Regulates Visual Attention without Affecting Route Recognition Performance. *International Journal of Geo-Information*, 7(12), 1–13. **https://doi.org/10.3390/ijgi7120469**

   Julian Keil planned, designed, and carried out the experiment, analyzed and visualized the data, and wrote the paper. Franz-Benjamin Mocnik contributed to writing parts of the introduction and the discussion of the paper. Lars Kuchinke gave suggestions regarding the experiment design and the analysis. Comments and suggestions of all authors and anonymous reviewers were integrated into the final version of the paper by Julian Keil.

3. Keil, J., Edler, D., Kuchinke, L., Dickmann, F. (2020). Effects of visual map complexity on the attentional processing of landmarks. *PLoS ONE*, 15(3): e0229575. **https://doi.org/10.1371/journal.pone.0229575**

   Julian Keil planned, designed, and carried out the experiment, analyzed and visualized the data, and wrote the paper. Feedback concerning the study design was provided by Lars Kuchinke and Frank Dickmann. Comments and suggestions of all authors and anonymous reviewers were integrated into the final version of the paper by Julian Keil.

4. Keil, J., Edler, D., Reichert, K., Dickmann, F., Kuchinke, L. (2020). Structural salience of landmark pictograms in maps as a predictor for object location memory performance. *Journal of Environmental Psychology,* 72, 101497. **https://doi.org/10.1016/j.jenvp.2020.101497**

   Julian Keil planned, designed and supervised the experiment, analyzed and visualized the data, and wrote the paper. Katrin Reichert contributed to the stimulus design and carried out the experiment. Feedback concerning the study design was provided by Lars Kuchinke and Frank Dickmann. Comments and suggestions provided by all authors and the anonymous reviewers were integrated into the final version of the paper by Julian Keil.

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List of Abbreviations

JPEG	Digital image file format, the name is derived from the "Joint Photographic Expert Group"
OSM	OpenStreetMap, a free and collaborative mapping project
PNG	Portable Network Graphics, a digital image file format that supports image transparency
VAS	Visual analogue scale, a continuous response scale
VGI	Volunteered geographic information

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1 Introduction

The life of human beings unfolds within three-dimensional space. Their daily routine leads them through the space of their homes and the familiar environment around their homes. This familiar environment is characterized by the availability of a mental representation of space, i.e. knowledge about locations, the spatial relation between these locations, and routes connecting them (Millonig & Schechtner, 2007). People know how to get from their homes to work, to the supermarket, or their favorite restaurant. Usually, they even know multiple alternative routes connecting familiar locations. Such routes consist of a start location, a target location, and potentially several decision points marking locations where the travel direction needs to be adjusted, e.g., a right turn at a crossroads. Recognizing decision points while following a route can be achieved based on landmarks along the route (Janzen, 2006). Landmarks are salient and memorable spatial objects with a sufficiently permanent spatial location (Anacta, Schwering, Li, & Muenzer, 2017; Basiri, Amirian, & Winstanley, 2014; Ishikawa & Montello, 2006; Sorrows & Hirtle, 1999). From the perspective of their perceiver, landmarks pop out of their surrounding objects (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Röser, 2017). Therefore, they are more likely to attract visual attention than other spatial objects (Sorrows & Hirtle, 1999). This makes them ideal spatial reference points that can be used to identify one's current location and the location of the next decision point (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Elias & Paelke, 2008; Millonig & Schechtner, 2007).

However, it is not uncommon for people to leave their familiar environment. Whenever they go on a business trip, a vacation, an excursion, or just a short hike, people may enter areas of which they have no or only very limited spatial knowledge. Under these circumstances, rather than relying on memorized routes and landmarks, efficient and effective navigation depends on the availability of external spatial information, i.e. in the form of maps (Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998). Maps are representations of geographical space (Montello, 2002). They often display road structures, terrain characteristics as relief and flora, buildings, as well as landmarks (Thrower, 2008). Therefore, they can be used to study and memorize unfamiliar environments even without being physically present.

If landmarks are displayed in a map representing an unfamiliar environment, matching these landmark representations to landmarks perceived in real-world space allows people to orientate themselves and to follow a selected route (Anacta et al., 2017; Montello, 2012; Peebles, Davies, & Mora, 2007). As the selection of real-world objects to be displayed in a map is often made a priori by cartographers, the landmarks represented in maps may differ from the real-world landmarks used for orientation and navigation. However, the expanding availability of maps based on volunteered geographic information (VGI) might help to reduce this discrepancy, because volunteers usually map spatial elements within real-world space. Therefore, the cognitive processes that affect the selection of landmarks in real-world space should also affect the selection of landmarks to be represented in a VGI-based map. If people are able to integrate these landmarks and their map representations into their mental representation of space, their dependence on external representations of space is assumed to decrease, because these landmarks can be used for orientation and navigation without relying on map information.

To use landmarks for orientation, navigation, and to integrate them into a mental representation of space, they need to be perceived. This is true for real-world landmarks, as well as landmark representations in maps. As highly salient objects are more likely to receive visual attention (Corbetta & Shulman, 2002), landmark salience can affect their usefulness for spatial tasks as orientation and navigation, as well as their likelihood to be integrated into spatial memory by directing visual attention towards these spatial objects (see Figure 1.1, Santangelo, 2015). Additionally, landmarks are discussed to play an important role for the formation mental representations of space (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Foo, Warren, Duchon, & Tarr, 2005; Millonig & Schechtner, 2007). According to Golledge (1999a), they act as reference points for surrounding spatial objects. Therefore, visual attention directed towards salient landmarks may not only affect spatial memory of the landmarks themselves. The availability of salient landmarks may also affect spatial memory of surrounding spatial objects.

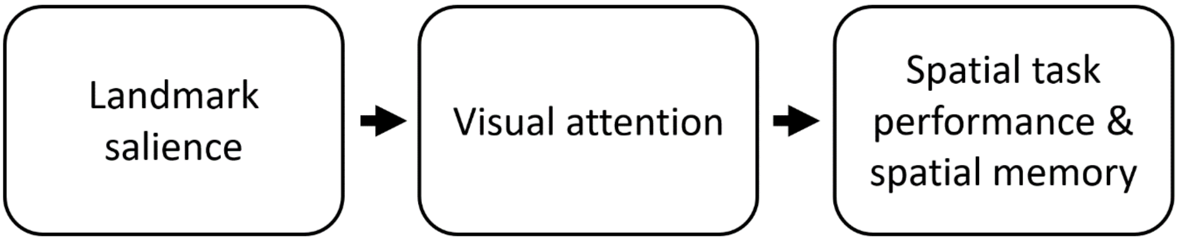

Figure 1.1. *Relation between landmark salience, visual attention and spatial task performance and memory. Salient landmarks pop out of their surroundings (Röser, Krumnack, & Hamburger, 2013) and are therefore more likely to receive visual attention (cf. Corbetta & Shulman, 2002). If landmarks are not visually perceived, they cannot be used in spatial tasks or integrated into mental representations of space. Therefore, visual attention is assumed to act as a mediator variable between the salience of landmarks, their effects on spatial tasks and the formation of mental representations of space.*

Several studies have investigated what makes landmarks in 3D space salient, thus what makes them more likely to be perceived (e.g. J. Miller & Carlson, 2011; Röser, 2017; Röser, Krumnack, Hamburger, & Knauff, 2012) Others evaluated how the availability of landmarks affects orientation, navigation, and the formation of mental representations of space (e.g. Anacta et al., 2017; Klippel & Winter, 2005; Lovelace, Hegarty, & Montello, 1999). However, the parameters that affect the salience of landmark representations in maps, and how the salience of these landmark representations affects spatial memory, has received little attention yet. This thesis reports five studies aimed to fill this gap. All studies are already published in peer-reviewed journals and will be presented as a succeeding series of evaluations in the following chapters. The next chapter acts as an introduction to relevant characteristics of maps, landmarks, landmark salience and mental representations of space. The chapters 3, 4, 5 and 6 consist of four peer-reviewed research papers that report the five studies investigating effects of the salience of landmark representations on visual attention and spatial memory. The final chapter consists of a general discussion of all studies including their limitations, proposed related future research and implications for map design.

2 Background
2.1 Maps

Maps are graphic representations of space used to communicate information about the represented space (Montello, 2002). Although maps can be either two-dimensional or three-dimensional, two-dimensional maps are the most commonly used external representation of space (Edler, Husar, Keil, Vetter, & Dickmann, 2018). Such 2D maps usually represent spatial elements and visualize the spatial relation between these elements. However, maps usually cannot represent all spatial elements that are located in the spatial dimensions shown on the map, because real-world space usually consists of numerous spatial elements and the available space in a map is limited. Furthermore, representing too many spatial elements would cause a map to be visually extremely complex. Visual complexity has been found to depend on the number of displayed graphical elements (MacEachren, 1982; Oliva, Mack, Shrestha, & Peeper, 2004) and is associated with an increased difficulty to read and interpret visual stimuli (Ciołkosz-Styk & Styk, 2011; Rosenholtz, Li, & Nakano, 2007). This can be ascribed to the fact that visualizing a high number of spatial elements makes it likely that some of these elements are clutter, i.e. excess items that are irrelevant and could distract the map user (Rosenholtz, Li, Mansfield, & Jin, 2005; Touya, Decherf, Lalanne, & Dumont, 2015; Wolfe, 1994). Especially small-scale maps have to address this issue, because the areas they represent are larger and therefore contain more spatial elements. The general solution to this limitation is generalization, the process of simplifying a map by adjusting the level of detail (Jones & Mark Ware, 2005; Sester, 2020). Examples are the selection of a set of spatial elements to be displayed in a map, or the merger of multiple spatial elements into one object representation (Dickmann, 2018). Additional generalization principles like shape smoothing have been identified (cf. Plazanet, Affholder, & Fritsch, 1995). Generalization decisions are made by cartographers as map developers. In the ideal case, they are based on the relevance of spatial elements for the spatial tasks a map is intended to support (Sester, 2020). In other words, a map should represent all spatial elements required for the spatial tasks for which a map is designed, but as few clutter elements as possible that could distract from the relevant map elements (Rosenholtz et al., 2007; Wolfe, 1994).

In paper maps, the most traditional type of map (Słomska, 2018), task-based generalization is difficult, because cartographers must predict each possible use case of a map. If multiple use cases exist and require different spatial elements to be displayed in the map, cartographers must weigh their generalization between these different potential use cases with different unknown likelihoods. They can either decide to remove some spatial elements required for one of the use cases, or accept some visual clutter and keep all spatial elements required for all predicted use cases. Usually, generalization rules are defined and applied consistently across the whole map (cf. Forrest, 1999). Examples are the exclusion of small roads in small-scale maps, or the merging of a group of trees into a forest area displayed as a green background color. As the generalization rules may assign a higher relevance to specific spatial elements, the distribution of displayed object representations in the map can be uneven. Human-made objects are often assigned a higher priority than natural objects. Therefore, urban map areas usually have a higher visual complexity than rural map areas (Ciołkosz-Styk & Styk, 2011, see example in Figure 2.1).

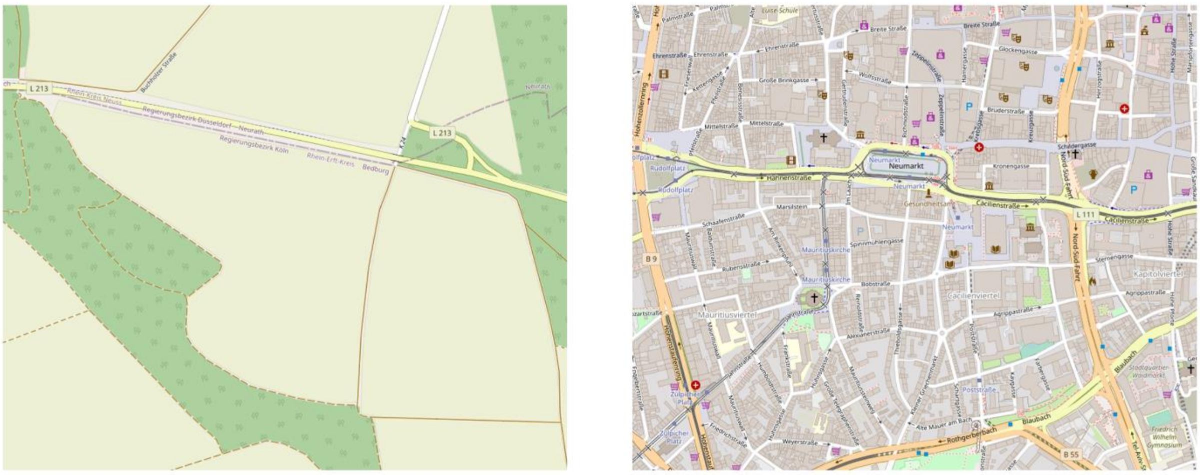

Figure 2.1. *Visual map complexity differences caused by generalization rules. Human-made objects are usually less likely to be excluded from maps based on generalization rules. This leads to map complexity differences between urban and rural map areas. The left map represents a rural area with low visual complexity and the right map represents an urban area with high visual complexity. The displayed maps were obtained from* ***OpenStreetMap.org*** *in the same map scale.*

Since the introduction of smartphones and mobile internet into everyday life, the predominance of paper maps is challenged by digital maps provided by web mapping services. These digital maps are not only available always and everywhere, provided an internet connection is available. They also enable the display of dynamic map content. People can adjust the displayed map area and scale, or use radio navigation signals like GPS to track their location in the map (Brakatsoulas, Pfoser, Salas, & Wenk, 2005; Cecconi, Weibel, & Barrault, 2002; Yuan, Zheng, Zhang, Xie, & Sun, 2010). Additionally, digital maps can be programmed to react dynamically to user input. E.g., map generalization processes can be applied in real time when the map scale is adjusted (see Figure 2.2). Theoretically, the ability to modify map design dynamically can also be used for task-oriented adjustments of map content. If specific visualization requirements are identified for a map-based task as orientation, navigation, or route memory, these requirements can be used to adjust the map design according to these requirements and a selected task. For example, if people select a route in a map, objects identified as supportive for route memory could be highlighted in the map.

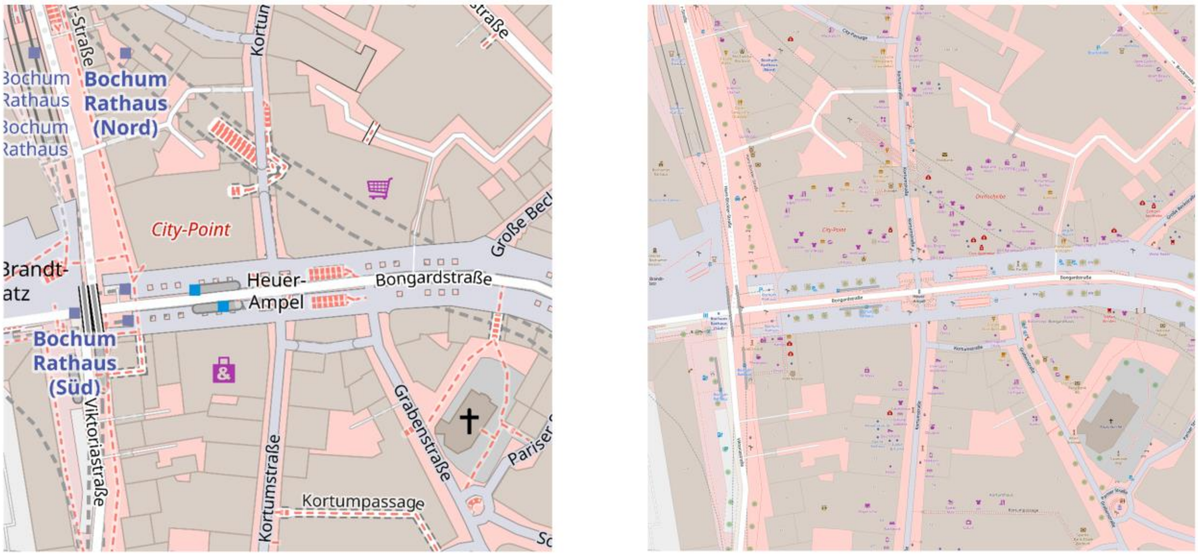

Figure 2.2. *Scale-based dynamic map generalization. Both maps were obtained from* ***OpenStreetMap.org****. Although both maps show the same map section, the right map contains more spatial elements (especially landmarks). This is due to the fact that it was extracted in a larger scale. OSM applies different generalization rules based on the selected map scale.*

Two highly influential examples of digital maps are Google Maps and OpenStreetMap (OSM). Although both maps can be used free of charge, clear differences exist in terms of motivation, data acquisition and complexity of the available data. Google Maps is a product of Google LLC. As a commercial business, the goal of Google is to generate revenue. Concerning the data acquisition, virtually anybody can request to add spatial data to Google Maps, e.g. the location of a store. However, Google can decide which data is added to Google Maps and which information layers are available to the users. OSM on the other hand is made available by the OpenStreetMap foundation, a non-profit foundation that aims to provide map data for free to anybody who wants to use it. The underlying geodata is provided by volunteers and national mapping agencies (OpenStreetMap Foundation, 2020). In contrast to Google Maps, users can access and extract all layers of the geodata, including tags, coordinates and vector data of objects. In order to address potential effects of the background and data acquisition processes of commercial and non-commercial map providers on map design, these two map providers will be used as examples in the following sections.

2.2 Landmarks and landmark representations

Landmarks are salient spatial elements acting as spatial reference points for places or surrounding spatial elements (Anacta et al., 2017; Basiri et al., 2014; Bestgen, Edler, Kuchinke, & Dickmann, 2017; Richter & Winter, 2014). Their salience directs attention towards them, making them more likely to be perceived than surrounding elements (Caduff & Timpf, 2008; Millonig & Schechtner, 2007; Sorrows & Hirtle, 1999). What characteristics make a landmark salient is discussed in detail in the following chapter. It has been argued that landmarks play an important role in the formation of mental representations of space, because they act as an abstraction layer that helps to make sense of complex environments (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Foo et al., 2005; Sorrows & Hirtle, 1999). Golledge (1991) describes the function of landmarks as dominant anchor points for surrounding elements. Thus, instead of memorizing the absolute locations of objects around a landmark, they may be memorized in spatial relation to the respective landmark.

In addition to their function for spatial memory, landmarks have been found to support orientation, navigation, and the provision with route descriptions (Anacta et al., 2017; Blades & Medlicott, 1992; Kiefer, Giannopoulos, & Raubal, 2014; May, Ross, Bayer, & Tarkiainen, 2003; Ross, May, & Thompson, 2004; Tom & Denis, 2003). According to Cheng and Newcombe (2005), people use landmark geometries for orientation. By matching visible landmarks to landmarks in an internal or external representation of space, the current location and heading within 3D space can be assessed (Montello, 2012). Concerning navigation, Elias and Paelke (2008) describe landmark-based navigation as “the most natural concept for humans to navigate”. Navigation requires people to continuously update orientation information while they follow a route (Loomis, Klatzky, Golledge, & Philbeck, 1999). Landmarks support this task, because they act as markers for intermediate goals along a route, as well as directional pointers towards the next intermediate goal (Millonig & Schechtner, 2007; Steck & Mallot, 2000). Thus, for example, a chain of landmarks can be used to memorize, describe, and follow a route.

Theoretically, every spatial element, whether natural or human-made, can act as a landmark (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Röser et al., 2013). However, landmarks need to have a sufficient spatial permanence (Anacta et al., 2017; Basiri et al., 2014). If they are moved, their location will no longer match the memorized location in a mental representation of space, or its location in a map or route instruction. This could cause people to lose their orientation, or even to get lost. Classical examples of sufficiently spatially permanent landmarks include, but are not limited to, buildings, monuments, crossroads, mountains, lakes or trees. The usability of spatial elements as landmarks can vary greatly, even within the same semantic category. For instance, some buildings are more salient than others, and some cars may be parked for long enough in the same parking space to have a sufficient spatial permanence, whereas other cars are moved on a daily basis, making them a bad choice as a landmark. The usefulness of specific spatial elements as landmarks also differs between individuals (Golledge, 1991; Röser et al., 2012) and different temporal contexts as seasons (Kettunen, Irvankoski, Krause, & Sarjakoski, 2013) or daytime (Krukar, Schwering, & Anacta, 2017; Winter, Raubal, & Nothegger, 2005). For example, an otherwise inconspicuous building may be an important landmark for its inhabitants, or a suitable landmark during nighttime if its façade is illuminated.

According to their location relative to an observer and a specific route, landmarks are categorized either as local or global. Local landmarks are located close to a specific route (Anacta et al., 2017). They are discussed to support route knowledge, because they can act as proximal cues that can be used to ensure that a specific route is followed correctly (Hurlebaus, Basten, Mallot, & Wiener, 2008; Millonig & Schechtner, 2007; Ruddle, Volkova, Mohler, & Bülthoff, 2011). The exact location of local landmarks can be further specified based on their relevance for navigation instructions (see Figure 2.3, cf. Elias & Paelke, 2008; Lovelace et al., 1999). Landmarks *along the route* are passed during navigation, but are not located next to an intersection. Thus, it is unlikely that they are used as indicators for a required adjustment of the travel direction. Landmarks at *potential decision points* are located next to an intersection where the travel direction does not have to be adjusted. They can be used as reference points for instructions to prevent an erroneous adjustment of the travel direction. Landmarks at *decision points* are located next to an intersection where the travel direction needs to be adjusted. These landmarks are discussed to have the highest relevance for route instructions and effective navigation, because a route can be memorized or followed without knowledge about potential decision points or about every landmark that is passed during navigation - but not without knowledge about locations where the travel direction needs to be adjusted. Still, information about landmarks along the route and at potential decision points can affect the trust in navigation instructions, because they can be used to ensure that people are still on the right way (Millonig & Schechtner, 2007).

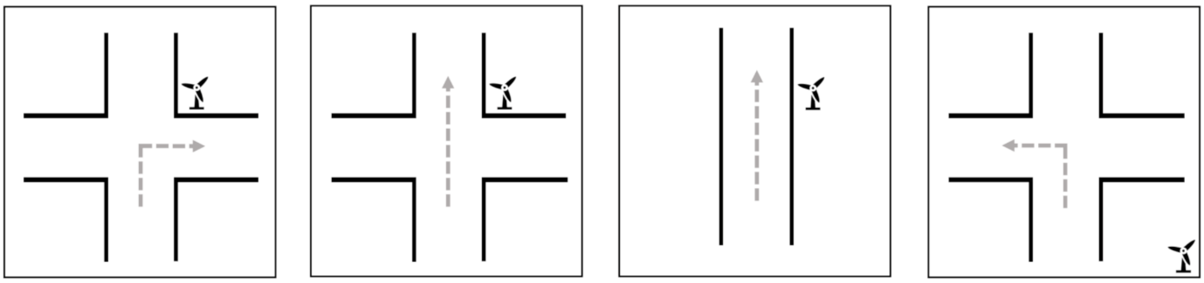

Figure 2.3. *Relative landmark locations. Landmarks can be classified based on their relative location to a route and required adjustments of the travel direction during navigation. Local landmarks not located close to an intersection are classified as landmarks along the route. Local landmarks located next to an intersection are classified as landmarks at a decision point if the travel direction needs to be adjusted at this intersection. Otherwise, they are classified as landmarks at a potential decision point. Global landmarks are located offside the route and are not passed during navigation (figure adapted from Bauer, 2018).*

Global landmarks are usually located far away from the observer or a specified route (Anacta et al., 2017; Elias & Paelke, 2008; Wenig et al., 2017). Therefore, their position relative to the observer is less affected by movement through space (Steck & Mallot, 2000). This allows to use global landmarks as indicators for world directions (Lin et al., 2012; Wenig et al., 2017). Thus, they can be used as beacons to identify the travel direction. Possibly the best example of a good global landmark is the North Star. Independent of a person's movements, it is always located almost exactly in the northern direction (although it is only visible from the northern hemisphere). However, this extreme example should not dispute that relatively close spatial elements can also be used as global landmarks. The intensity of relative directional changes of global landmark is affected by the individual travel distance and travel direction. If the individual mobility radius is smaller, closer landmarks can be used as global landmarks. Additionally, if an individuum travels towards, or away from a landmark, instead of orthogonal to the landmark direction, the relative direction of the landmark will not change. In these cases, even extremely close landmarks could be used as global landmarks. Given that global landmarks are not located along a route, they may easily be covered by spatial elements along the route. Therefore, size can be a relevant characteristic for the selection of spatial elements as global landmarks, as shown by Stülpnagel and Frankenstein (2015), who found that the likelihood of global landmarks to be included in a sketch map was affected by their size.

According to Anacta et al. (2017), global landmarks are primarily used as reference points for longer routes. This reflects the task requirements of short and long navigation tasks, and the spatial information provided by global landmarks. Short routes require very precise location information to identify the target location. This information can be provided by local reference points, but not by global landmarks, because the latter only provide directional information (Lin et al., 2012; Steck & Mallot, 2000). On long routes on the other hands, people may use global landmarks to identify the approximate travel direction and to navigate towards the target location. However, when the target location is approached, local landmark information should again be required to identify the exact target location. As global landmarks only provide directional information instead of precise local information, they are assumed not to be of use for memorizing or communicating specific routes (cf. Ruddle et al., 2011). This limitation of global landmarks is reflected in the finding that people are more flexible with their route choices when they navigate using global landmarks as reference points (Hurlebaus et al., 2008). Instead of following a predefined route, they spontaneously select paths that approximately lead to the target direction.

In 2D maps, landmarks are often represented as pictograms. These pictograms usually do not reflect the visual characteristics of the represented landmarks. Instead, landmarks are grouped into semantic categories and all landmarks from a specific category are represented by the same abstract symbolic pictogram (see Figure 2.4). In the ideal case, the pictograms effectively communicate the purpose or meaning of the represented landmarks and enable the map user to match the pictograms to the represented objects in real-world space (Elias & Paelke, 2008; Kiefer et al., 2014). However, there seems to be a tradeoff between communicating purpose or meaning and enabling matching between represented object and representing pictogram. Many landmarks, especially buildings, often do not communicate their purpose or meaning based on their visual characteristics. In these cases, matching between represented object and representing pictogram can be difficult if the pictogram only communicates purpose or meaning of the landmark instead of visual characteristics. People could also mix up two landmarks from the same semantic category if they are located close to each other. If on the other hand the pictogram communicates visual characteristics, it can be difficult to understand the purpose or meaning of the landmark merely based on the representing pictogram. Additionally, as landmarks from the same semantic group can have very different visual characteristics (see Figure 2.4), countless pictograms would be required to account for these visual characteristics.

Figure 2.4. *Semantic grouping of landmarks in maps. Although they can have different visual characteristics, landmarks with a similar purpose or meaning are grouped into the same category and represented in maps with the same pictogram.*

Pictograms representing landmarks in maps can also have a cultural component that may affect the ability of people from specific cultures to interpret the pictograms (Spinillo, 2012). For example, in predominantly Christian countries, medical facilities are usually represented by a red cross. However, in predominantly Muslim countries, these facilities are usually represented by a red half-moon. Therefore, people from predominantly Muslim countries may interpret the red crosses as representing a church or chapel. Cartographers need to consider these cultural effects by designing localized map versions or using pictograms that convey the same meaning to a broad variety of cultures.

As mentioned before, every spatial element with a sufficient spatial permanence can act as a landmark. However, to ensure readability, not every potential landmark can be represented in a map (Ciołkosz-Styk & Styk, 2011). Which landmarks are selected to be represented differs between maps due to the use of different generalization rules. In the past, this selection was made by cartographers as the map designers. However, since the introduction of web mapping services, VGI collected by map users can affect this selection process. Both Google Maps and OSM allow users to contribute landmarks to be represented in the maps. Still, landmark representations in maps are usually limited to objects with a semantic property or function, e.g. commercial venues, public buildings, historical sites or cultural hotspots.

2.3 Landmark Salience

The visual space usually contains many spatial elements. As people cannot perceive and process each of these spatial elements simultaneously, a filter mechanism needs to select spatial elements that (ideally) have the highest relevance and direct visual attention towards these elements (Li, 2002). The allocation of visual attention is affected by top-down and bottom-up processes (Connor, Egeth, & Yantis, 2004; Itti & Koch, 2001; Itti, Koch, & Niebur, 1998). Top-down processes describe goal-directed filter mechanisms. For example, visual search for a specific person in a crowd can be affected by knowledge about the color of the clothes this person is wearing. Bottom-up processes on the other hand are stimulus-driven. The visual cortex of the human brain is sensitive to elements that visually pop out of surrounding elements, for example a red car between multiple black cars. Visual scenes are interpreted in the form of saliency maps that is used to direct visual attention towards the most salient elements (Itti & Koch, 2001).

As mentioned earlier, salience is an essential characteristic of a landmark. Thus, landmarks are more likely to be perceived than surrounding objects (Millonig & Schechtner, 2007; Röser, 2017). As perception is a precondition for the use of landmarks in spatial tasks, salience is also argued to predict the memorability of landmarks and their use as spatial reference points for orientation, navigation and route descriptions (see Figure 1.1, cf. Santangelo, 2015; Stülpnagel & Frankenstein, 2015). Salience levels of spatial elements depend on their visual characteristics, their location relative to a spatial task, as well as their semantic properties. Therefore, three main salience characteristics can be distinguished: visual salience, structural salience and semantic salience (Claramunt & Winter, 2007; Klippel & Winter, 2005).

2.3.1 Visual Salience

The visual salience of an object is defined by its visual characteristics as size, color, texture, spatial orientation, or luminance (Clarke, Elsner, & Rohde, 2013; Davoudian, 2011; Duckham, Winter, & Robinson, 2010; Ishikawa & Montello, 2006; Klippel & Winter, 2005; Li, 2002; Röser, Hamburger, & Knauff, 2011). Visually salient landmarks have been found to be fixated more often (Wenczel, Hepperle, & Stülpnagel, 2017). Thus, visually salient landmarks are argued to attract more visual attention. The direction of visual attention towards visually salient objects is a bottom-up process, because it is purely stimulus-driven (Itti, 2005). Due to the lack of influence of the perceiver on visual salience, visual salience has also been labeled a passive salience (Bestgen, Edler, Kuchinke, & Dickmann, 2017). The mentioned visual characteristics used to predict visual salience must be interpreted within their visual context. A landmark is visually salient relative to its surrounding spatial elements (Claramunt & Winter, 2007; Klippel & Winter, 2005). Thus, an object with specific visual characteristics can be visually salient in one environment, but unremarkable in another environment. For example, a tall building would be highly salient, and therefore a good landmark, if no other tall buildings are located around it. However, if it is surrounded by buildings with a similar height, it might attract less attention (see example in Figure 2.5).

Figure 2.5. *Context dependence of visual salience. The Tokyo Tower, a radio tower inspired by the Eiffel Tower in Paris, is surrounded by the enormous skyline of Tokyo. Its high visual salience is therefore primarily based on its color and unusual shape, rather than its extreme size.*

As mentioned in the previous section, landmarks are often represented in maps as pictograms that do not share the visual characteristics of the represented objects. Instead, they are grouped into semantic categories and represented by a common abstract pictogram. Therefore, the visual salience of landmark representations in maps depends on the design of the abstract pictograms. Both Google Maps and OSM apply color schemes to landmark pictograms based on semantic main categories used to characterize the landmarks (see Figure 2.6). For example, medical facilities are red, gastronomy stores are orange and public transport facilities are blue. By applying different colors to different semantic categories of landmark pictograms, visual salience can be directed to seemingly more important landmarks. Of course, it is important to take into account that the color of a pictogram interacts with the colors of surrounding map elements (cf. Klippel & Winter, 2005). In order to increase visual salience of specific landmarks, colors should be used that contrast the colors of surrounding map elements. Therefore, if specific pictograms are supposed to attract more visual attention, they should have a color that is rarely used for other map elements. In contrast to the coloring, the size, texture and luminance of landmark representations in maps are usually standardized. The size only comprises minimal variations between different pictograms that are based on pictogram design. Therefore, the effects of size, texture and luminance on the visual salience of specific landmark representations can be neglected.

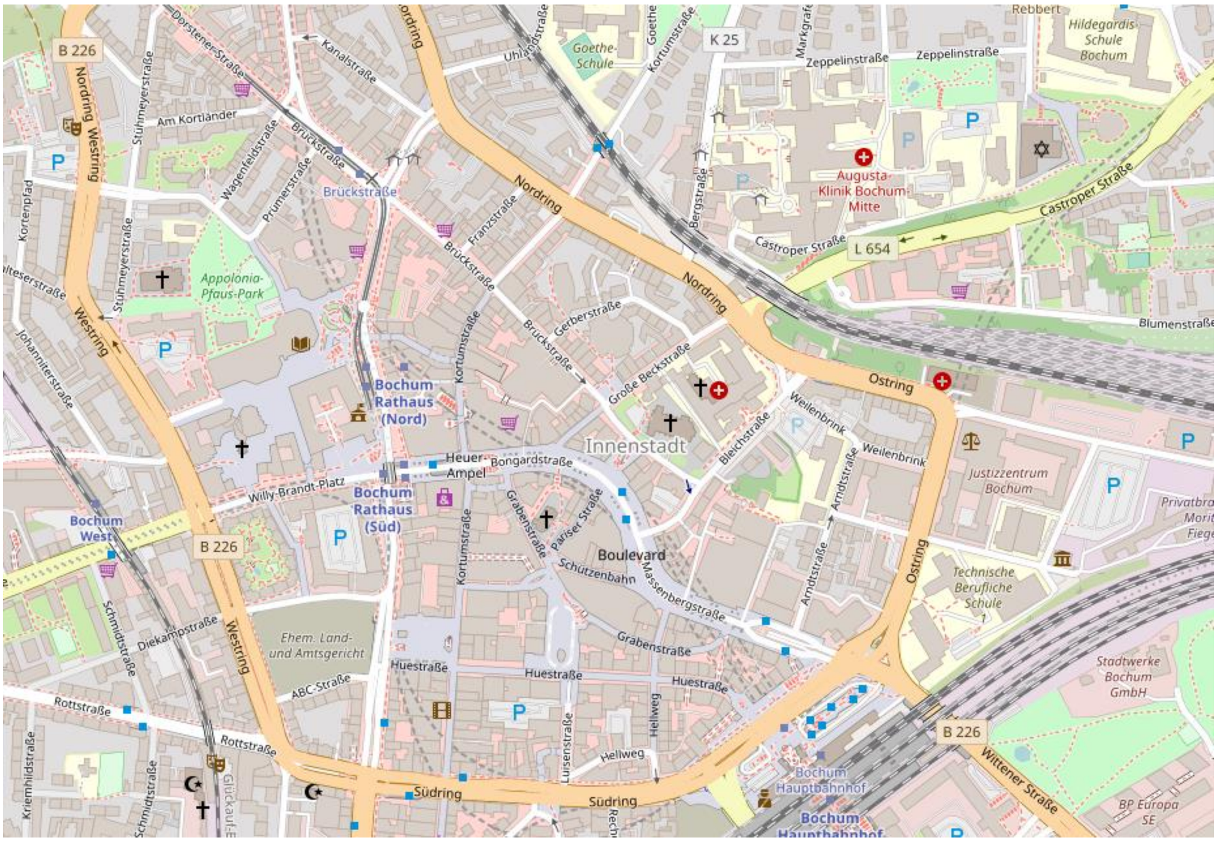

__Figure 2.6.__ Visual salience differences of landmark representations in OSM. Landmark representations are color coded according to their semantic properties. This affects their visual salience. The displayed map was obtained from __OpenStreetMap.org__.

2.3.2 Structural Salience

The structural salience of spatial elements depends on their location relative to a defined route (Klippel & Winter, 2005; Röser et al., 2011). Thus, structural salience is a task-dependent filter for visual attention that is affected by both top-down (individual route selection) and bottom-up (structure of the environment) processes. According to Klippel and Winter (2005), structurally salient landmarks can be easily conceptualized in route directions. As demonstrated by Wenczel et al. (2017), when people try to memorize a route, they intentionally focus on these structurally salient landmarks. Albrecht and Stuelpnagel (2018) found that the availability of structurally salient landmarks improved route memory performance. It has been mentioned earlier that the location of local landmarks can be conceptualized based on their relevance for navigation instructions if they are located *along the route*, *at decision points* or *potential decision points* (see Figure 2.3). The reasoning is that landmarks along the route help to confirm that a route is followed correctly (Michon & Denis, 2001). Landmarks at decision points on the other hand can be used as an indicator that the travel direction needs to be adjusted and landmarks at potential decision points indicate that an adjustment of the travel direction should be avoided (Blades & Medlicott, 1992; Millonig & Schechtner, 2007). Therefore, the distance of spatial elements to the route, decision points and potential decision points is assumed to predict their structural salience and, in consequence, their likelihood to be used as landmarks in route-based spatial tasks (see Figure 2.7, Claramunt & Winter, 2007). Similar to visual salience, the structural salience of a spatial element is interpreted compared to surrounding spatial elements (Claramunt & Winter, 2007). For example, a building can be structurally salient, because it is located closer to a decision point than surrounding buildings. Especially landmarks close to decision points have been argued to play an important role for route descriptions and wayfinding, because they communicate the absolute minimal information required for navigation (Lovelace et al., 1999). Therefore, distance to decision points can be assumed to be the most important predictor for the structural salience of spatial elements. The location of a landmark relative to a decision point can be further specified. Landmarks located at a decision point can either be located in the direction of the turn (e.g. on the right side of the road next to a right turn of the route), or against turning direction (Klippel & Winter, 2005). Landmarks at decision points have been demonstrated to have a higher structural salience if they are located in the direction of a turn (Röser et al., 2012; Röser et al., 2013). Based on an eye movement study, Wenczel et al. (2017) confirmed effects of the mentioned parameters of structural salience on visual attention. Landmarks at decision points and in the direction of a turn were found to be more likely to be fixated.

To what extent the described predictors for structural salience are applicable to landmark representations in maps has still to be investigated. It could be argued that landmark representations close to a displayed or selected route and its (potential) decision points or close to other relevant map locations have a higher structural salience, because they can act as spatial reference points for relevant locations (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Millonig & Schechtner, 2007). Thus, visual attention should not only be directed towards landmark representations close to relevant map locations, the availability of structurally salient landmark representations could also improve memory for these map locations.

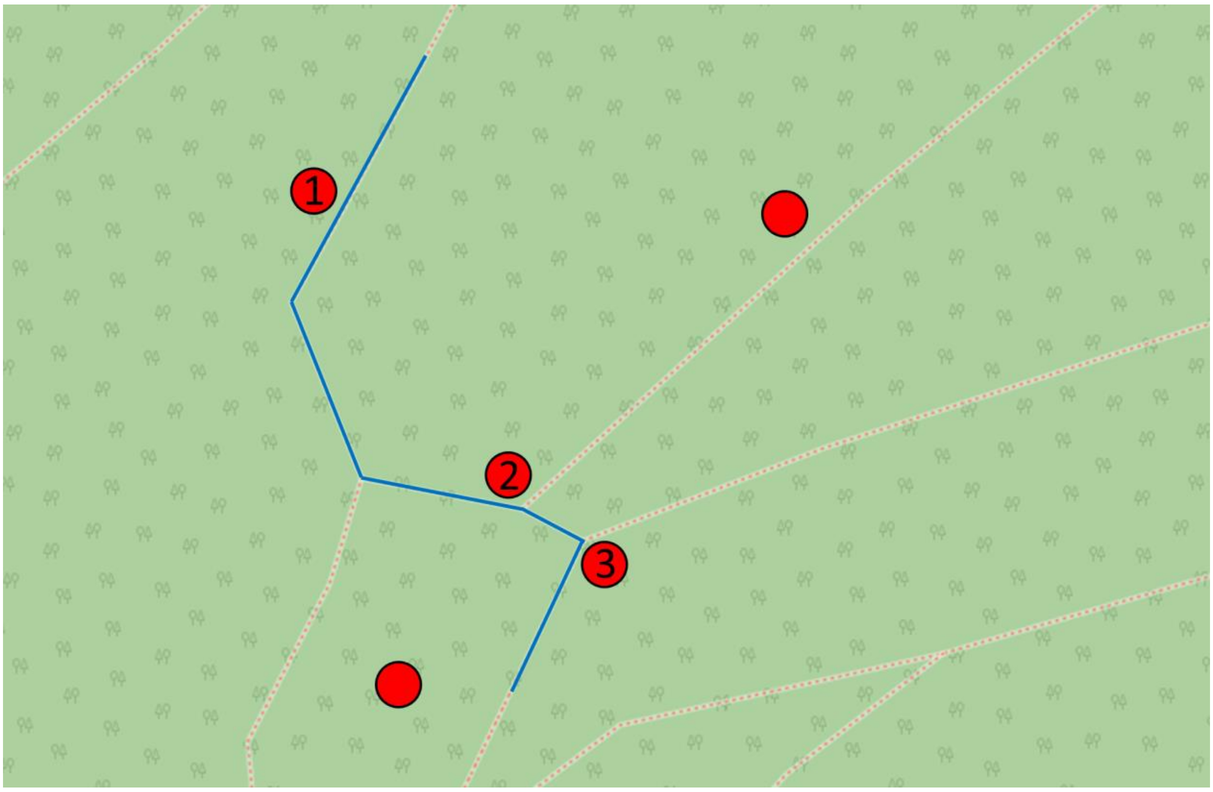

Figure 2.7. *Structural salience of landmarks. The blue line marks a predefined route. The red dots represent landmarks. The landmarks 1, 2, and 3 are assumed to have a high structural salience, because they are located either along the route (1), close to a potential decision point (2), or close to a decision point (3). The background map was obtained from* ***OpenStreetMap.org***.

2.3.3 Semantic Salience

Semantic salience depends on knowledge about a spatial element, as its function or meaning (Dong, Qin, Liao, Liu, & Liu, 2020; Röser et al., 2011). It is a top-down filter directing attention based on knowledge and experience. Spatial elements have a higher salience if the perceiver has more semantic associations with them (see Figure 2.8). As demonstrated by Pilarczyk and Kuniecki (2014), semantic salience can have a strong effect on the direction of visual attention. They found that semantically salient stimuli received more visual attention than visually salient stimuli. This indicates that top-down filters may be more important for the direction of visual attention than bottom-up filters. Similar to other salience characteristics, the semantic salience of a spatial element is assessed relative to surrounding elements (Claramunt & Winter, 2007). Spatial elements are semantically salient if the perceiver has more or thematically different associations with them than with surrounding elements. Earlier theories of semantic salience focus on the general cultural and historical importance of spatial elements (Nothegger, Winter, & Raubal, 2004; Raubal & Winter, 2002). However, this approach neglects the relevance of individual differences in the assignment of semantic salience to spatial elements (Quesnot & Roche, 2015a). Semantic salience depends on individual knowledge, experience, interests and goals (Nuhn & Timpf, 2017). For instance, a culturally highly important building like the Anne Frank House has a low or even no semantic salience if people have no knowledge about its historical context. The relevance of individual experience is emphasized by the finding of Quesnot and Roche (2015b) that locals use more semantically salient landmarks for wayfinding than non-residents. Whether non-residents use semantically salient landmarks for wayfinding is assumed to depend on the popularity of the landmarks (Quesnot & Roche, 2015a). For example, the Empire State Building or the Eiffel Tower are globally famous and it is assumed that many tourists have semantic associations with them.

Figure 2.8. *Semantic salience of landmarks. The semantic salience depends on an individual's knowledge of and associations with a spatial element. Even an inconspicuous location can be a semantically salient landmark for some individuals if they have important associations with it, for example a romantic date.*

As semantically salient landmarks have been found to be important for wayfinding and the allocation of visual attention (Pilarczyk & Kuniecki, 2014; Quesnot & Roche, 2015b), it appears reasonable to use measures of semantic salience for the selection of landmarks to be displayed in maps. However, the mentioned individual differences make it difficult to select the landmarks with the highest semantic salience. Quesnot and Roche (2015a) argue that landmarks being represented in maps already indicates that they are semantically salient, because adding a landmark to a map reflects the contributor's interest in the landmark. This argument may be applicable to VGI-based maps as OSM, because the contributors of VGI data are also map users. However, the interest of a contributor in a landmark need not reflect the interest of all map users. Additionally, it must be considered that design rules can affect which landmarks are displayed in a map (cf. Forrest, 1999). If such design rules limit the choice of contributors which landmarks should be displayed in a map, these rules will also limit a potential effect of semantic salience on the selection of landmarks. Quesnot and Roche (2015a) also propose a selection approach that uses geosocial data. Landmarks that are mentioned more often in social media are assumed to have a higher semantic salience. Although the semantic salience levels assessed based on this approach cannot be generalized to the entirety of potential map users, it expands the assessment from an individual level to a group level.

If specific landmarks are represented in maps based on their semantic salience, the design of the representations also needs to be considered. Similar to visual salience, the semantic salience of landmark representations in maps does not reflect the semantic salience of the represented objects. For example, consider that a church has a high individual semantic salience if a person married in this church. As all churches are usually represented by the same pictogram in a map, this church loses its individual attributes. Therefore, it can be assumed that the map representation of the church has a lower semantic salience that the building itself. According to Röser et al. (2011), the semantic salience of spatial elements can be reflected in the availability of an associated name, as a name is already a semantic property. Thus, the semantic salience of a landmark pictogram in a map may be increased if it is annotated with a name label.

2.4 Mental representations of space

When people perceive space, either directly or represented in maps, they progressively form an internal representation of this space (Millonig & Schechtner, 2007; Montello, Hegarty, Richardson, & Waller, 2004). Such a spatial representation consists of knowledge about object locations and the spatial relations between them (McNamara & Valiquette, 2004; Morris & Parslow, 2004; Tversky, 2003). A commonly used term for such an internal representation of space introduced by Tolman (1948) is the cognitive map. However, according to Tversky (1993), the term map can be misleading, because human spatial memory contains systematic distortions and cannot be used to make metric judgements of distance. (Dickmann, Edler, Bestgen, & Kuchinke, 2013; Foo et al., 2005). Examples of spatial memory distortions are the tendency to memorize the alignment of spatial elements as more horizontal or vertical than they are (Tversky, 1981, 1992), and the tendency to underestimate distances between places inside the same semantic region, e.g. a campus or a market area (Hirtle & Jonides, 1985). However, one must consider that maps can also be distorted. A classic example is the Mercator map projection. By attempting to display the approximately spherical surface of the earth on a flat map, sections of the earth surface are stretched in the map leading to areas close to the poles being displayed disproportionately large (Monmonier, 2004). The intensity of this distortion depends on the map scale. Whereas small-scale maps display larger areas of the earth surface and are strongly affected by the curvature of the earth, distortions in large-scale maps are often negligibly small. Thus, similar to internal spatial representations, the ability to make metric judgements of distance based on maps can be limited. Still, it can be argued that distortions in internal spatial representations are less systematic than distortions in external spatial representations, because the accuracy of internal spatial representations is affected by the completeness of available spatial information (Tversky, 1993). Therefore, in cases where differences of how the spatial structure is distorted in internal and external representations of space need to be stretched, a delimiting term as ‘mental representation of space’ should be used.

Building on the work of Siegel and White (1975), Werner, Krieg-Brückner, Mallot, Schweizer, and Freksa (1997) differentiate between three types of spatial knowledge that reflect how a mental representation of space is gradually developed: landmark knowledge, route knowledge and survey knowledge. Landmark knowledge is knowledge about single spatial elements acting as spatial reference points (Millonig & Schechtner, 2007) and has been argued to be the “first building block for the development of a cognitive map or mental representation” (Bestgen, Edler, Kuchinke, & Dickmann, 2017). Landmark knowledge is not interconnected, but fragmented, similar to a “series of photographs” (Millonig & Schechtner, 2007). By identifying memorized landmarks in the environment, people can orientate themselves and determine their current location without relying on external representations of space (Sorrows & Hirtle, 1999).

The second step in the formation of a mental representation of space is to identify and memorize connections in the form of routes between pairs of landmarks representing a start and target location (Millonig & Schechtner, 2007). Routes consist of a sequence of landmarks that are passed during navigation towards the target location (Wen, Ishikawa, & Sato, 2013; Werner et al., 1997). Acquiring route knowledge is not only important for effective route planning and navigation within space, but also for the formation of a mental representation of space, because routes consolidate locations in a general spatial structure. Through ongoing interaction with an environment, people identify more and more landmarks and routes connecting these landmarks (Millonig & Schechtner, 2007). This growing mental spatial structure of interconnected landmarks can be formalized as a network of nodes and edges connecting these nodes (see Figure 2.9, Werner, Krieg-Brückner, & Herrmann, 2000). Each node represents a memorized landmark and each edge represents a route segment connecting two landmarks. With each edge that is added to the mental model, people become more flexible when they have to select a route between two landmarks, because they can choose between more alternative route segments. Based on personal preferences or specific task requirements, they might for example choose a route that is short, quick, scenic, or leads past specific landmarks on the way.

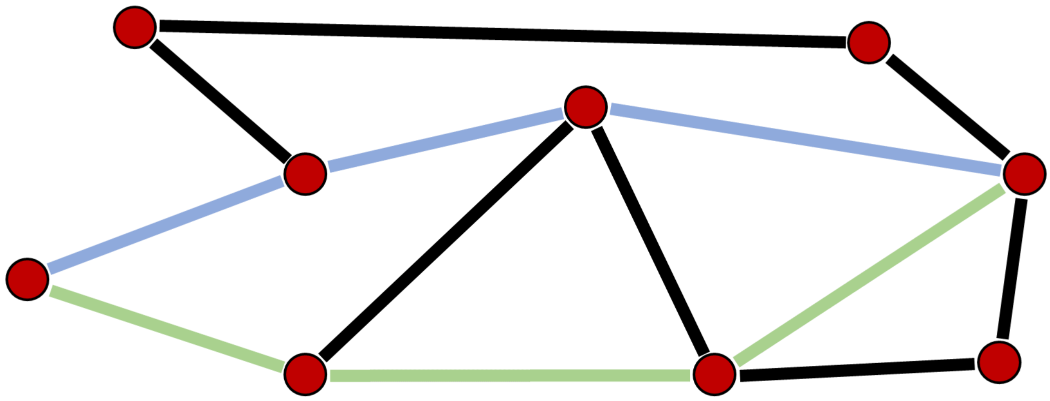

Figure 2.9. *Representation of landmark and route knowledge. According to Werner et al. (2000), the fusion of landmark and route knowledge can be visualized as a network of nodes and edges. The red dots (nodes) represent memorized landmarks used as reference points for locations. The lines connecting pairs of landmarks (edges) represent memorized routes or route segments. The blue and green edges show how alternative routes can be selected if enough edges are added to the mental model. If two nodes are not connected with an edge, a direct route connecting the two represented landmarks either does not exist, or has not been added to the mental model yet.*

Both landmark and route knowledge are egocentric if they are acquired via direct interaction when moving through space (Millonig & Schechtner, 2007). However, via ongoing interaction with an environment, people combine spatial information acquired from different egocentric perspectives into a single spatial model of allocentric survey knowledge (Werner et al., 1997). Such a model may look similar to the network in Figure 2.9. The acquirement of an allocentric perspective of spatial memory enables more flexible route planning and navigation (Edler, Bestgen, Kuchinke, & Dickmann, 2014). This is due to the map-like structure of survey knowledge that provides information about the general spatial structure and can be used to determine the spatial relations and distances between object pairs (Millonig & Schechtner, 2007; Thorndyke & Hayes-Roth, 1982). Knowledge of the general spatial structure even allows to plan routes not yet travelled if the target direction can be inferred (Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006).

Theoretically, it is possible to acquire survey knowledge purely based on spatial information gathered from the egocentric perspective (Meilinger & Vosgerau, 2010). However Thorndyke and Hayes-Roth (1982) argue that this transformation is very difficult, as shown by the fact that people have difficulties drawing geometrically accurate maps of the environments they live in. A more effective way to acquire survey knowledge is by studying maps. Maps often display spatial relations as distances and angles between spatial elements (Izard, O'Donnell, & Spelke, 2014; Kitchin & Blades, 2002; Münzer et al., 2006), usually from an allocentric perspective (Wen et al., 2013). Therefore, opposed to survey knowledge acquired based on egocentric spatial perception, a transformation of perspective is not required. Additionally, as all spatial elements are visible simultaneously, the mental representation of space does not have to be created based on fragmented spatial experiences gathered over time (Kitchin & Blades, 2002). Similar to egocentric spatial information, it is possible to acquire survey knowledge purely based on allocentric map information. This raises the question whether egocentric spatial information is actually necessary for the formation of a mental representation of space, as maps can also provide information about landmark locations and potential routes connecting these landmarks. However, it is important to consider that purely map-based mental representations of space cannot be assumed to be transferred to egocentric spatial tasks as orientation and navigation at no cost. For these tasks, the allocentric information needs to be transformed into the egocentric perspective (Münzer et al., 2006). Without prior egocentric experience with the environment, people will have difficulties to match map representations to the corresponding real-world objects, or to quickly select a route and follow it towards a target location. Thus, maps can support the formation of a mental representation of space, but they cannot completely replace direct and egocentric spatial perception.

Mental representations of space, whether formed based on direct interaction with space, maps, or a combination of both, will always be incomplete (Tversky, 1993). Not only is it impossible to have a complete mental representation of the whole world. It is even unlikely that people know, let alone memorize, every street and every spatial element in their hometown or village. This inability to store unlimited spatial information is addressed by landmark knowledge. As mentioned earlier, landmarks act as reference points for a location and their surroundings (Basiri et al., 2014; Millonig & Schechtner, 2007). Thus, landmarks can be interpreted as an abstraction layer used to reduce the number of spatial elements required to make sense out of space (Sorrows & Hirtle, 1999). For example, instead of memorizing each building in a city, a selection of important landmarks can be memorized. Personal relevance of specific buildings increases their semantic salience and thereby qualifies these buildings as landmarks (Golledge, 1991). Other buildings may be selected as landmarks, because they support orientation and navigation (Klippel & Winter, 2005; Peebles et al., 2007). If these landmarks suffice to make sense out of space and to carry out every day spatial tasks, a ‘complete’ mental representation of space is not required. As landmarks are argued to play such an important role for spatial memory and spatial tasks, it is important that external representations of space such as maps communicate information about landmarks effectively and efficiently. If landmark representations in maps can easily be transferred into the mental representation of space, the future dependency on map information for spatial tasks is assumed to be reduced. Consequentially, maps that communicate information about landmarks more efficiently may become obsolete more quickly, because they can be more easily replaced by a mental representation of space.

2.5 Motivation

In the previous sections, similarities and differences between landmarks and landmark representations in maps have been discussed. It has been argued that landmark representations are usually abstract pictograms and therefore do not share the visual characteristics of the real-world landmarks they represent. Furthermore, as pictograms can contain and convey culture dependent associations (cf. Spinillo, 2012), representing landmarks as pictograms can affect their semantic salience and how they are visually processed, interpreted and used by specific individuals or groups. Based on this assumption, the first study reported in this thesis (chapter 3) assessed to what extent people can assign a meaning to landmark pictograms and how the perceived meaningfulness relates to the attraction of visual attention. In other words, the study investigated whether semantic salience as a means to predict visual attention can be applied to landmark representations in maps. As salience has been argued to also affect object memory (Santangelo, 2015), potential relations between the perceived meaningfulness of landmark pictograms and object memory were also assessed. In addition to the general investigation of the effects of pictogram semantics on visual attention and object memory, the purpose of this study was to sensitize map creators for potential cultural and interpersonal knowledge differences and their effects on map perception and use. Identifying and accounting for these expected differences with dynamic map design could greatly improve spatial knowledge acquisition and the performance in spatial tasks.

Landmarks as particularly salient spatial reference points have been claimed to be highly relevant for spatial memory (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Foo et al., 2005; Sorrows & Hirtle, 1999). In the context of route memory and navigation, the relevance of specific landmarks is argued to depend on structural salience parameters as their location relative to the route and (potential) decision points (Elias & Paelke, 2008; Lovelace et al., 1999, see Figure 2.3). Although previous research did not yet investigate to what extent these parameters of structural salience are applicable to the perception of routes displayed in maps, it seems likely that landmark representations close to the route and (potential) decision points receive more visual attention and support route memory, because they can act as reference points for memorizing route sections (Richter & Winter, 2014). The study reported in chapter 4 aimed to investigate whether these established parameters of structural salience can be applied to routes displayed in a map. The motivation of this study was to deduce the task-relevance of specific landmark pictograms for route-based tasks, because landmarks pictograms that receive less visual attention are assumed to have less effect on spatial memory (see Figure 1.1, cf. Santangelo, 2015).

Despite the reported relevance of real-world landmarks for route memory (Millonig & Schechtner, 2007; Ruddle et al., 2011), it remains unclear to what extent people rely on landmark representations when they memorize a route displayed in a map. Opposed to real-world landmarks, which are selected individually, landmark representations in maps are pre-selected, often based on semantic characteristics. When selecting spatial reference points, map users do not necessarily have to select these semantic landmark representations. Other visually salient map elements as roads, crossroads, buildings or parks may also be useful spatial reference points for their mental representations of space. Furthermore, potential blending of visual and structural salience effects cannot be ruled out. Visually highly salient landmark representations and other map elements offside a displayed route may direct visual attention away from structurally salient map elements that support route memory (cf. Wenczel et al., 2017), resulting in a deterioration of route memory. In order to assess to what extent the distribution of visual attention across the map is affected by the visual salience of map elements with a low semantic salience, the study reported in chapter 4 also manipulated the visual salience of map areas offside a displayed route. In addition to the demonstration of a blending of visual and structural salience effects, this manipulation was also meant to provide a potential solution for such blending effects.

Whereas the study reported in chapter 4 investigated the general distribution of visual attention across maps visualizing routes, the two studies reported in chapter 5 built on this by assessing how landmark representations attract visual attention based on their location relative to a route and its (potential) decision points. Thus, these studies aimed to confirm that, similar to real-world landmarks (Claramunt & Winter, 2007), the structural salience and consequentially the visual attention directed towards landmark representation can be predicted based on the distance of the landmark representation to the route and (potential) decision points. Furthermore, the assumed use of additional map elements as spatial reference points aside from landmark representations was further investigated by manipulating the number of map elements. It was assumed that the availability of more potential spatial reference points would direct visual attention away from specific landmark representations, because some of these potential spatial reference points will have a higher structural salience than specific landmark representations based on their location relative to the displayed route. The number of available map elements may also affect the ability to memorize a displayed route. According to Michon and Denis (2001), landmarks along a route can be used to confirm that a route is followed correctly. Therefore, it can be assumed that landmark representations and other spatial reference points displayed in a map can also be used to memorize and recall fragments of a displayed route. Thus, similar to real-world objects (cf. Albrecht & Stuelpnagel, 2018), the availability of structurally salient map elements could improve route memory. This assumption was tested by comparing route memory performance between maps with manipulated levels of visual detail.

The structural salience of landmarks as spatial reference points is usually defined based on their location relative to a predefined route (Klippel & Winter, 2005; Röser et al., 2011). However, it can be argued that structural salience may also be applicable to the location of objects relative to a single relevant spatial object. For example, people could memorize the location of a building relative to a visually highly salient landmark or a landmark that is already stored in the individual's mental representation of space. If these landmarks attract visual attention based on their relative location, they can be argued to have a high structural salience. The final study reported in this thesis (chapter 6) addressed this by investigating whether specific landmark representations in maps receive more visual attention based on their location relative to a to-be-learned object location. Similar to the previous studies, structural salience parameters as a means to predict the distribution of visual attention across the map and around the to-be-learned object were aimed to be identified. Furthermore, as structurally salient landmarks have been found to be important for spatial memory (Albrecht & Stuelpnagel, 2018), the study investigated whether the availability of structurally salient landmark representations in maps can be related to an improved object location memory performance.

The general purpose of the reported studies was to demonstrate to what extent salience characteristics used to predict visual attention directed towards real-world landmarks can be applied to landmark representations in maps and potentially other map elements. Furthermore, the findings could extend our current understanding of how landmarks are cognitively processed and used to form mental representations of space or perform spatial tasks to 2D representations of landmarks in maps. Based on the findings, cartographers could be supported in the design of task-oriented maps that facilitate the acquirement of accurate spatial memory. If the experiments can demonstrate what characteristics make landmark representations in maps salient, and which spatial elements effectively support the acquisition of spatial memory, cartographers and other map creators could help map users to form more accurate mental representations of space and support spatial tasks by directing visual attention towards map elements relevant for these spatial tasks.

3 Meaningfulness of Landmark Pictograms Reduces Visual Salience and Recognition Performance

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Abstract

Landmarks, objects in the environment used for orientation, navigation and the formation of cognitive maps are often represented in maps as pictograms. In order to support these tasks effectively and efficiently, landmark pictograms also need to be salient, as the map user needs to identify and process them quickly and easily. Two additional relevant characteristics for the usability of landmark pictograms are their meaningfulness and recognition performance. Meaningfulness is required to understand which categories of objects are represented by the pictograms. Ease of recognition prevents the necessity to consult a map repetitively and may support the formation of a cognitive map of the environment. In the present study, we investigated the relation between salience, meaningfulness and recognition performance of OpenStreetMap (OSM) pictograms and the potential effects of the visual complexity of pictograms on these usability characteristics. Salience was measured via eye fixations on specific pictograms, meaningfulness with an explicit continuous scale and recognition performance with a yes/no recognition memory paradigm. Statistical analyses showed that pictograms drew more visual attention if they were visually complex or if their meaning was inapprehensible or ambiguous. Less apprehensible pictograms were also recognized more often. Interestingly, the data indicated that longer fixations could lead to worse recognition performance. Long fixations on a pictogram may increase the likelihood of false recognition in subsequent situations where the pictogram is no longer valid or relevant. Based on the findings, we suggest balancing the meaningfulness and visual complexity of contiguous pictograms to enhance their recognition and to provide an optimal level of salience of single objects.

Keywords

Cognitive Cartography; Empirical Cartography; Spatial Cognition; Volunteered Geographic Information; Landmarks; Pictograms; Salience; Memory; Recognition; Meaningfulness; Cartosemiotics

3.1 Introduction

Navigation and spatial orientation are everyday tasks that are executed in familiar and unfamiliar environments. In order to reach a desired destination, people have to identify their current location and orientation, and to determine a route between their current and target location. When following the route, information about the current location must be updated continuously to identify positions where the travel direction needs to be adjusted (Golledge, 1999a).

When people want to assess their current location, they need to identify the position of landmarks, relative to the surrounding space (Millonig & Schechtner, 2007; Sorrows & Hirtle, 1999). Landmarks are understood as natural or artificial salient objects serving as anchors for their geographic locations (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Klippel & Winter, 2005; Richter, 2013). Examples of landmarks are buildings, statues, crossroads, hills or trees. If people are familiar with their surroundings, they have formed a mental representation of their surroundings, commonly referred to as cognitive map (Montello, 2002). A cognitive map includes locations of landmarks and the relations between them. Although a cognitive map can include spatial distortions (Edler, Bestgen, Kuchinke, & Dickmann, 2015; Tversky, 1993), it can be used to estimate the current location and the directions in navigation and wayfinding tasks by matching visible landmarks in the environment to the landmark representations in the cognitive map (Foo et al., 2005). If several known landmarks are identified successfully, the current position and the viewing direction can be assessed by estimating the distance to these landmarks as well as the angles between them. If people are however unfamiliar with their current location or the area between their current and target location, they need to use external tools representing their environment (Field, O'Brien, & Beale, 2011).

The most traditional navigation tool that has been used for centuries is the analogous map. These maps usually also contain landmarks represented as pictograms. Spinillo (2012) defines pictograms as “graphic representations of concepts through visual synthesis, used to communicate messages to broad audiences” (p. 3398). When being used in maps as landmark representations, pictograms assist orientation and navigation (Elias & Paelke, 2008; May et al., 2003). To be successful in map-based orientation and navigation tasks, people need to identify the current as well as the target location on the map. Identifying the target location is often supported by a road index specifying the grid position of each road displayed on the map. Identification of the current position can be achieved by identifying landmarks in the surrounding area and recognizing their respective pictograms (usually point symbols) in the map. As soon as the current and target location are identified on the map, a route connecting those two locations needs to be selected. To follow the chosen route, the map user needs to continuously compare the position of landmarks to the position of the respective landmark and in the map (Golledge, 1999a). So far, landmark pictogram design has not been based on the visual characteristics of the object represented but on predefined design standards linked to the function of the object (Elias & Paelke, 2008). In other words, cartographers often transfer their individual associations to map design by representing an object with a specific image ("pars pro toto"). This can make it difficult for map users to interpret landmarks and to match them with their representations if they are not familiar with the representing pictogram, if the function or characterization of the object is not visually apparent, or if the pictogram is poorly designed (Elias & Paelke, 2008). The ability to understand what a symbol represents is referred to as meaningfulness (Collins & Lerner, 1982; Vukelich & Whitaker, 1993). Landmark pictograms could either be meaningful and easily interpretable or less meaningful and difficult to interpret. Another factor influencing the usability of landmark pictograms is their salience. Salience defines the likelihood of an object to draw a person's visual attention (Caduff & Timpf, 2008). Differences between visual, structural and semantic salience have been suggested (Quesnot & Roche, 2015a). Visual salience, also referred to as passive salience, describes objective attributes, such as color and structure of an object, compared to its surrounding (Bestgen, Edler, Kuchinke, & Dickmann, 2017). Structural salience is defined by an object position relative to a specific route (Klippel & Winter, 2005), thus relative to the context provided by the map. Semantic salience is defined by associations with an object, like memories or personal importance (Duckham et al., 2010). If the concepts of salience are used to evaluate landmark pictograms instead of the represented objects, it is important to consider that the relevance of specific map elements depends on the subjective case of application. Different orientation or navigation tasks may require the use of different landmarks. Therefore, it may be reasonable to keep the visual salience of all landmark pictograms used in a map at a comparable level. If a map element, which is required for an orientation or navigation task, has a very low visual salience, it may be overlooked. However, if map elements that are not suitable for these tasks have a very high visual salience, these elements may distract the user from actually useful elements just like a colorful banner ad on a website might distract users from its relevant content (Burke, Hornof, Nilsen, & Gorman, 2005). In contrast to visual salience, semantic and structural salience depend on the user and use case. Therefore, even though they affect the total salience of an object, they cannot be optimized in general but only for specific scenarios.

A third factor that may potentially affect the usability of landmark pictograms is their memorability or recognition performance. Landmark pictograms should be easy to recognize in order to prevent users from quickly forgetting what pictograms they have identified in a map. This could enhance the process of reading a map in an orientation or navigation task. Direct recognition of pictograms could also reduce the time needed to capture their meaning. If a visual stimulus is familiar, it may be used as a cue that links its perception directly to an association or action (Frutiger, 1981; Rasmussen, 1983). This would allow the perceiver to skip the task of conscious interpretation of a pictogram. Haber and Myers (1982) showed that, compared to word and picture stimuli, people can recognize pictograms relatively accurately. However, there may be differences in memorability between different pictograms. According to Snodgrass and Vanderwart (1980), the complexity of a visual stimulus can affect the likelihood of its recognition. Additionally, recognition performance of pictograms may be influenced by their meaningfulness. According to Franzwa (1973) and Koen (1969), recognition performance is better for pictures with high meaningfulness. In contrast to this, Baldwin and Runkle (1967), who compared meaningfulness and recognition performance of six symbols, found that the symbol with the lowest meaningfulness showed the best recognition performance. If the meaningfulness and recognition performance of landmark pictograms were positively related, it would be recommendable to use highly meaningful pictograms. However, if they were negatively related, this would imply a tradeoff between these two characteristics. In this case, a balance between meaningfulness and recognition performance would be required.

With the spread of smartphones and the expansion of mobile internet availability, the use of analogous maps and navigation systems have been more and more replaced by free web mapping services like Google Maps. These applications allow automatic localization and route planning. However, they also enable users to inspect the broad environment with its landmarks and road structure to perform orientation and route planning tasks manually. This could support the adequate formation of a cognitive map of the environment. A second innovation stimulated by smartphones and mobile internet was the collection of volunteered geographic information (VGI), which is geodata collected and shared by a community of volunteering mappers (Goodchild, 2007). The most popular example is OpenStreetMap (OSM), a freely available, editable and user generated world map. Like analogous complements, the OSM project also involves landmark pictograms. These pictograms have to meet the same demands as their analogous counterparts: they need to be easily interpretable, memorable and salient.

The study presented in this paper is intended to examine the relationships between usability characteristics of OSM landmark pictograms. In this paper, usability is defined as the ability to perceive elements quickly and easily (visual salience), to understand the meaning of the elements (meaningfulness), and to remember the perceived elements (recognition). Additionally, potential effects of visual complexity on these usability characteristics are examined. If relations between the investigated pictogram characteristics could be identified, the findings might not only help to optimize the design of landmark pictograms in maps but also of pictograms from other domains, based on their visual salience, recognition and meaningfulness requirements.

3.2 Methods

The study was controlled and approved by the ethics committee of the Faculty of Geosciences at the Ruhr-University Bochum.

3.2.1 Participants

Twenty-eight students (18 males and 10 females) of the Ruhr- University Bochum participated in the experiment for pay (10 €). The mean age was 21.8 years, with a range between 19 and 31 years. Preconditions for participation were a normal or corrected vision, and the absence of neurological or psychiatric diseases.

3.2.2 Research Design

The experiment consisted of two parts. The first part measured recognition memory performance and visual salience differences between the landmark pictograms. The second part assessed the meaningfulness of the pictograms. In both parts of the experiment, the same stimuli were shown to each participant but the order of presentation was randomized between participants.

3.2.3 Measures/Materials

All landmark pictograms were taken from the pictogram repository of OpenStreetMap (OSM). After exclusion of the pictograms representing surface areas (e.g. forest, meadow or beach), which may only be used as landmarks if they are spatially confined enough to clearly define a specific location, 153 landmark pictograms remained. To avoid salience effects caused by color differences, all pictograms were colored black (R: 0, G: 0, B: 0).

3.2.3.1 Visual Salience and Recognition Memory

A method commonly used to assess salience based on visual attention is eye-tracking. Higher numbers and long durations of eye-fixations on a target object indicate that visual attention is targeted at the respective object (Foulsham & Underwood, 2007; Holmqvist et al., 2011; Loftus & Mackworth, 1978). They were also found to be positively related to a deeper cognitive processing of the target object (Just & Carpenter, 1976; Rayner, 2009). Additionally, studies demonstrated that salient objects in a scene are fixated earlier (Foulsham & Underwood, 2007; Parkhurst, Law, & Niebur, 2002). Therefore, the quantitative eye-tracking measures total fixation duration, mean fixation duration and time to first fixation were chosen to measure visual salience of landmark pictograms. They were assessed with a Tobii TX-300 (300 Hz, 23 inches) eye-tracker. To compare fixation durations and time to first fixation between the different OSM landmark pictograms, 39 stimulus images containing 12 of the 153 pictograms (three rows, four columns) were designed (for an example of such a 12-item-image see Figure 3.1). The number of 12 items per stimulus image was selected to ensure that participants could not memorize all pictograms in a stimulus image, as this would eliminate the possibility of comparing recognition performance between pictograms. According to G. A. Miller (1956), the human working memory (originally called immediate memory) has a capacity of 7 ± 2 items or chunks (meaningful units of items). Cowan, Morey, and Chen (2007) argued that working memory capacity may be lower than 7 items if no new chunks are formed between the items or chunks. However, formation of pictogram chunks, for example in the form of a story connecting the meaning of pictograms, could not be ruled out. To prevent that all items can be transferred to long term memory, we decided to present sufficient concurrent items to exceed working memory capacity even if chunking effects occurred. Each of the pictograms was shown in at least three images with no pictogram being shown more than once in one image. As the division of 153 by 12 leaves a remainder, nine pictograms were shown in four 12-item-images.

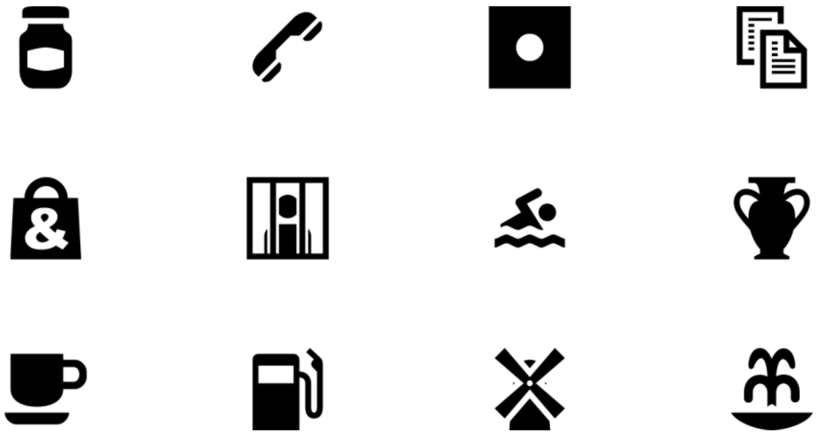

Figure 3.1. *Example of a stimulus image with OSM landmark pictograms. [Thirty-nine stimulus images, each containing 12 OSM landmark pictograms were created to compare their visual salience.]*.

Recognition memory performance was measured using a yes/no recognition paradigm. The already mentioned 12-item-images (Figure 3.1) were used as stimuli for the study phase. For the recognition phase, 24 single pictogram images were created for each of the 39 study phase stimuli. Twelve of these pictograms were also displayed in the corresponding 12-item-image (old stimuli), the other twelve were not (new stimuli). In order to prevent primacy or recency effects, the psychological phenomena describing that people can remember the first and last stimuli in a row better than the ones in the middle (Murdock, 1962; Neath, 1993), pictogram positions in the 12-item-images were partially randomized. Each pictogram was shown in each of the three pictogram rows at least once. To be able to control for potential confounding effects of visual complexity on pictogram recognition, complexity differences between the pictograms were retrieved from the image file size (JPEG file format) as an additional measure. The JPEG file format has been shown to correlate highly with user ratings of image complexity (Donderi & McFadden, 2005; Stickel, Ebner, & Holzinger, 2010). As mentioned earlier, map context and personal associations with an object also affect its salience (structural and semantic salience). However, the randomization of object positions and the generalization across participants allowed us to focus only on visual salience.

3.2.3.2 Meaningfulness

Landmark pictograms in maps do not only serve as local cues for orientation and navigation. They may also aid map users in identifying locations with a specific function (Sorrows & Hirtle, 1999) like the closest gas station or restaurant. Therefore, an explicit understanding is required to find locations on the map that are related to a specific function. If a map user cannot unambiguously interpret the meaning of a landmark pictogram, successful matching of the pictogram with the represented object in the environment is difficult or even impossible. Consequently, landmark pictogram meaningfulness was assessed with an explicit measure, a continuous Visual Analogue Scale (VAS) with a range from zero ("meaning completely unknown") to one ("meaning unambiguous"). The middle area of the scale represented ambiguity. This area was to be selected when a pictogram could represent several objects or if participants were not certain that they interpreted a pictogram correctly. VAS have been shown to correlate highly with frequently used numeric self-rating scales (DeLoach, Higgins, Caplan, & Stiff, 1998; Phan et al., 2012). However, compared to numeric scales, they are more sensitive to response differences (Joyce, Zutshi, Hrubes, & Mason, 1975).

3.2.4 Procedure

3.2.4.1 Part 1: Recognition Paradigm

Knowledge of the purpose of a study and the experimenter's hypotheses can affect the participant's behavior (Adair & Schachter, 1972; Sigall, Aronson, & van Hoose, 1970). Therefore, the participants were not provided with information about the study purpose before they finished the experiment. Before the start of the experiment, participants gave written informed consent. The experimenter told them that detailed information concerning the study purpose would be revealed after the experiment. They were seated in front of a computer with the eye tracker monitor and asked to sit comfortably, as they should not change their head position during the experiment.

The first part of the experiment, the recognition task, consisted of one practice trial followed by 39 experimental trials including a study and a recognition phase. Each study trial began with the presentation of one of the prepared 12-item-images containing 12 landmark pictograms (see example in Figure 3.1) for 20 s. Participants were requested to memorize as many of the landmark pictograms as possible. The stimulus images were followed by a filler task image, also shown for 20 s. These images contained a crowded scene. Participants were asked to find a specific person in the image. Hereafter, during the recognition phase of this trial, 24 OSM landmark pictograms were presented consecutively one at a time. The presentation order of these pictograms was randomized. For each pictogram, participants needed to indicate whether it was part of the previous stimulus image. They gave their responses by pressing one of two keyboard buttons redesigned with “yes” and “no” labels.

3.2.4.2 Part 2: Meaningfulness Rating

The second part of the experiment was also carried out on a computer display but no eye-tracking data was recorded in order to minimize the amount of junk data. During this part, all 153 pictograms were shown to the participants successively, each together with a continuous VAS rating scale ranging from zero to one. Using the mouse cursor, participants chose a meaningfulness value on the scale. This value corresponded to the currently shown pictogram. Participants had to click on a button below the scale to confirm their input and to continue to the next pictogram.

3.2.5 Statistics

Based on the signal detection theory (Nevin, 1969), the responses in the recognition paradigm were rated according to their correctness as hits, misses, false alarms or correct rejections (see also Bestgen, Edler, Müller, et al., 2017). As each scoring of a hit was simultaneously scored as the absence of a miss, and each false alarm was simultaneously scored as the absence of a correct rejection, these two pairs naturally had to be perfectly negatively correlated. Because of this redundancy, only the misses and false alarms are reported in the following sections. The distinction between misses and false alarms is commonly used in recognition experiments (e.g. Berry, Shanks, Speekenbrink, & Henson, 2012; Schacter, Buckner, Koutstaal, Dale, & Rosen, 1997; Snodgrass & Corwin, 1988; Wilding & Rugg, 1996), as it allows to differentiate between different processes leading to false responses. While misses may be interpreted as forgetting of the stimulus, false alarms indicate mix-ups of stimuli, recognition of stimuli from previous (and no longer valid) trials, or general familiarity with the stimulus (Lewis, 1997). Additionally, d’ values were calculated based on the hits, misses, correct rejections and false alarms. These values reflect the relative proportion of correct (hits and correct rejections) and incorrect responses (misses and false alarms). In other words, d’ represents the signal strength (Nevin, 1969), the participant's ability to discriminate a learned stimulus from a distractor stimulus. The selected visual salience measures total fixation duration, mean fixation duration and time to first fixation were calculated per participant and pictogram during the 20 s study phase intervals. The results from the meaningfulness rating were used to calculate the average meaningfulness value for each of the 153 OSM landmark pictograms. The pictograms were then sorted according to these meaningfulness values. For the following analyses, all values were aggregated across all participants to generate one mean score per pictogram for each measure. This allowed to compare meaningfulness, visual complexity, visual salience and recognition memory performance between pictograms at the item level. Correlation coefficients were assessed between meaningfulness, visual complexity, the visual salience measures (fixation durations and time to first fixation), and the recognition memory performance measures. Given that the nature of memory performance measures implies a perfect negative correlation between the hits and misses, as well as between the correct rejections and false alarms, only the misses and false alarms were investigated. As not all measurements were normally distributed, the Spearman correlation measure was selected.

3.3 Results

Significant negative correlations were found between meaningfulness and the visual salience measures mean fixation duration ($r_s(151) = -0.263$, $p=.001$) and total fixation duration ($r_s(151) = -0.270$, $p < .001$). Total fixation duration was also negatively correlated to the time to first fixation ($r_s(151) = -0.247$, $p = .002$). No significant correlations were identified between the visual complexity and the recognition measures. However, a significant correlation was found between the visual complexity and the total fixation duration ($r_s(151) = 0.237$, $p = .003$). The correlation between the visual complexity and the time to first fixation was not significant ($r_s(151) = -0.136$, $p = .093$). The meaningfulness of pictograms was positively correlated to the ratio of misses ($r_s(151) = 0.367$, $p < .001$) and negatively correlated to the d' values ($r_s(151) = -0.254$, $p = .002$) in the recognition task. Figure 3.2 shows a scatterplot of pictogram meaningfulness and the miss rate, which illustrates that the mean and variance of the misses was higher for meaningful pictograms. The positive correlation between the total fixation duration and the false alarms marginally failed to fall below the significance level of 0.05 ($r_s(151) = 0.153$, $p = .066$) (Table 3.1).

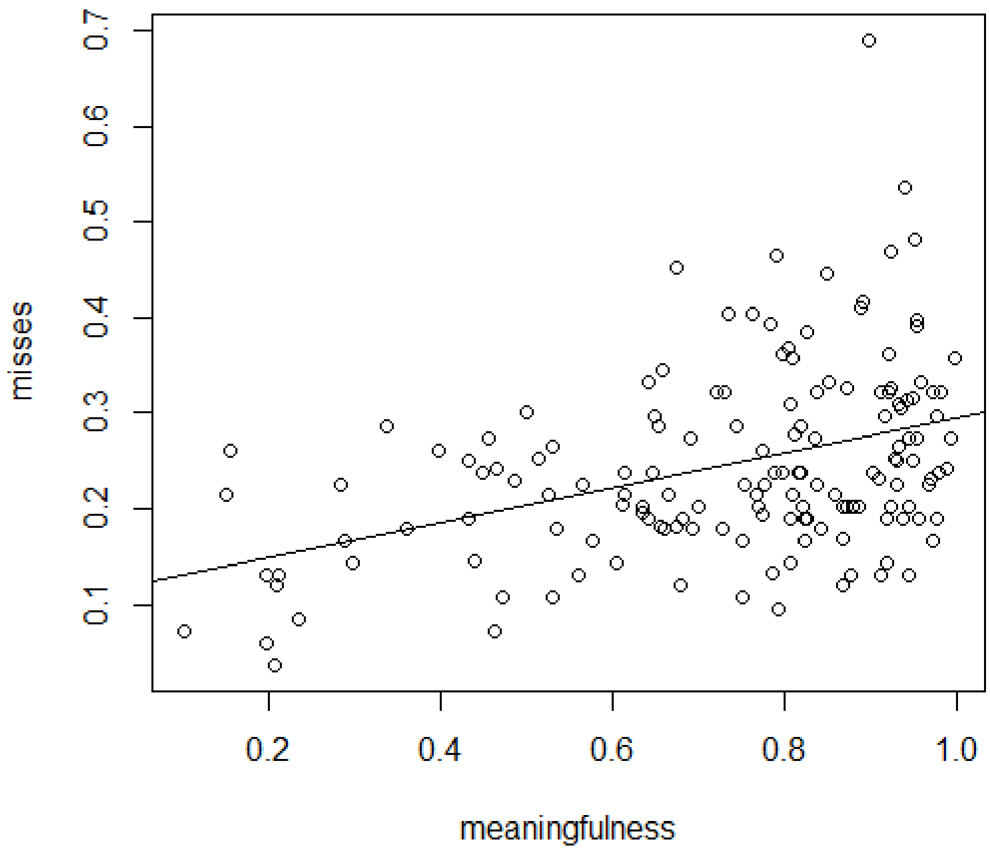

Figure 3.2. *Relation between meaningfulness and misses in the recognition task. [The scatterplot shows that meaningful pictograms were missed more often in the recognition task than less meaningful pictograms ($r_s(151) = 0.367, p < .001$).].*

Table 3.1. *Spearman correlations between the measures for visual complexity, meaningfulness, visual salience and recognition performance.*

Variable	1	2	3	4	5	6	7
1. Visual complexity							
2. Meaningfulness	.061						
3. Total fixation duration	.237**	-.27***					
4. Mean fixation duration	.031	-.263**	.187*				
5. Time to first fixation	-.136	-.1	-.247**	.154			
6. Misses	-.095	.367***	-.112	-.092	.147		
7. False alarms	.014	-.038	.153	-.058	-.047	-.07	
8. d’	-.018	-.254**	-.068	.053	-.035	-.478***	-.661***

*p < .05, **p < .01. ***p < .001

3.4 Discussion

The results show that when multiple pictograms are visible at the same time, people tend to look longer at pictograms with higher visual complexity and lower meaningfulness. Taken together, this indicates that pictograms are more visually salient and therefore attract more attention if they have many visual details and their meaning is ambiguous or inapprehensible. People are also less likely to miss pictograms or to confound learned stimuli with distractor stimuli if their meaning is less explicit. Our findings fit those of Corbetta and Shulman (2002) that unexpected stimuli can distract from other stimuli. They also match other studies (Walther, Rutishauser, Koch, & Perona, 2004, 2005) showing that selective attention increases recognition performance, as less meaningful pictograms were both looked at and recognized more often. That no direct relation between the visual salience and the recognition performance was found in our experiment can be explained by the fact that other pictogram characteristics affect either the visual salience or the recognition performance but not both. An example is the pictogram complexity. That visually complex pictograms were fixated more often did not affect their recognition performance. It seems that the increased visual salience did not outweigh the difficulty to memorize a more complex stimulus. Although the relation between fixation duration and false alarms narrowly missed the selected significance level, the data suggests that pictograms, which were fixated longer, were also more likely to produce false alarms in trials where they were not shown in the 12-item-image during the study phase. As each pictogram was shown multiple times during the study phase and the recognition phase, participants had to suppress the memory of items from earlier trials. Apparently, it was more difficult to suppress the memory of a pictogram after it lost its relevance if it had a high visual salience. However, to verify this conclusion, larger sample sizes would be needed to assess whether significant results of the relation between fixation duration and false alarms can be achieved.

That highly meaningful pictograms were missed more often contradicts the findings of Franzwa (1973) and Koen (1969) but it fits to the findings of Baldwin and Runkle (1967). This may be explained by the fact that Franzwa (1973) and Koen (1969) investigated recognition of complex paintings while Baldwin and Runkle (1967) assessed recognition of minimalistic pictograms. Additional research could unveil whether stimulus detail acts as a moderator variable for the relation between meaningfulness and recognition performance. Given that total and mean fixation duration negatively correlated with the meaningfulness of pictograms, one may conclude that fixation duration does not represent visual salience but that participants merely needed more time to memorize ambiguous pictograms. Additionally, Parkhurst et al. (2002)

argue that effects of salience on eye movement behavior are strongest directly after stimulus onset. This means that later fixations may be less representative for salience. However, the data is in accordance with Foulsham and Underwood (2007), who report that later fixations are still partially affected by visual salience. Based on these findings and the fact that pictograms with larger fixation duration values were also fixated earlier, we are confident that fixation duration was indeed a valid measure for visual salience in our experiment design.

3.4.1 Design Implications

The findings could tempt cartographers to favor the use of pictograms with low meaningfulness and high visual complexity, as map users would be more likely to recognize them. However, it is important to consider that the users will have great difficulties to match map pictograms with low meaningfulness to their surroundings, as they do not understand what they represent. Maximizing visual salience also incorporates the risk that map users are distracted by perceiving only specific map elements, as cognitive control would be necessary to ignore the highly salient pictograms (Lavie, 2005; Tipper & Driver, 1988). This may reduce the efficiency of orientation or navigation tasks, as distractor objects could slow down an orientation or navigation task for several seconds (Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991). Therefore, visual complexity and meaningfulness of pictograms in maps should be kept on a similar and moderate level to ensure similar levels of visual salience. Additional research could unveil how the visual salience of pictograms interacts with map characteristics as density, scale and color contrast. However, map use is not the only task where people are confronted with multiple pictograms that may try to grasp the attention of the user. Pictograms are, for example, commonly used as button labels in graphical user interfaces of computer programs, as representations of laundry instructions, or as traffic and warning signs. Different usage scenarios of pictograms can call for different levels of visual salience, meaningfulness and recognition performance. While warning signs need to be highly salient and interpretable to draw the user's attention, graphical user interfaces should balance visual salience, meaningfulness and recognition performance between pictograms to prevent that some buttons and their underlying functions are missed. Figure 3.3 shows the five landmark pictograms with the lowest meaningfulness scores, as well as the five pictograms with the highest meaningfulness scores. One may try to guess the meaning of the upper five pictograms.

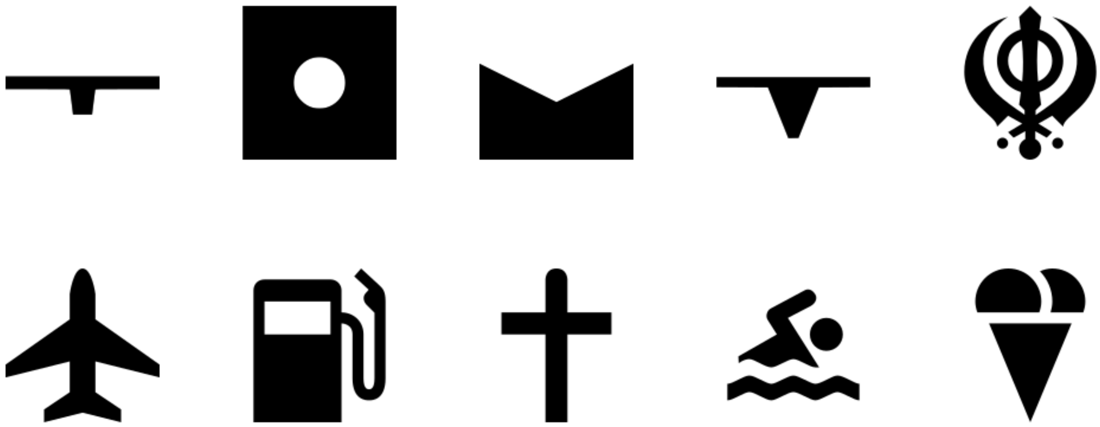

Figure 3.3. *OSM landmark pictograms with the lowest and highest meaningfulness. [The top row contains five of the OSM landmark pictograms with the lowest meaningfulness scores. From left to right: embankment, power tower (transmission tower), saddle (landform), cliff, and Sikh temple. Participants were not able to derive a meaning from these pictograms. In the bottom row are five of the landmarks with the highest meaningfulness scores. From left to right: aerodrome, gas station, church, swimming pool and ice cream parlor. The meanings of these pictograms were unambiguous for the participants.].*

3.4.2 Conclusions

With the present study, we aimed to unveil the relations between pictogram meaningfulness, visual complexity, visual salience and recognition performance. We were able to show that the visual complexity and meaningfulness of pictograms influence their visual salience and recognition performance. Based on the requirements of a pictogram, different levels of meaningfulness and visual complexity need to be selected to achieve the desired levels of visual salience and recognition performance, and therefore to accentuate single pictograms or, in contrast, to prevent such accentuation.

4 Reduction of Map Information Regulates Visual Attention without Affecting Route Recognition Performance

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Abstract

Map-based navigation is a diverse task that stands in contradiction to the goal of completeness of web mapping services. As each navigation task is different, it also requires and can dispense with different map information to support effective and efficient wayfinding. Task-oriented reduction of the elements displayed in a map may therefore support navigation. In order to investigate effects of map reduction on route recognition and visual attention towards specific map elements, we created maps in which areas offside an inserted route were displayed as transparent. In a route memory experiment, where participants had to memorize routes and match them to routes displayed in following stimuli, these maps were compared to unmodified maps. Eye movement analyses revealed that in the reduced maps, areas offside the route were fixated less often. Route recognition performance was not affected by the map reduction. Our results indicate that task-oriented map reduction may direct visual attention towards relevant map elements at no cost for route recognition.

Keywords

Cognitive Cartography; Empirical Cartography; Spatial Cognition; Volunteered Geographic Information; Landmarks; Map Pictograms; Route Memory; Recognition; Story Telling

4.1 Introduction

In today's world, human life is accompanied by high mobility. Traveling to unfamiliar regions has become simple and cheap, increasing the need for navigation in unfamiliar environments. Geographic information in the form of maps or navigation systems is thus of increasing importance. Modern web mapping services such as OpenStreetMap, an example of Volunteered Geographic Information (VGI) (Mocnik, Zipf, & Raifer, 2017), and Google Maps provide fairly accurate geographic information at no cost (Cipeluch, Jacob, & Winstanley, 2010; Haklay, 2010). In the era of smartphones and mobile internet, these map distributers can be used virtually everywhere. Additionally, navigation apps can support wayfinding in unfamiliar environments.

Besides navigation, maps are often used for telling stories. Television, films, social media, travelogues, newspapers, and audio books are ubiquitous examples of media used for conveying stories, demonstrating their high social relevance. As stories often have a spatial component—things exist and happen in space—maps can be used for this purpose. Today, maps can easily be extended with other valuable media, such as texts, audio, and video (Brauen, 2014; Peterson, 2007; Taylor & Lauriault, 2007). This helps to widen the number of map genres and to adapt the needs of a spatial story (Mocnik & Fairbairn, 2018).

In both cases—navigation and storytelling—it can be advantageous to focus on the essential information. Many maps, especially topographic maps, are task-independent. Such maps are created to represent the real environment in a most complete way. Thus, they display all information that complies with the categories provided in the legend or an ontology. As an example, one expects a city map to contain all streets in the depicted area. Such information might, however, be irrelevant to the user when performing a certain task. Leaving out unneeded information can have several consequences. One might assume that reduced maps which do not display all information provide fewer distractions when navigating. Also, the user of a reduced map might get an impression that the map is, in fact, incomplete. As a consequence, the user develops an open-world assumption. Assuming gaps or errors in the map opens the possibility of more flexible use and might aid the map user when telling a story or being confronted with inaccurate map information. Despite of the assumed usefulness of reduced maps, potential positive or negative consequences have only been examined in part so far (Meilinger, Hölscher, Büchner, & Brösamle, 2006; Mocnik & Fairbairn, 2018).

In this article, we examine in which way the absence of information in a map used for a navigation task influences our cognition. A reduced map provides less information that distracts the user, but also less information that provides context to the relevant parts of the map. We focus on the following two research questions.

RQ1. Does the reduction of map elements towards only the informative parts of the map affect route memory?

RQ2. Does the reduction of the represented content of a map shift visual attention towards a displayed route?

For answering these questions, participants were asked to memorize a route in a reduced map. Thereafter, it was tested how well the participants performed at recognizing the shape of the route. These results were set into context by a comparison to recognition performance when using a conventional nonreduced map.

4.2 Background

Both digital maps and navigation systems enclose a tradeoff based on their design. As mentioned before, maps are usually task-independent and strive for completeness. Additionally, they allow users to obtain survey knowledge of their surroundings (Thorndyke & Hayes-Roth, 1982). However, they also contain a lot of information that is irrelevant for specific navigation tasks. Studies have shown that the degree of visual complexity in a map affects performance in map-based memory tasks (Edler, Bestgen, et al., 2014; Edler, Dickmann, Bestgen, & Kuchinke, 2014; Kuchinke, Dickmann, Edler, Bordewieck, & Bestgen, 2016). While Kuchinke et al. (2016) showed that topographic detail improved recognition performance of object locations in maps, Edler, Bestgen, et al.; Edler, Dickmann, et al.; Edler, Keil, Bestgen, Kuchinke, and Dickmann (2014; 2014; 2018) found that improvements of memory performance based on the presentation of additional map elements become less noticeable at exceedingly high levels of map complexity. Given that visual complexity of stimuli can increase the cognitive load of the perceiver (Lee, Plass, & Homer, 2006), existence of a tipping point can be presumed where the amount of displayed information is no longer helpful for map-based memory tasks and distracts from relevant visual elements. Navigation apps on the other hand are highly task-oriented and, as usual for location-based services (LBS), the displayed content depends on the context (current position). They support efficient wayfinding in unfamiliar environments, but they usually visualize only a narrow area around the position of the user. This can impair orientation and route memory, as distant global landmarks are not displayed (Ishikawa, Fujiwara, Imai, &

Okabe, 2008). Additionally, the lack of active interaction with the environment prevents the acquisition of spatial knowledge about the environment (Parush, Ahuvia-Pick, & Erev, 2007). An ideal navigation aid would therefore combine the strengths of digital maps and navigation systems—fast and efficient wayfinding, limited cognitive load, focus on relevant map elements, and a survey view of the environment that supports the formation of survey knowledge (Münzer et al., 2006; Thorndyke & Hayes-Roth, 1982).

In our experiment, we examine the use of reduced maps adapted to specific use cases in order to overcome the tradeoffs of maps and navigation systems in wayfinding tasks. When people want to communicate a route without external aids, they often use sketch maps, hand-drawn maps that show the whole route at once, but leave out most peripheral elements shown in a "classical" map. They are usually incomplete (Blaser, 2000; Wang & Li, 2013; Wang & Schwering, 2009), i.e., they only contain roads and road sections alongside the route, and landmarks at decision points (Tversky & Lee, 1999). Such sketch maps are a graphical representation of the task-oriented cognitive map of their creators (Billinghurst & Weghorst, 1995). These sketch maps seem to be perfectly reduced to tell the story of how to follow the route to aid route learning and navigation. Therefore, reducing maps based on sketch map pattern may improve route memory performance.

Based on this assumption, we investigate the possibility to limit the complexity of maps and the consequential effects on cognitive load. The common cartographic approach for reducing map complexity is generalization. Generalization describes the process of simplifying boundaries of map elements and removing seemingly less relevant elements (Robinson, 1953). However, map users may not recognize task-oriented map generalization instantly, certainly not what elements have been removed. Consequentially, an open-world assumption will not be generated before the map user is confronted with a confusing mismatch of the current position and its map representation, e.g., if a small road is not displayed in the map. Therefore, we apply a different approach by displaying areas offside of the route transparent. Given that visual attention is affected by the transparency of stimuli (Colby & Scholl, 1991), transparent areas offside the route could shift the visual attention of the user towards relevant map elements, namely the area around the route, while a nongeneralized survey view of the environment is still available. Eye fixations are reported to indicate visual attention and are therefore commonly used to assess visual attention towards specific stimulus areas (Just & Carpenter, 1976; Liu & Heynderickx, 2011; Tsai, Hou, Lai, Liu, & Yang, 2011). Consequently, investigating eye fixations on maps using an eye tracker could unveil whether displaying specific map areas transparent shifts visual attention towards other non-transparent map areas.

If all elements in a map offside a displayed route are invariably displayed transparent, it needs to be considered that this may also deteriorate positive aspects of a survey map. Especially landmarks are highly relevant for orientation, navigation and the formation of cognitive maps (Golledge, 1999b; Steck & Mallot, 2000) and are expected to be important elements of navigation stories. Therefore, the display format of landmark pictograms can affect navigation and route recognition performance (Tom & Denis, 2004). Landmark pictograms in OpenStreetMap and Google Maps are displayed based on the selected scale of the map. When a small scale is selected, only few of the deposited landmark pictograms are displayed. At the largest scale, all deposited landmarks are displayed. Removing or adding such map elements based on map properties as scale would force the user to rely on other map elements for route recognition, which may in turn impair recognition performance. In order to assess whether the task-specific reduction of maps and the display of landmark pictograms affect route perception and recognition, we test the following hypotheses in our experiment.

Hypothesis 1 (H1). Displaying areas offside of the route transparent does not impair route recognition performance.

Hypothesis 2 (H2). Displaying areas offside of the route transparent shifts visual attention towards the route.

Hypothesis 3 (H3). Adding or removing landmark pictograms after the route has been memorized impairs route recognition performance.

4.3 Methods

The study was conducted in accordance with the Declaration of Helsinki. The experimental design has been controlled by the ethics committee of the Faculty of Geosciences at the Ruhr-University Bochum and was classified as ethically acceptable (13 July 2018).

4.3.1 Participants

The study sample comprised 69 geography students (30 females, 39 males) of the Ruhr-University Bochum with normal or corrected vision and no neurological diseases. Their age range was between 18 and 37 years (M = 23.07, SD = 3.45). Participation was rewarded with a payment of 5 EUR.

4.3.2 Materials

Participants were sorted into two experimental between-subject conditions (standard vs. reduced maps) with the same distribution of sexes in each. For both conditions, six maps (study maps) containing a route marked with a red line, a green starting point indicator, and a red destination indicator were built (Figure 4.1). The base maps were extracted from OpenStreetMap (OSM) in a scale of 1:10,000 and represented the same six regions in both conditions. All maps showed European urban regions selected to prevent high familiarity of the participants with the displayed regions. In the first condition (reduced maps), all map areas with a distance of more than 10 pixels to the route were displayed transparent (alpha value = 12). In the second condition (standard maps), no map areas were displayed transparent.

Two variants of each map in both conditions were generated. One variant contained OSM landmark pictograms close to each route diversion as well as at additional random positions in the map. The used landmark pictograms were selected from the OSM landmark pictogram repository based on their salience and meaningfulness (Keil, Edler, Dickmann, & Kuchinke, 2019). Twenty landmarks with moderate salience and meaningfulness were chosen in order to prevent extensive attention towards single landmark pictograms with higher salience (Caduff & Timpf, 2008) or higher meaningfulness (Beaucousin et al., 2011). For each landmark position in the study maps, one of these 20 landmark pictograms was selected at random. The second study map variant contained no landmark pictograms. After the route was inserted and all street names were removed, maps were exported in a size of 30 × 20 cm (1063 × 709 pixels). See examples for both experimental conditions and variants in Figure 4.1.

Figure 4.1. *Study map conditions and variants. According to their experimental condition, participants saw either six reduced or six standard study maps. Participants from both conditions saw three maps with landmark pictograms and three maps without landmark pictograms.*

Additionally, four types of recognition stimuli (examples in Figure 4.2) were generated for each of the six study maps to test whether participants could recognize the correct route shape among incorrect route shapes. These stimuli had the same size as the study maps. They also contained a route marked with a red line, a green starting point indicator, and a red destination indicator. The recognition stimuli showed no map, but a blank white background. Per study map, at least one of the four corresponding recognition stimuli contained the same route shape as the study map (correct route). The other recognition stimuli contained altered versions of the original route shape (incorrect route). The random amount of correct route shapes was intended to prevent that participants recognize a constant proportion of correct and incorrect routes, as it would enable them to anticipate whether the following stimulus shows a correct route if all correct or incorrect route shapes have already been shown. Similar to the study maps, two variants of each recognition stimulus were generated. One variant contained the same landmark pictograms as the version with landmarks of their corresponding study map. The second variant contained no landmark pictograms. All correct and incorrect routes contained six route diversions. Route diversions of incorrect routes were also placed close to landmark pictograms positions (if the stimulus contained landmark pictograms), but different pictogram positions than the ones used for the correct route. In the case of incorrect routes in stimuli without landmarks, route diversions were placed close to the positions of landmark pictograms in their correspondent study map stimulus that included landmarks. In both experimental conditions (reduced and standard maps), the same recognition stimuli were used.

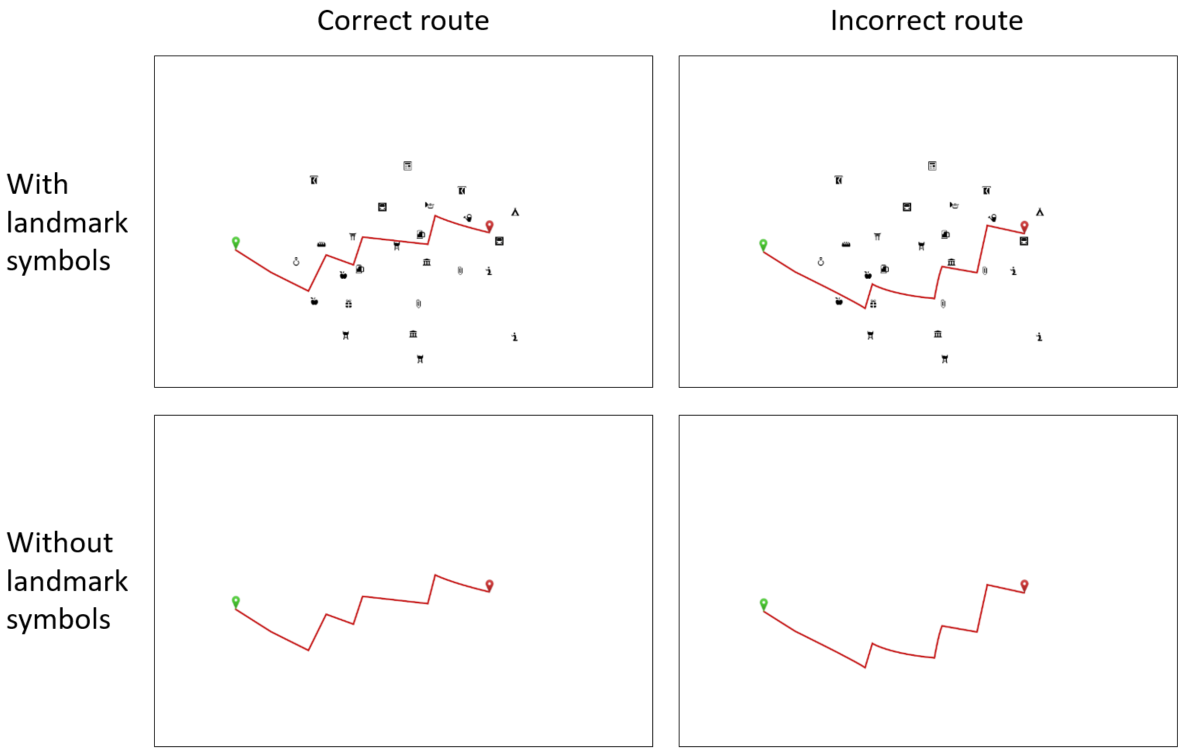

Figure 4.2. *Recognition stimulus variants. After each study map, four recognition stimuli were shown to the participants. At least one of these stimuli contained the same route as the study map. The rest contained slightly changed route shapes. Whether landmark pictograms were displayed in a recognition stimulus was determined at random.*

4.3.3 Procedure

In order to prevent response biases, no information about the study purpose was given to the participants before or during study participation (Nichols & Maner, 2008; Orne, 1962). They were told that information concerning the study purpose would be provided after the experiment. Before the experiment started, the procedure was explained and the participants gave informed consent. Hereafter, they took a seat in front of a Tobii TX-300 (300 Hz, 23 inches) eye-tracker monitor that was used to visualize the stimuli. The distance between the eyes and the monitor was 65 cm.

The experiment consisted of a practice trial and six experimental trials. At the beginning of each trial, a study map was shown for 30 s. During this time, participants had to memorize the route displayed in the map. Participants were presented only maps that belonged to the experimental condition a participant was assigned to (reduced maps or standard maps). Three of these six study maps shown in the experimental trials were randomly selected to display landmarks while the other 3 maps did not contain landmarks (i.e., within-subject factor ‘study map landmark’ yes or no). The presentation order of the six selected study maps was randomized. After every 30 s study phase, the four recognition stimuli belonging to the previously shown study map were presented successively, each for eight seconds. The presentation order and the variant selection of each recognition stimulus (with or without landmarks) were randomized. The matching of study maps and recognition stimuli with and without landmarks allowed to compare recognition performance between conditions in which landmarks were shown only in the study phase, only in the recognition phase, in both phases or in none of them. After every recognition stimulus presentation, participants had to answer whether the route displayed in the previous recognition stimulus had exactly the same shape as the route displayed in the last study map. The answers were given by pressing one of two keyboard keys labeled with “yes” and “no”.

4.3.4 Measures

4.3.4.1 Recognition Performance

Performance in the recognition task was assessed according to the signal detection theory (Nevin, 1969) in the form of hits, misses, correct rejections, and false alarms. If the route shape in a recognition stimulus matched the route shape in the study map (old stimuli), participants could either correctly state a match (hit) or wrongly state a mismatch (miss). If the two route shapes did not match (new stimuli) participants could either correctly state a mismatch (correct rejection) or wrongly state a match (false alarm). Because of the redundancy in these measures, only the hits and correct rejections were investigated in the statistical analyses. The misses and false alarms were merely used to calculate d’, an additional recognition performance measure based on all four response types. The benefit of d’ is that it puts correct signal detection (hits and correct rejections) and noise responses (misses and false alarms) in proportion (Harris, 2014; Nevin, 1969). The d’ value increases if the ratio of hits and correct rejection increase. It decreases if the ratio of misses and false alarms increase. This allows to make statements about the sensitivity of how well participants discriminate old from new stimuli. For information about d’ calculation see Macmillan and Creelman (1990).

4.3.4.2 Visual Attention

Eye fixation measures have been reported to be related to mental processing of visual stimuli (Just & Carpenter, 1976; Rayner, 2009). Therefore, average fixation duration and fixation count inside predefined Areas-of-Interest (AOIs) were used as measures for visual attention. Two

AOIs were placed in each study map of both experimental conditions (reduced and complete maps). The first AOI covered the displayed route and the area that was not displayed transparent in the first experimental condition (reduced maps). The second AOI covered all areas that were not covered in the first AOI (areas offside the route). This enabled us to compare the visual attention towards the displayed route (AOI 1) and other map areas (AOI 2) between the two experimental conditions. In eye-tracker studies, completeness of gaze data is an important quality criterion. Droopy eyelids and positioning the head outside of the tracking area of the eye-tracker may lead to gaze data loss (Bojko, 2013). Such data loss may cover up important information about visual attention towards specific areas of a stimulus. Therefore, eye-tracker recordings with massive gaze data loss should be removed from analysis. According to Bojko (2013), a gaze data loss threshold between 10% and 30% may be selected. Based on this suggestion, we defined a threshold of 25%.

4.3.5 Statistics

As our method generated multiple measurements per participant and item, and as visual inspections revealed that the response variables were skewed, we chose a generalized estimating equation (GEE) model for our first statistical analysis. The GEE model is an extended version of the generalized linear models. It can handle correlations of clustered data (repeated measures) and non-normally distributed response data (Ziegler, 2011) and can be seen as a robust alternative for multifactorial ANOVA models. Recognition performance (hits and correct rejections) main effects were calculated for the between-subject factor (reduced/standard map) and the two within-subject factors (landmarks/no landmarks in the study maps and the recognition stimuli). Additionally, interaction effects between the three factors were assessed.

Given that d’ values put correct and incorrect responses into proportion, calculating d’ requires aggregation of hits, misses, correct rejections, and false alarms across participants and specific conditions. This undermines the benefit of the GEE model to handle correlations of multiple responses from the same subjects at the level of single items. The same is true for the visual attention measures, which generated only one fixation count and average fixation duration value per participant and study map. In addition, the fixation data did not follow a Gaussian distribution. Therefore, the nonparametric Mann–Whitney U test was used to compare d’ and eye fixations data between the two map conditions (reduced/standard map). For the examination of the within-subject effects of landmarks (in study or recognition stimuli), d’ values and fixation data were analyzed with Wilcoxon signed-rank tests. Additionally, the Wilcoxon signed-rank test was used to compare fixation counts and average fixation durations between the route AOI and the AOI offside the route separately for each map condition (reduced/standard map).

Unfortunately, not all participant data could be used for the fixation analysis. For six participants, the eye-tracker could not be calibrated successfully. Seven other participants exceeded the predefined threshold of 25% gaze data loss. This reduced the sample size of the eye-tracking analyses from 69 to 56 participants.

4.4 Results

The GEE model that analyzes the hits found no statistically significant differences in the between-subjects condition (study map condition, $p = 0.757$), nor regarding the within subjects conditions (study map landmark condition, $p = 0.607$; recognition landmark condition, $p = 0.324$). Also, no significant interaction effect was found in the GEE (all p-values > 0.089). In contrast, the examination of the correct rejections revealed a significant effect of the study map landmark condition ($p = 0.028$). Correct rejection values were significantly higher when no landmarks were shown in the study map (see Figure 4.3, $M_{noLandmarks} = 0.931$, $M_{Landmarks} = 0.882$). No other effect regarding the correct rejections was significant (study map conditions, $p = 0.956$; recognition landmark condition, $p = 0.457$). No significant interaction effects were observed in the correct rejection data (all p's > 0.228).

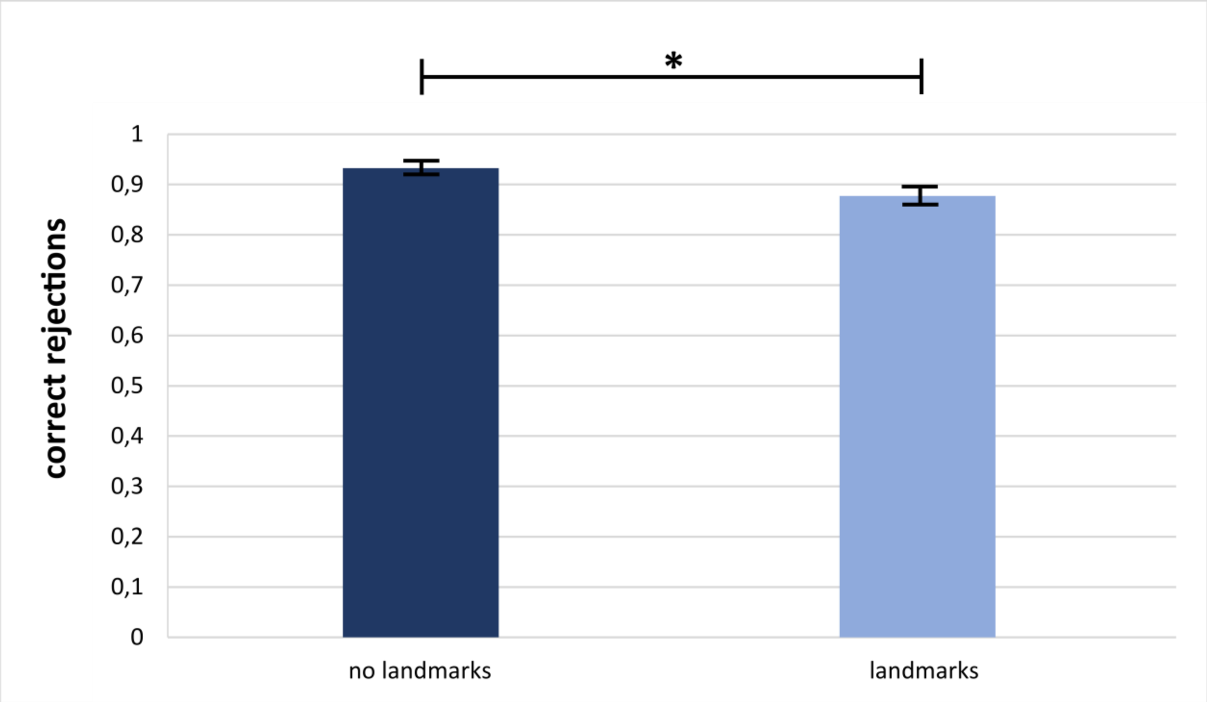

Figure 4.3. *Mean correct rejection difference between the study map landmark conditions. The mean correct rejection of incorrect routes was higher when no landmarks were shown in the study map ($M_{noLandmarks}$ = .931, $M_{Landmarks}$ = .882, p = .028).*

The examination of the discrimination performance measure d' revealed no differences between the participant groups (study map condition, U = 641, p = 0.583), the within-subjects effects of study map landmark condition (W = 1344, p = 0.416), or the recognition landmark conditions (W = 1182, p = 0.879).

This picture is different, when it comes to the eye-tracking data. Here, the fixation count differed significantly between the route AOI and the offside route AOI (see Figure 4.4) both in the reduced maps ($M_{RouteAOI}$ = 42.867, $M_{OffsideRouteAOI}$ = 2.724, W = 1, $p < 0.001$) and the standard maps ($M_{RouteAOI}$ = 45.506, $M_{OffsideRouteAOI}$ = 36.136, W = 88, p = 0.015). The differences of average fixation durations between the route AOI and the offside route AOI in the reduced maps ($M_{RouteAOI}$ = 0.379, $M_{OffsideRouteAOI}$ = 0.332, W = 22, p = 0.030) and in the standard maps ($M_{RouteAOI}$ = 0.350, $M_{OffsideRouteAOI}$ = 0.297, W = 11, $p < 0.001$) were also statistically significant. The fixation count on the AOI covering the areas offside the route differed significantly between the two study map conditions ($M_{Reduced}$ = 2.724, $M_{Complete}$ = 36.136, U = 0, $p < 0.001$), but not for the route AOIs ($M_{Reduced}$ = 42.867, $M_{Complete}$ = 45.506, U = 350, p = 0.496). Average fixation duration differences on the AOI offside the route (U = 224, p = 0.586), as well as average fixation duration (U = 438, p = 0.454) on the route AOI did not differ significantly between the two study map conditions.

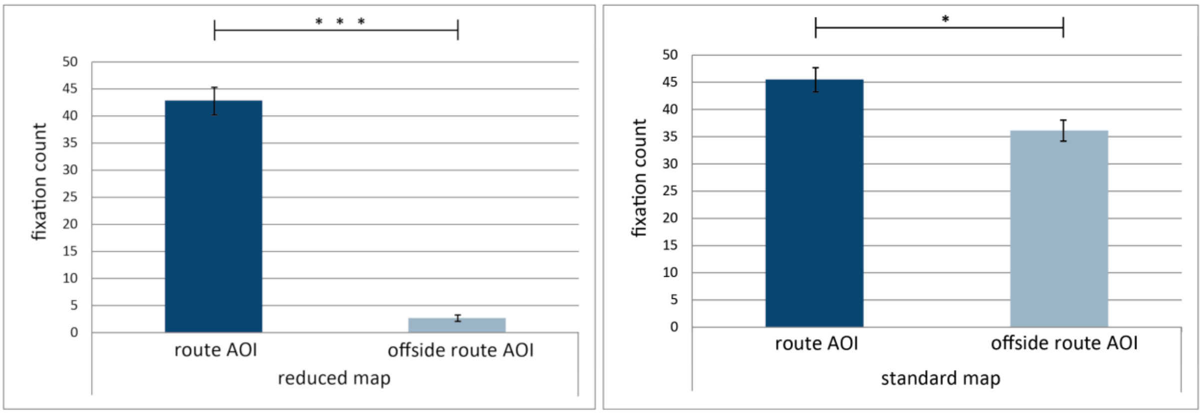

Figure 4.4. *Fixation count differences between the route AOI and the offside route AOI for both map conditions. In both map conditions, fixation counts on the route AOI were significantly higher than fixation counts on the AOI offside the route. In the reduced maps ($M_{RouteAOI}$ = 42.867, $M_{OffsideRouteAOI}$ = 2.724, W = 1, p < .001), the difference was larger than in the standard maps ($M_{RouteAOI}$ = 45.506, $M_{OffsideRouteAOI}$ = 36.136, W = 88, p = .015).*

4.5 Discussion and Conclusions

4.5.1 Discussion

The experiment presented above provides insights into how map reading is affected by reducing the amount of information displayed in a map. In the following, we discuss implications for the design of maps used in navigation tasks, among others, in respect to landmarks displayed on the map.

Regarding the general research question, two main results were obtained: Learning a route on a complete map display or with a reduced map that displays areas offside the route transparent did not affect route recognition memory performance and, in agreement with our first hypothesis, no behavioral differences were revealed between participants in the complete study map condition or the reduced study map condition. In other words, reducing the map display to only the significant ‘story’ of a map (in the present study the route) did not improve nor deteriorate performance in a route learning paradigm. Thus, we found some evidence that route learning does not depend on the distant or uninformative map regions but indeed on the detail (and also likely on the landmarks, see below) in the close neighborhood of the to-be-learned route. At first glance, these results seem surprising, as there is no evidence of an advantage in information processing when participants are forced to focus on the essential map information (Mocnik & Fairbairn, 2018). Besides the possibility of methodological factors contributing to a null effect (like a small number of items in a condition) and the logical difficulties when deriving inverse assumptions, the results still indicate that it is possible to reduce the map display without further costs when the task is to recognize a route. This is in agreement with the findings of earlier studies (Meilinger et al., 2006; O'Neill, 1991). Meilinger et al. (2006) showed that reduction of map complexity did not affect orientation and even improved wayfinding performance in larger areas. O'Neill (1991) also found that high map complexity may negatively affect wayfinding performance. These studies together with the present results demonstrate that simplified or reduced maps may support route-based tasks just as well as a standard map.

The second result refers to the eye-tracking data that is indicative of changes in visual attention. Here reduced maps clearly led to fewer fixations on map areas offside the route during the study map condition. This supports our second hypothesis and complements the results of Meilinger et al. (2006), who found that reducing the complexity of a map also reduced the time that participants needed for studying the map. The difference of fixation counts between the two map conditions is not visible for the close neighborhood of the route (i.e., in the route AOI). Thus, a reduction of visual input led to differences in how participants look at the map; not that they spent more fixations on the route (and its neighborhood)—the pattern changed for the whole map with proportionally more fixations directed towards the route. As stated before, eye fixations are assumed to indicate mental processing of stimuli (Just & Carpenter, 1976; Rayner, 2009). Even though the higher proportion of fixations towards the route did not directly contribute to better route memory performance in the present study, it seems likely that deeper processing explains to some extend why a reduced map does not lead to a drop of memory performance. Summing up, we can partially confirm our hypothesis that the reduction of map complexity shifts attention towards the route, as proportionally to all fixations on the map, more fixations were targeted on the route. It seems that users of the reduced map were less prone to distractions by map elements that are irrelevant to route memory.

Unexpectedly, neither the display of landmark pictograms in the study map, nor removing or adding landmark pictograms in the recognition stimuli affected route recognition performance (as it regards the learned old items). Displaying landmark pictograms along the route did not improve route recognition performance, which stands in contrast to the findings of Tom and Denis (2004), who showed that the display of landmark pictograms in maps improves route recognition. But displaying landmarks during memory encoding reduced the number of correct rejections. Hence, participants made more false alarms, i.e., falsely recognized a new route as being learned if landmarks are displayed during study. While the performance on old items (hits) was not affected by the availability of landmarks during study or recognition, the significant effect for new routes reveals that landmarks are part of the mental representation. Learning on a map with landmarks leads to higher false alarm rates. Thus, these data are in line with findings by Franke and Schweikart (2017), who demonstrate a positive effect of landmark display on the formation of cognitive maps. They also partially confirm our third hypothesis that adding or removing landmark pictograms after a route has been learned negatively affects recognition performance.

4.5.2 Limitations and Proposed Further Research

The presented study should be regarded as a first step towards the development of more user-friendly and task-oriented maps. Additional research in this area could give clear instructions about how maps used for navigation and route learning tasks should be designed.

Possible effects of landmark pictogram display on route recognition may have been inhibited by the experimental design. The availability of landmark pictograms in both the study maps and the recognition stimuli was completely randomized. Therefore, participants may have learned after a few trials that they cannot rely on learning the route based on its relative position to landmark pictograms, as these may not be available in the recognition phase. In order to assess the effect of landmark pictograms on route recognition more accurately, availability of landmark pictograms should be a between-subject factor, or at least consistent across a single trial including study phase and recognition phase. If the experiment would be adjusted accordingly, we would expect to find significant results comparable to previous studies (Meilinger et al., 2006; O'Neill, 1991).

The lack of significant results in the recognition task implies that it might have been too easy. Reducing the presentation time may lead to more distinct recognition performance differences between the experimental conditions. Furthermore, requesting participants to respond during stimulus presentation instead of afterwards would allow to use time on task as a measure for task efficiency.

Additional levels of transparency (alpha levels) should be investigated. When lower transparency levels of areas offside the route are selected, visual attention should approach the pattern of standard maps as the map complexity increases. If map areas offside the road are on the other hand completely removed, a radical change of visual attention and recognition performance may occur. In this case, visual attention would be expected to only focus on the route and potentially displayed landmarks, as no other objects would be available offside the route. The question remains whether route recognition performance would still remain stable with such radical map reduction, as the amount of visual anchors inside the map would be massively reduced to the close neighborhood of the to-be-learned route.

There are additional aspects beyond route recognition performance and visual attention that could be affected by map reduction. As shown by Dutta-Bergman (2004), trust in information is affected by its completeness. This raises the question whether map reduction can affect the credibility of the map, because users expect relevant information to be missing. Obviously missing map elements could on the other hand also, as mentioned in the introduction, lead to an open-world assumption. Being aware of the incompleteness of the map could lead to a higher flexibility when representations of real-world objects in the map are inaccurate or unexpectedly missing (Mocnik & Fairbairn, 2018). Therefore, deliberately activating an open-world assumption via directly recognizable map reduction may be advantageous if the accuracy and completeness of map information cannot be guaranteed. Effects of map reduction and the activation of an open-world assumption on trust in the displayed content and the use of inaccurate and incomplete information could be investigated by confronting people with deliberately incomplete and inaccurate maps of familiar environments.

Additional focus might also be set on the impact of storytelling on route memory and navigation performance. As Bellezza, Six, and Phillips (1992) demonstrated, generating story mnemonics with to-be-learned objects improves memory performance. Such a storytelling approach could also be incorporated into the present study design: In the landmark condition, there was a landmark pictogram close to each decision point of all routes. Effects of storytelling on route recognition could be investigated by comparing results of our study design with maps where the same landmark symbol is shown at each decision point of all routes. If the effects of map reduction and landmark placement on navigation performance and map credibility are better understood, maps could be designed in a way that supports wayfinding efficiently and effectively without sacrificing the users' trust.

4.5.3 Summary

The present study was targeted at assessing the effects of map reduction and landmark display on route recognition and visual attention. We were able to demonstrate that reducing a map by displaying map areas offside a route transparent does not affect route recognition performance. However, reducing the map shifted proportionally more fixations towards a displayed route. Presenting incongruent information by removing or adding landmark pictograms after a route had been memorized only affected recognition performance of new stimuli (correct rejections and false alarms), but not of old stimuli (hits and misses), which we argued to be affected by our experiment design. Overall, our findings indicate that task-oriented reduction of map complexity is a feasible approach to reduce the cognitive load of the user without compromising route recognition. Besides navigation apps, other map-based LBS as point of interest locators may benefit from our results. However, further research concerning map reduction levels, completeness, landmark display, and their effects on orientation and navigation performance is required for gaining a deeper understanding of how to design task-oriented maps.

5 Effects of Visual Map Complexity on the Attentional Processing of Landmarks

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Abstract

In the era of smartphones, route-planning and navigation is supported by freely and globally available web mapping services, such as OpenStreetMap or Google Maps. These services provide digital maps, as well as route planning functions that visually highlight the suggested route in the map. Additionally, such digital maps contain landmark pictograms, i.e. representations of salient objects in the environment. These landmark representations are, amongst other reference points, relevant for orientation, route memory, and the formation of a cognitive map of the environment. The amount of visible landmarks in maps used for navigation and route planning depends on the width of the displayed margin areas around the route. The amount of further reference points is based on the visual complexity of the map. This raises the question how factors like the distance of landmark representations to the route and visual map complexity determine the relevance of specific landmarks for memorizing a route. In order to answer this question, two experiments that investigated the relation between eye fixation patterns on landmark representations, landmark positions, route memory and visual map complexity were carried out. The results indicate that the attentional processing of landmark representations gradually decreases with an increasing distance to the route, decision points and potential decision points. Furthermore, this relation was found to be affected by the visual complexity of the map. In maps with low visual complexity, landmark representations further away from the route are fixated. However, route memory was not found to be affected by visual complexity of the map. We argue that map users might require a certain amount of reference points to form spatial relations as a foundation for a mental representation of space. As maps with low visual complexity offer less reference points, people need to scan a wider area. Therefore, visual complexity of the area displayed in a map should be considered in navigation-oriented map design by increasing displayed margins around the route in maps with a low visual complexity. In order to verify our assumption that the amount of reference points not only affects visual attention processes, but also the formation of a mental representation of space, additional research is required.

Keywords

Landmarks; Pictograms; Cognitive Cartography; Empirical Cartography; Spatial Cognition; Memory; Route Recognition

5.1 Introduction

Navigation is a complex everyday task that is executed when someone intends to reach a desired location. Independent of the mode and distance of travel, people need to compare their current position to their target position and choose a route that connects the two positions (Field et al., 2011; Golledge, 1999a). Following the chosen route requires them to continuously update their current position in order to identify the next required adjustment of the direction of travel (Loomis et al., 1999).

In a familiar environment, people are able to plan a route and update their current position by resorting to their cognitive map, a previously learned mental representation of the environment (Kuipers, 1982; Millonig & Schechtner, 2007; Montello, 2002). However, in unfamiliar environments, they rely on external aids, such as maps or navigation systems (Baskaya, Wilson, & Özcan, 2016).

Since the spread of smartphones, web mapping services like OpenStreetMap (OSM) and Google Maps are available almost everywhere. These services not only offer maps for free (Cipeluch et al., 2010; Haklay, 2010), they also provide route planning functions (Graser, 2016; Schmidt & Weiser, 2012). Additionally, landmarks, salient objects in the environment (Anacta et al., 2017; Bestgen, Edler, Kuchinke, & Dickmann, 2017; Röser, 2017), are represented in these maps as pictograms. Landmark representations not only support the formation of a cognitive map, they also facilitate orientation, as users can match them to surrounding landmarks in the environment and thereby triangulate their current positions (Anacta et al., 2017; Bestgen, Edler, Kuchinke, & Dickmann, 2017; Foo et al., 2005). Additionally, they act as memory anchors for decision points, i.e. positions where the direction of travel needs to be adjusted (Klippel & Winter, 2005).

In case of topographical maps empirical evidence exists showing that object location memory performance improves with increasing map complexity (Bestgen, Edler, Müller, et al., 2017; Edler, Bestgen, et al., 2014; Edler, Dickmann, et al., 2014). These authors also found that artificial map elements (grids) added to a map improve object location memory performance, especially in maps with low complexities. This counterintuitive finding may be best explained by the assumption that mental representations of space are generated based on spatial relations between single objects (McNamara & Valiquette, 2004; Tversky, 2003) that serve as reference points. Thus, the higher availability of reference points in complex topographic maps may support the formation of more accurate cognitive maps (Golledge, 1999a) up to some asymptote where the addition of detail no further improves memory performance (also see discussion in Bestgen, Edler, Müller, et al., 2017). In case of route memory tasks, no such empirical data exists. Based on what we know from object location memory, we assume that adjusting a map display to increase visual complexity may also improve route memory. This question seems of particular interest in the context of volunteered geographic information (VGI) like OSM in the present study, where the amount of available detail depends on the engagement of their volunteers and the number of active VGI contributors in a specific area (e.g. Barrington-Leigh & Millard-Ball, 2017).

If web mapping services are used to plan a route, this route is displayed on top of the map layer. Based on the aspect ratio of the used device, a map scale is selected that allows to display the route in its entirety. Additionally, a margin is left around the route that prevents the route from intersecting the map borders. The map content displayed in this margin area contains spatial information, like landmarks, which act as navigation aids and can be used to generate a cognitive map (May et al., 2003; Millonig & Schechtner, 2007; Sorrows & Hirtle, 1999). Increasing this margin area would also increase the amount of spatial elements that can be displayed in the map, which may further improve the accuracy of the cognitive map. However, this would also decrease the size of the displayed route and, accordingly, its readability.

The tradeoff between displaying additional information around the route and ensuring a good visibility of the displayed route raises the question to what extent people use map elements such as landmarks offside a displayed route to memorize this route. If landmarks far offside the route are not used as spatial references, inserting large margins around the route would decrease readability of the route without any benefits. However, if landmarks offside the route play an important role in the formation of spatial representations, increasing margins around the route would be of advantage. In two consecutive experiments, we intended to identify factors affecting the task-relevance of landmark representations in route memory tasks based on their relative position to the route and the visual complexity of the map.

5.2 Background

A precondition for the use of landmark representations as tools for route memory or navigation is their attentional processing. Whether map elements are processed is strongly affected by their salience, the tendency of an object to catch attention (Caduff & Timpf, 2008; Shinn-Cunningham, 2008). Concerning the attentional processing of landmark representations in route planning and navigation tasks, two subcategories of salience are expected to play an important role: visual salience and structural salience.

Visual salience defines the attention generated by physical characteristics of the landmark representations, like color contrast and the size of landmark pictograms (Bestgen, Edler, Kuchinke, & Dickmann, 2017; Klippel & Winter, 2005). Keil et al. (2019) investigated the visual salience of OSM landmark pictograms using eye fixation measures and found large differences between the available pictograms. Without equalization of the visual salience of pictograms in web mapping services, effects of visual salience on the attentional processing of specific landmark representations cannot be avoided. However, in a controlled experiment the use of landmark pictograms with similar levels of visual salience is expected to reduce undesired effects on attentional processing.

Structural salience on the other hand represents the degree of visual attention allocated towards an object based on its relative position to a specified route (Klippel & Winter, 2005; Röser et al., 2012). In navigation tasks, four types of route elements relevant for wayfinding instructions and route knowledge (Anacta et al., 2017; Janzen, 2006; Lovelace et al., 1999) can be distinguished (see Figure 5.1). *Decision points* are positions where at least two road branches exist (e.g. crossroads, T or Y junctions) and the route does not follow the previous course of the road. *Potential decision points* are positions with at least two road branches, but the route unambiguously follows the previous course of the road. Positions *along the route* are close to the route, but not close to any road branches. *Global* positions are offside the route and cannot be linked to specific route sections. Landmarks at *decision points* indicate that the direction of travel needs to be adjusted. Landmarks at *potential decision points* and along the route can be used to assure that the navigating person is still following the correct route. *Global landmarks* on the other hand are a special case. They are located offside the route and are only used to estimate cardinal directions (Steck & Mallot, 2000; Wenig et al., 2017). Information about cardinal directions allows to identify an approximate travel direction, but it is not sufficient to follow an exact route. Therefore, we focus on the other three types of landmark positions in this study (at decision points, at potential decision points and along the route).

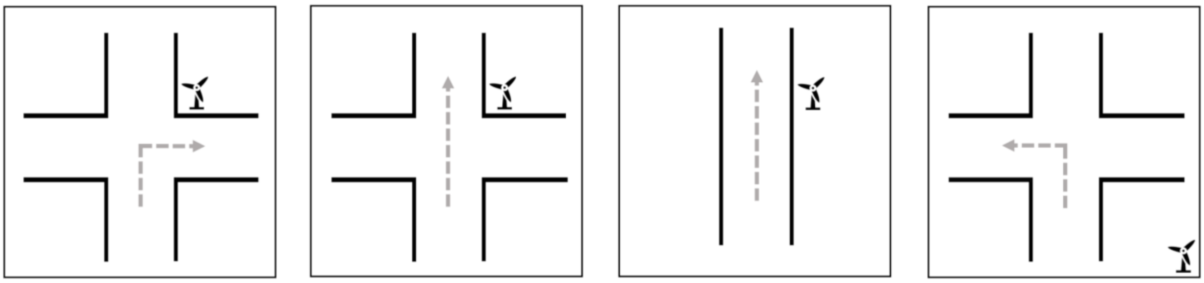

Figure 5.1. *Possible positions of landmark pictograms relative to the route. Landmarks can be located close to decision points, potential decision points, along straight route sections or offside the route (adapted from Bauer, 2018).*

In addition, landmark representations can be located either close to the start or end of the route. As the start point of the route is the location of initial orientation, this location cannot be deduced from a previously identified location. However, once the start point has been identified in the map, people can apply counting strategies (e.g. take a right turn at the second crossroad) to update their current position and to support navigation and route memory (Furukawa, 2015). As such strategies based on deducing the current position from a previous position are not functional for the start point of the route, a higher number of landmark pictograms acting as reference points could be required to identify this position than any other subsequent position along the route.

To understand which landmarks are required for memorizing a route and specific route segments, we need to assess which map elements are perceived and processed and which are not. In Geosciences and Geography eye tracking has been established as a measure to examine cognitive and attentional processing of map users (Brychtova & Coltekin, 2016; Fabrikant, Hespanha, & Hegarty, 2010; Keil et al., 2019; Kiefer et al., 2014; Kuchinke et al., 2016) and to be able to examine different temporo-spatial strategies a user applies in route learning, navigation and other map reading tasks (Burch, 2018; Çöltekin, Fabrikant, & Lacayo, 2010; Netzel, Hlawatsch, et al., 2017; Netzel, Ohlhausen, et al., 2017). Of relevance for the examination of attentional processing of particular map objects are the fixation duration and the fixation count on these objects (defined as Areas-Of-Interest, AOIs, on the map). Both measures indicate attentional processing of spatial objects (J. Henderson, 2003; Kuchinke et al., 2016; Rayner, 1992), as well as with the depth of cognitive processing of objects (Grant & Spivey, 2003; Just & Carpenter, 1976). Therefore, in the present study these fixation measures will be used to examine attentional processing of landmark representations during navigation and route learning. Some first evidence now exists that the area distant from a to-be-learned route attracts less visual attention as indicated by fixation measures (see Keil, Mocnik, Edler, Dickmann, & Kuchinke, 2018), but the relation to map complexity and the processing of landmark representations has not been examined so far.

As we are interested in the attentional processing of landmark representations, we want to examine the likely relationship between visual map complexity, attentional processing and route memory. With regard to the structural salience of landmark representations, distances of landmark representations to decision points, potential decision points and the route in general will be investigated as potential predictors for their cognitive and attentional processing (as indicated by eye fixation measures). If structural salience directs visual attention towards landmark representations, we expect that the attentional processing of landmarks decreases with an increasing distance to the route, decision points and potential decision points of the route (H1). Second, landmark representations close to the start point of the route should receive especially high levels of attentional processing (H2). Third, route memory is expected to be better when the route is displayed in maps with high visual complexity (H3). Fourth, in maps with low visual complexity, map users are expected to use landmark representations as reference points that are further away from the route (H4). If we are able to verify the proposed relations between the visual complexity of maps, the relative position of landmark representations and their attentional processing in route memory tasks, we could deduce implications for map design. Findings could be used to select margin widths around displayed routes based on the requirement of reference points for memorizing a route.

5.3 Experiment I

5.3.1 Methods

The study was conducted in accordance with the Declaration of Helsinki. The used research design was controlled and approved by the ethics committee of the Faculty of Geosciences at the Ruhr-University Bochum (13 July 2018).

5.3.1.1 Participants

The study sample included 66 students of the Ruhr University Bochum (RUB). Exclusion criteria were neurological diseases or uncorrected poor eyesight. Based on quality criteria described in the statistics section, nine participants were removed from the final statistical analyses, which reduced the sample size to 57 participants (29 females, 28 males). The average

age of the remaining sample was 22.8 (SD = 2.6), with a range between 19 and 30. Participants received a compensation of 5 EUR for participation in the study.

5.3.1.2 Materials

Participants were randomly assigned to one of two between-subject conditions. Eight maps with a size of 45 x 20 cm were retrieved from OSM in a scale of 1:10,000. Four of these maps displayed urban areas with a high visual complexity, the other four displayed rural areas with a low visual complexity (**map density conditions**, see Figure 5.2).

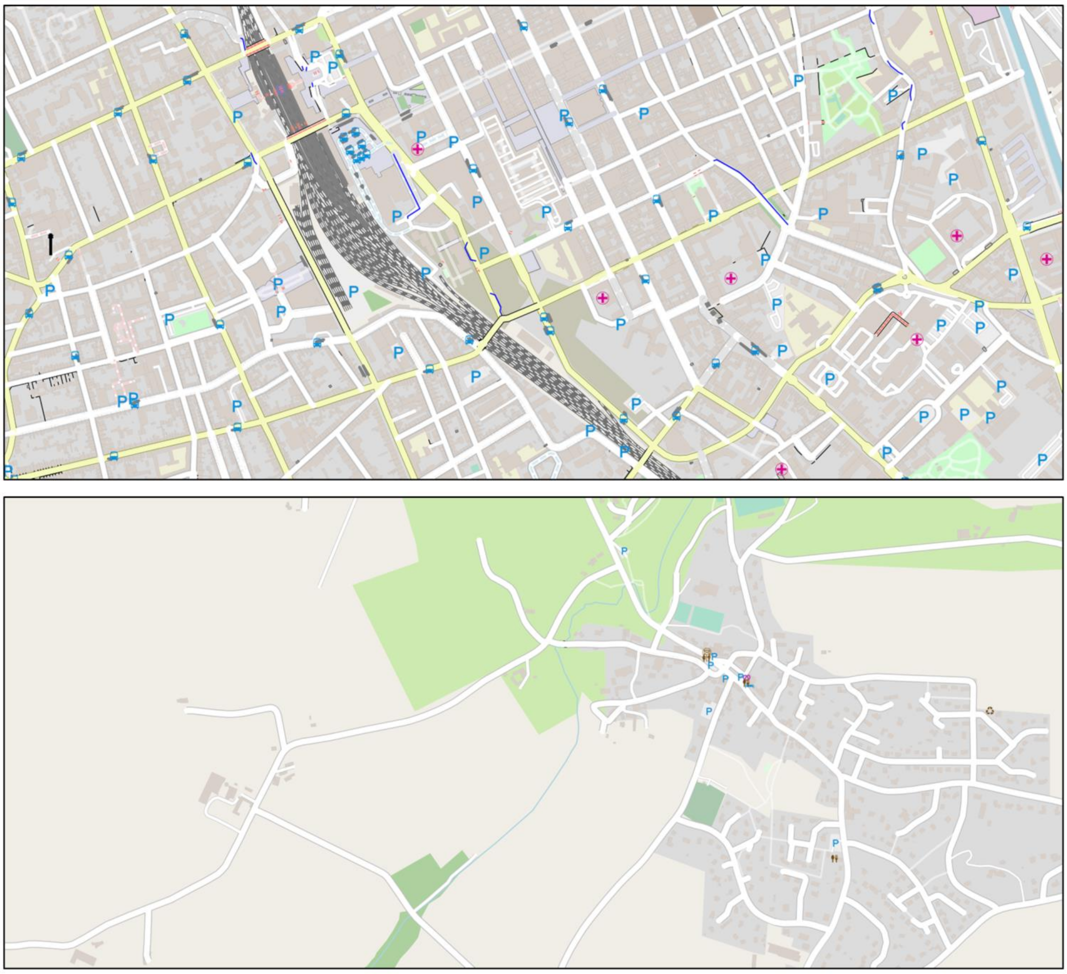

Figure 5.2. *Map density conditions. The top half of the figure shows an example of an urban map (high visual complexity). The bottom half of the figure displays a map of a rural area (low visual complexity). The displayed maps were replicated with Maperitive using geodata obtained from* ***OpenStreetMap.org****.*

In order to validate our allocation of the selected areas as being either urban or rural, we compared the JPEG file size of the extracted maps. As JPEG file size correlates highly with subjective ratings of visual complexity (Donderi & McFadden, 2005; Stickel et al., 2010), it can be used to differentiate between urban regions containing high amounts of map elements and rural regions containing only few map elements. Given that the mean file size (in KB) of our urban maps (M_{Urban} = 580.3, MIN_{Urban} = 479, MAX_{Urban} = 649) was higher than the mean file size of our rural maps (M_{Rural} = 191.8, MIN_{Rural} = 168, MAX_{Rural} = 219), we guaranteed a selection of representative map areas. After exporting all maps from OSM, a roughly horizontally running route containing six turnoffs (decision points) was drawn into each map (complete route). In order to control for potential effects of visual salience differences between landmark pictograms on visual perception, all landmark representations in the map were randomly replaced by a set of 20 OSM landmark pictograms (see Figure 5.3) assembled by Keil et al. (2019), based on similar levels of visual salience.

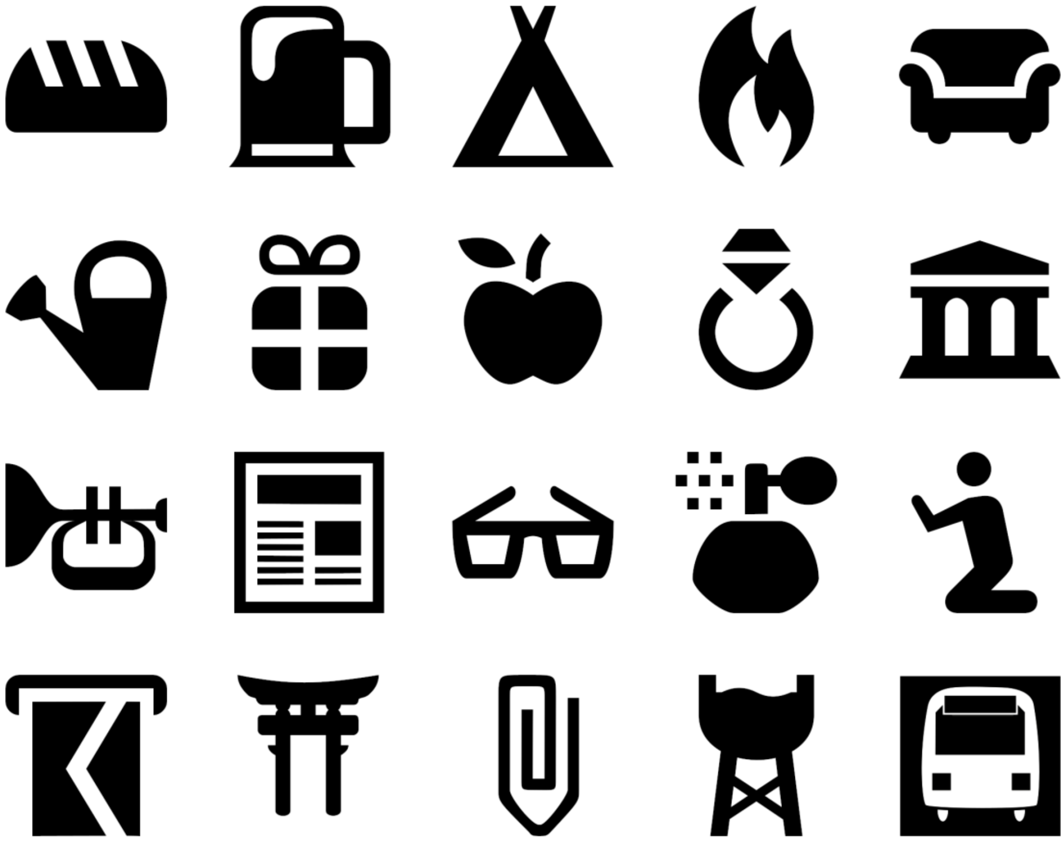

Figure 5.3. *The used landmark pictograms. The displayed landmark pictograms were used as replacements for the original landmark pictograms in the stimulus maps. The selection of pictograms was based on findings of Keil et al. (2019) with the aim to ensure similar levels of visual salience.*

Subsequently, two versions of each map were generated to be used as **study phase** stimuli. The first version displayed only the left two-thirds of the original map. The second version displayed only the right two-thirds of the original map (**map area conditions**). Accordingly, the two versions shared an overlap of 50% (see Figure 5.4). In each map, this overlapping area contained four of the six turnoffs of the complete route. As only two-thirds of the original map were used, either the start or end of the complete route was cut off. The routes in the study phase stimuli were shortened to prevent that they crossed the edge of the map.

Figure 5.4. *Stimulus design. The left side of the figure demonstrates how two study phase stimulus maps, with an overlap of 50%, were generated from a wide map (**map area conditions**). The overlapping area is highlighted by the blue dashed rectangle. The landmark pictograms in this area are, based on the condition, either close to the start or end of the route. The right side of the picture compares two recognition phase stimuli. The top map contains the correct route. The route in the bottom map is incorrect, as indicated by the black ellipses. The displayed maps were replicated with Maperitive using geodata obtained from **OpenStreetMap.org**.*

For each of the 16 study phase stimuli (eight regions, two versions per region), four **recognition phase** stimuli were generated. These stimuli contained the same map as their corresponding study phase stimulus as well as a route. At least one of the four recognition phase stimuli showed the same route as the corresponding study phase stimulus. The other recognition phase stimuli contained a slightly modified route.

All study and recognition phase stimuli were exported as PNG files with a size of 30 x 20 cm (1133 x 755 pixels) and assigned to one of the two between-subject conditions (condition A or B) with an even distribution of left/right and urban/rural study phase stimuli.

5.3.1.3 Measures

Attentional processing. In order to assess attentional processing of landmark pictograms, we measured fixation durations and fixation counts using a Tobii TX-300 (300 Hz, 23 inches) eye-tracking monitor. Circular Areas-of-Interest (AOIs) were placed on each landmark pictogram, inside the overlapping area of the two map area conditions (the blue dashed rectangle in Figure 5.4). Using the eye-tracking software Tobii Studio (version 3.4.7), we calculated and exported the fixation counts and durations on each defined AOI per participant. Mean fixation durations were then calculated based on the fixation counts and total fixation durations. Concerning the diameter of the AOIs, it was important to consider an inherent tradeoff. As no eye-tracker has perfect accuracy, choosing a very small diameter would lead to many fixations on AOIs which are not recognized. In contrast, applying a large AOI diameter would score fixations close to a landmark pictogram as fixations on the pictogram. Therefore, we chose the AOI diameter by calculating a balanced proportion of AOI fixations being recognized according to the reported accuracy of the Tobii TX-300, which is 0.6˚ with a standard deviation of 0.7˚ for a gaze angle of 30˚ (Tobii Technology AB, 2013). We selected a diameter of 60 pixels (1.58 cm). At a distance of 65 cm between the eyes and the eye-tracker monitor, this leads to a rate of on average 74.2% recognized fixations on AOIs.

Relative landmark position. The relative position of a landmark was measured based on its minimal distance to the route, to the next decision point of the route and to the next potential decision point of the route. The distance was measured in pixels. In accordance with the attentional processing measurement, only the landmarks in the overlapping map areas were investigated.

Recognition performance. Route recognition performance was assessed through a yes/no response task. In this task, participants were asked to compare routes with previously learned routes. Based on the signal detection theory (see Nevin, 1969), responses were scored as *hits* (correct route was recognized), *misses* (correct route was not recognized), *correct rejections* (route deviation was spotted) or *false alarms* (route deviation was not spotted). Hits, misses, correct rejections and false alarms were then translated into *d’* values, which represent the proportion of correct and incorrect responses (Bestgen, Edler, Müller, et al., 2017; Harris, 2014;

Nevin, 1969) aggregated per participant to indicate recognition performance (i.e. how well participants are able to differentiate old from new items). d' values above 0 indicate recognition memory performance above chance level.

5.3.1.4 Procedure

Preceding the start of the experiment, participants gave informed consent and the experimenter explained the procedure. As knowledge about the study purpose could have led to response biases (Nichols & Maner, 2008; Orne, 1962), participants were told that a debriefing concerning the study purpose would take place after the experiment. After that, they were seated in front of the eyetracker monitor with a distance of 65 cm between the eyes and the monitor. The study consisted of one training trial and eight experimental trials. At the beginning of each trial, participants were shown a stimulus map (study phase) for 30 seconds. Their between-subject condition defined whether the left or right version of a specific map (map area conditions) was shown. Both between-subject conditions contained the same amount of left and right map areas (four left/right map areas). Participants were required to memorize the route displayed in the map. After each study phase stimulus, the four corresponding recognition phase stimuli were displayed successively, each for eight seconds. After each recognition phase stimulus presentation, participants had to indicate whether the route displayed in the recognition phase stimulus matched the route in the corresponding study phase stimulus by pressing one of two keyboard buttons labeled with 'yes' and 'no'.

5.3.1.5 Statistics

In order to test our hypotheses, we investigated the relations between the independent variables (visual complexity, map area conditions, relative landmark positions) and the recorded dependent variables (eye fixations, recognition performance). As mentioned above, the data of some tested participants was excluded from statistical analyses. Five participants had to be excluded, as the eye-tracker calibration was not successful. A second exclusion criterion was the completeness of the eye fixation data. Many factors as lighting, head movements or eye shape can affect the ratio of successful eye fixation recording (Al-Rahayfeh & Faezipour, 2013; Zhu, Fujimura, & Ji, 2002; Zhu & Ji, 2005). If this ratio is low, important information concerning stimulus processing may be lost. As the remaining recorded eye gaze data may not be representative, including participants with low ratios of successful eye fixation ratios could lead to misinterpretations of their actual gaze patterns. Therefore, a minimum threshold of successful eye-tracking must be applied. Based on the suggestion of Bojko (2013), we selected a threshold of 75%, which required us to remove the data of four additional participants from our analyses.

Our first hypothesis assumed relations between the distance of landmark representations to the route, decision points, potential decision points and the attentional processing of landmark representations. To test this assumption, eye fixation data was aggregated across participants to obtain one total fixation duration, mean fixation duration and fixation count value per landmark representation. Spearman correlations were then calculated between all fixation and distance measures.

Potential differences of the attentional processing of landmarks between the start point of the route and route sections near the end point of the route (H2) were examined by comparing the fixations on landmark representations between the two map area conditions using Spearman correlations.

Effects of visual complexity on route memory (H3) were assessed by aggregating recognition responses per map density condition to receive two d' values per participant (one for urban maps and one for rural maps). Subsequently, d' values were compared between urban and rural maps using the paired Wilcoxon signed-rank test.

Whether the visual complexity affected the distance of perceived landmark representations to the route, decision points and potential decision points (H4) was investigated by comparing the average of the mentioned distances between urban and rural maps. For this purpose, mean distance values were calculated per participant based on all landmark representations that were fixated at least once, but separately for urban and rural maps. Distance values were then compared between urban and rural maps with the paired Wilcoxon signed-rank test. Additionally, in order to test whether the distribution of landmark representations was similar in both map density (complexity) conditions, average distances of all landmark representations to the route, decision points and potential decision points were compared between urban and rural maps using Mann-Whitney U tests.

5.3.2 Results

As shown in Table 5.1, all fixation measures (total fixation duration, fixation count and mean fixation duration) were highly negatively and significantly correlated to all three distance measures (distance to the route, distance to decision point, distance to potential decision point).

Table 5.1. *Spearman correlations between fixations on landmark pictograms and their distance to the route, decision points and potential decision points. Values were aggregated across participants in order to create one value per landmark pictogram.*

Variable	1	2	3	4	5
1. Total fixation duration					
2. Fixation count	.993***				
3. Mean fixation duration	.996***	.989***			
4. Distance to route	-.8***	-.804***	-.8***		
5. Distance to decision point	-.69***	-.692***	-.687***	.852***	
6. distance to potential decision point	-.809***	-.811***	-.808***	.976***	.895***

*p < .003, **p < .0007, ***p < .00007, Bonferroni correction applied

All three fixation measures correlated positively and significantly when fixations on landmarks in the overlapping area were compared between the two map area conditions (see Table 5.2).

Table 5.2. *Spearman correlations of fixations on landmark pictograms between the two map area conditions (landmark position close to the start or end of the route).*

Variable	r_s
1. Total fixation duration	.788***
2. Fixation count	.797***
3. Mean fixation duration	.788***

*p < .05, **p < .01, ***p < .001

The Wilcoxon signed-rank test showed no statistically significant difference of route recognition performance between the two map density conditions (M_{Urban} = 2.056, Mdn_{Urban} = 2.195, M_{Rural} = 2.192, Mdn_{Rural} = 2.199, W= 645, p = .15). The positive d' values in both map density conditions demonstrate that the differentiation between correct and incorrect routes was above chance level.

Although visual inspection of Figure 5.5 seems to indicate that participants looked at landmarks farther offside the route in the rural maps, statistical mean comparisons did not support this impression. The mean distance to the route of fixated landmarks (in pixels) did not differ significantly between the urban and rural maps (M_{Urban} = 41.52, Mdn_{Urban} = 39.53, M_{Rural} = 41.77, Mdn_{Rural} = 39.11, W= 831, p = .975). In contrast, the mean distance of fixated landmarks to decision points (M_{Urban} = 89.18, Mdn_{Urban} = 87.48, M_{Rural} = 67.88, Mdn_{Rural} = 59.94, W= 244, p < .001) and potential decision points (M_{Urban} = 51.45, Mdn_{Urban} = 49.33, M_{Rural} = 45.67, Mdn_{Rural} = 43.46, W= 539, p < .05) was even higher in urban maps. We also found that the average distance to the route (M_{Urban} = 142.15, Mdn_{Urban} = 125.22, M_{Rural} = 96.26, Mdn_{Rural} = 85.95, U = 1449, p = .063), decision points (M_{Urban} = 168.4, Mdn_{Urban} = 163.45, M_{Rural} = 139.59, Mdn_{Rural} = 126.17, U = 1556, p = .146) and potential decision points (M_{Urban} = 148.3, Mdn_{Urban} = 133.33, M_{Rural} = 107.22, Mdn_{Rural} = 95.52, U = 1480, p = .081) of all landmarks displayed in the maps was higher in urban maps. However, these differences were not statistically significant.

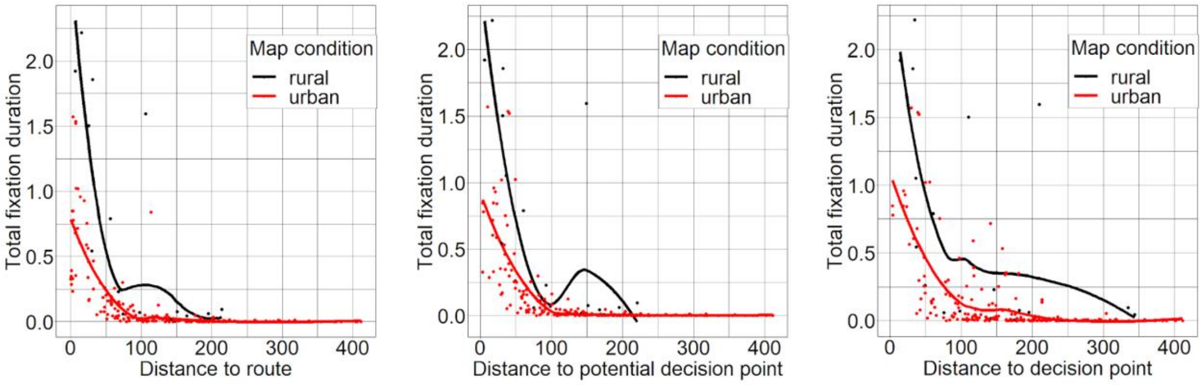

Figure 5.5. *Relation between the total fixation duration on landmark representations and their distance to the route, decision points and potential decision points in pixels. The line graphs indicate that landmarks close to the route were fixated longer in the rural maps. They also show that urban maps contained more landmarks, especially far offside the route, decision points and potential decision points.*

5.3.3 Discussion

The negative correlations between the distance measures and the fixation measures (Table 5.1) demonstrate that, in line with our first hypothesis, landmark representations close to the displayed route, decision points and potential decision points were fixated more often. We conclude that these landmark representations have a higher structural salience. It may also be an indication that they are preferably used as reference points for memorizing the route.

Based on the high correlations of the fixation measures between the two map conditions we have to reject our second hypothesis. Participants fixated the same landmark representations independent of whether they were located close to the start or end point of the route. Therefore, increasing map margins close to the start point of the route does not seem to be important in future map design.

Inconsistent with our third hypothesis, no recognition memory performance differences were found between the two map density conditions. Thus, we cannot confirm that route memory performance is better in maps with high visual complexity. However, the lack of significant findings may have been caused by the low level of task difficulty. In fact, there were only very few incorrect responses in trials with both urban and rural maps. Additionally, the low visual complexity of rural maps may have affected the task difficulty in an undesired way. The rural maps did not only contain less landmark representations that could be used as reference points. They also contained less roads and less evenly distributed road structures. As Stevenage et al.

(2013) demonstrated that recognition performance is affected by the amount of distractors, using maps with unevenly distributed roads may have unwillingly led to a lower task difficulty, because mix-ups of roads were less likely and it was therefore easier to memorize what road sections were or were not part of the displayed route. This may be prevented by displaying comparable road layouts in routes with different levels of visual complexity. This limitation should be addressed in a follow-up study by using map stimuli with more similar road structures.

Given that the average distance of fixated landmark representations was not significantly higher in the rural maps, we cannot confirm our fourth hypothesis that maps with lower visual complexity motivate to adopt reference points farther offside the route for memorizing the route. We assume that the different distribution of landmarks across the map covered potential effects of map complexity on the attentional processing of landmarks offside the route. Although the higher mean distance of all landmarks to the route, decision points and potential decision points was not statistically significant, Figure 5.5 indicates that the urban maps contained many more landmark representations far offside the route than the rural maps. In order to overcome this limitation, we designed a second experiment. Experiment 2 was meant to replicate and extend the results of experiment 1 by using stimulus maps with different levels of visual complexity but a similar distribution of landmark representations across the map. While we expect to replicate the findings regarding the negative correlations between the distance of landmarks to the route and attentional processing, the second experiment was particularly designed to test the hypotheses of whether a lower visual complexity of a map leads to worse route memory and more attentional processing of landmark positions further away from the route.

5.4 Experiment II

5.4.1 Methods

In the second experiment, the same measures and the same procedure as in experiment 1 were applied. However, a new study sample and a new set of stimuli were used.

5.4.1.1 Participants

The study sample for the second experiment consists of 69 students of the Ruhr University Bochum. As in the first experiment, neurological diseases and uncorrected poor eyesight were exclusion criteria. Based on the quality criteria described in the previous statistics section, nine participants were removed from statistical analyses, leaving a sample size of 60 participants (28 females, 32 males). The age range of the remaining sample is between 18 and 32 (M = 23.9, SD = 2.8). Participants received a compensation of 5 EUR for participation in the study.

5.4.1.2 Materials

As in the first experiment, participants were randomly assigned to one of two between-subject conditions. Eight maps with a size of 30 x 20 cm were retrieved from OSM in a scale of 1:12,500 (high visual complexity). A roughly horizontally running route with six turnoffs (decision points) was inserted into each map. Similar to the maps in the first experiment, each landmark representation in the map was replaced by a randomly selected OSM landmark pictogram from the set of 20 OSM landmark pictograms assembled by Keil et al. (2019) based on similar levels of visual salience. Hereafter, a second variant (**map area condition**) was generated from each map by selecting a central map section with a size of 13.5 x 9 cm and stretching it to 30 x 20 cm (low visual complexity, see Figure 5.6). The route displayed in the stretched map was shortened to prevent it from crossing the map borders, but it still contained six turnoffs. Stretching the map area reduced the map complexity (elements per cm), while the relative distribution of landmark representations and the road structure remained similar between the two map area conditions. This was meant to overcome the likely bias induced by different task difficulties and landmark distributions of urban and rural maps in experiment 1. Stretching the map also increased the size of the landmark representations. However, as all map elements were increased by the same factor, visibility of landmark representations relative to other map elements did not change. Both the original sized and the stretched maps were used as **study phase** stimuli.

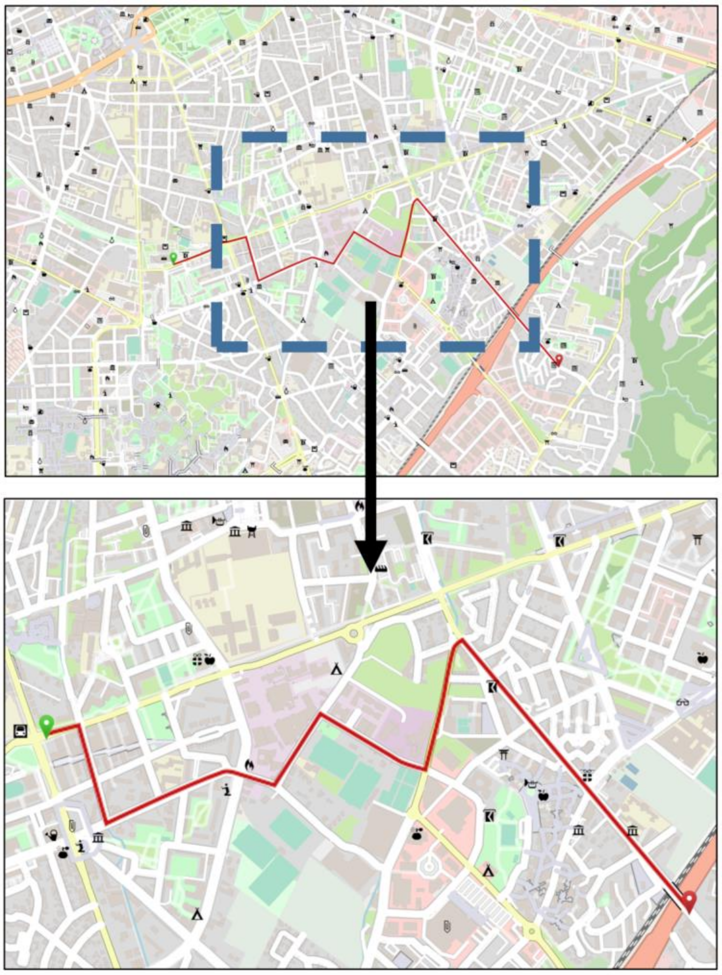

Figure 5.6. *Stimulus design. The top map was retrieved from OSM in the scale of 1:12,500 and exported in the size of 30 x 20 cm (large region condition with a high visual complexity). The blue dashed rectangle (not visible in the stimulus) indicates the extraction area for the small region condition with a low visual complexity displayed in the bottom map (stretched from 13.5 x 9 cm to 30 x 20 cm). Therefore, the dashed rectangle also indicates the overlapping area between the two* ***map area conditions****. The displayed maps were replicated with Maperitive using geodata obtained from* ***OpenStreetMap.org****.*

Similar to the first experiment, four **recognition phase** stimuli were generated for each of the 16 study phase maps. Again, these stimuli contained the same map as their corresponding study phase stimulus and either the same or a slightly modified route. At least one of the four recognition phase stimuli contained the same route as the study phase stimulus. All study and recognition phase stimuli were exported as PNG files with a size of 1133 x 755 pixels and assigned to one of the two between-subject conditions with an even distribution of non-stretched/ stretched study phase stimuli.

5.4.1.3 Statistics

Matching the statistical analysis of the first experiment, the relation between the distance measures of landmark representations (distance to the route, decision points and potential decision points) and the attentional processing of landmark representations (H1) was assessed based on the mentioned distance measures and the fixation measures (total fixation duration, mean fixation duration and fixation count). After aggregating the eye fixation data across participants, Spearman correlations were calculated between the fixation and distance measures.

Inspired by the limitations found in the design of the first experiment, potential differences of route memory performance (H3) and landmark processing between maps with high and low visual complexity (H4) were not investigated by comparing urban and rural maps. Instead, route memory performance and landmark processing were compared between the original-sized and the stretched maps (map area conditions). This ensured a more similar road and landmark distribution between the two conditions. Recognition performance (d') and distance values of landmarks to the route and (potential) decision points were aggregated across participants and map area conditions. Recognition performance was then compared between the map area conditions using the paired Wilcoxon signed-rank test. In order to compare the distance measures of fixated landmark representations between the map area conditions, independent samples Mann-Whitney U tests were applied.

5.4.2 Results

Table 5.3 shows that all investigated fixation measures (total fixation duration, fixation count and mean fixation duration) were highly negatively and significantly correlated to all three distance measures (distance to the route, distance to decision point, distance to potential decision point).

Table 5.3. *Spearman correlations between fixations on landmark pictograms and their distance to the route and (potential) decision points. Values were aggregated across participants in order to create one value per landmark pictogram.*

Variable	1	2	3	4	5
1. Total fixation duration					
2. Fixation count	.993***				
3. Mean fixation duration	.991***	.981***			
4. Distance to route	-.882***	-.893***	-.877***		
5. Distance to decision point	-.756***	-.761***	-.738***	.771***	
6. distance to potential decision point	-.867***	-.876***	-.858***	.965***	.81***

*p < .003, **p < .0007, ***p < .00007, Bonferroni correction applied

Concerning route recognition performance, no statistically significant difference of d' values was found between the large map area condition with high visual complexity and the stretched area condition with low visual complexity (M_{High} = 0.953, Mdn_{High} = 1.095, M_{Low} = 0.982,

Mdn_{Low} = 1.095, W= 456, p = .26). Similar to the results in the first experiment, both d' values were positive. Hence, the ability to differentiate between correct and incorrect routes was above chance level in both map area conditions.

In contrast to the comparison between urban and rural maps in experiment 1, the mean distance (in pixels) of fixated landmarks to the route (M_{High} = 28.85, Mdn_{High} = 25.17, M_{Low} = 46.86, Mdn_{Low} = 45.07, U = 568, p < .001), decision points (M_{High} = 59.79, Mdn_{High} = 58.65, M_{Low} = 119.41, Mdn_{Low} = 119.15, U = 6, p < .001) and potential decision points (M_{High} = 33.95, Mdn_{High} = 30.54, M_{Low} = 62.69, Mdn_{Low} = 61.5, U = 173, p < .001) differed significantly between the two map area conditions (large area maps/stretched maps, see Figure 5.7).

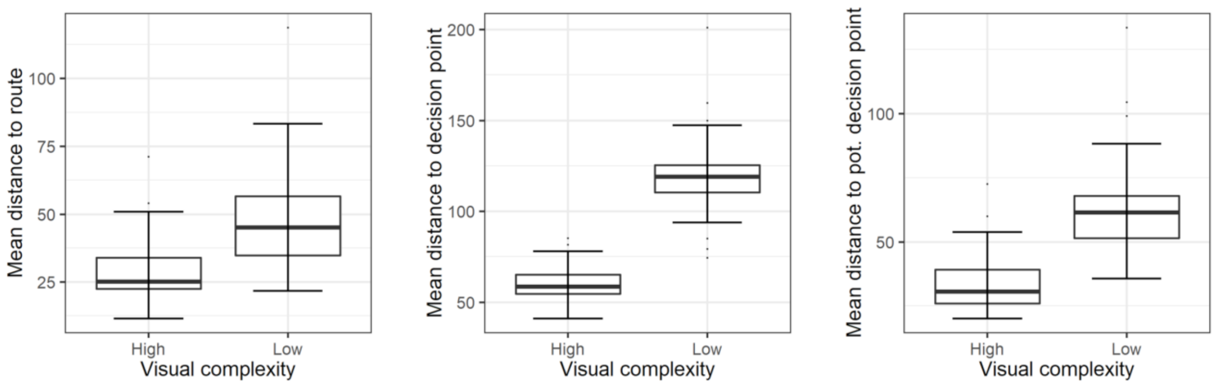

Figure 5.7. *Mean distances of the fixated landmark representations per map area condition. The mean screen distance of the fixated landmarks to the route, decision points and potential decision points (in pixels) was significantly shorter in the large map areas with high visual complexity than in the stretched map areas with low visual complexity.*

5.4.3 Discussion

Concerning the first hypothesis, the findings in the second experiment replicated the results of the first experiment. The closer landmark representations were to the route, a decision point or a potential decision point, the more often they were looked at.

Similar to the first experiment, route memory performance was not found to be affected by the visual complexity of a map. This contradicts the findings of Edler, Dickmann, et al. (2014) found for object location memory in topographic maps. Potential causes for the lack of significant differences of route memory performance between maps with varying visual complexity are presented in the general discussion.

Regarding our fourth hypothesis, using stimuli with a more similar distribution of landmark representations compared to the stimuli of our first experiment led to the confirmation of our prediction. In maps with lower visual complexity, and thus less reference points, people more frequently looked at landmark representations further offside the route and (potential) decision points. We have therefore found some evidence that people may require a certain amount of reference points to form spatial relations, and that they use more distant reference points if less reference points are available in close proximity to the route.

5.5 General Discussion and Conclusion

The findings of the two described experiments enabled us to identify relevant factors for effective display of routes in maps.

Both experiments found clear indications for a strong negative relation between the visual perception of landmark representations and their distance to the route and (potential) decision points. The fact that similar results were obtained with different study samples and stimuli emphasizes the robustness of the findings. Hence, we can safely infer that the relevance of landmark representations for learning a route decreases with increasing distance to the route and (potential) decision points. This supports the assumption of Winter, Tomko, Elias, and Sester (2008) that the dominance of a landmark is inverse to its distance to an individual's current position. It also fits to the findings of Keil et al. (2018), which showed that areas offside a to-be learned route attract less visual attention. Although our results do not allow to deduce a definite recommendation for the width of map margins around a displayed route, they indicate that applying excessively wide margins is unlikely to improve route memory, especially, as this would simultaneously reduce the readability of the map and the displayed route. As the experiments were purely map based, it is important to mention that the pattern of attention towards specific landmark representations may differ if people have to perform real-world navigation tasks. In these cases, landmark visibility is likely to affect visual attention towards specific landmark representations. Thus, map representations of close landmarks that are hidden behind other objects are expected to attract less visual attention, whereas map representations of distant global landmarks are expected to attract more visual attention. Therefore, the findings may be generalized to map-based route planning, but not to real-world navigation tasks, as the relation between the visual perception of landmark representations and their distance to the route is expected to be much weaker. An additional question to be answered in future experiments is a potential interrelation of decision points and potential decision points concerning route memory performance. If people use close landmarks to memorize decision points, the presence of one or multiple potential decision points close to a decision point (and the memorized landmark) might lead to a mix-up between the decision point and a potential decision point. This could be investigated by manipulating the amount of potential decision points and their distance to the next decision point.

As demonstrated in the first experiment, perception of landmark representations close to the start point of the route is highly similar to the perception of landmarks further away from the start point of the route if they are placed at the same distance to the route and (potential) decision points. This implies that the distance to the route and (potential) decision points is more relevant than the distance to the start point of the route. Therefore, we see no necessity for increasing the amount of visible reference points around the start point of the route compared to other route sections, e.g. by increasing displayed margin regions around the start point of a route. Similar to the findings concerning the distance of landmarks to the route, it is important to consider how attention towards specific landmark representations may differ in real-world orientation tasks. For initial orientation, which was not required in the described experiments, people may use a mixture of visible local and global landmarks. Therefore, before the phase of planning and memorizing a route can be initialized, larger margin regions around the current location that also display global landmarks may be required.

Previous findings showing that visual complexity of a map increases memory performance in map-based memory tasks (Edler, Bestgen, et al., 2014; Edler, Dickmann, et al., 2014) were not replicated in the present experiments. Therefore, we cannot deduce recommendations for the size of applied map margin regions around a displayed route based on the visual complexity of the map region. One explanation for our lack of significant results could be that previous studies (Edler, Bestgen, et al., 2014; Edler, Dickmann, et al., 2014) used a location-based recall task instead of a route-based recognition task. Recall tasks usually have a higher level of difficulty (Craik & McDowd, 1987; Singh, Rothschild, & Churchill, 2018), which promotes performance differences between experimental conditions. Therefore, applying a route recall task instead of a recognition task might uncover potential route memory performance differences based on map complexity. A second explanation could be that even though experiment 2 was intended to reduce the task difficulty differences between the two map area conditions in experiment 1, the low complexity map area might still have had an overall lower level of difficulty. Although the road structure was more similar than in experiment 1, the stretched low complexity map still contained less roads than the nonstretched map and therefore less possibilities for different route shapes. This might have compensated the assumed increased difficulty caused by the reduced amount of reference points in the stretched maps. In order to compare route recognition performance differences based on visual complexity differences, stimuli need to have even more similar road structures. Therefore, in follow-up experiments, we suggest to use the same map sections in both conditions and to modify the amount of all map elements excluding roads. Additionally, as learned from experiment 1, a similar distribution of map elements in both conditions should also be ensured. Still, comparing the different approaches it gets evident that the effect of visual complexity on recognition memory is clearly task-dependent. Finally, even if previous studies (Edler, Bestgen, et al., 2014; Edler, Dickmann, et al., 2014) found that location memory performance increased with map complexity, it cannot be deduced that the relation is linear. Other studies found that high visual complexity can distract from relevant stimuli, as more irrelevant stimuli are competing for visual attention (Donderi & McFadden, 2005; Pieters, Wedel, & Batra, 2010). Therefore, we assume that a tipping point exists where the benefit of having additional visual reference points usable for exact localization of objects is compensated by the difficulty to recover these reference points between competing visual stimuli. Thus, we assume that the relation between location memory performance and map complexity has an inverse u-shape (cf. Bestgen, Edler, Müller, et al., 2017). Future experiments could investigate this assumption by investigating location memory performance in maps with extensively high visual complexity.

Our last hypothesis implied that eye fixation patterns in route memory tasks depend on the visual complexity of the used map. The first experiment found no statistical evidence for this hypothesis, which we argued to have been caused by an unequal distribution of landmarks across the stimulus maps, as landmarks in the maps with low visual complexity were on average closer to the route. However, the second experiment with a more similar distribution of landmarks found distinct differences of viewing patterns between maps with different levels of visual complexity. In maps with low visual complexity, people scanned a wider area around the route. These findings are in line with the assumption of Tversky (2003) and McNamara and Valiquette (2004) that people require reference points to form spatial relations as a foundation for a cognitive map. If less reference points are available in close proximity to the route, people seem to widen the scanned area in order to find suitable reference points for memorizing the route. However, our findings do not allow to explicitly ascribe correct route recall to the formation of a cognitive map. Even if people perceived landmarks and other spatial reference points, they may have memorized route shapes without relying on these reference points. To test whether people form a cognitive map based on spatial reference points and use it for memorizing the route, follow-up experiments should contain a control condition without spatial reference points. An additional aspect to consider in future experiments investigating effects of map complexity is the plausibility of the displayed map elements. In this study, findings from a previous study (Keil et al., 2019) were used to control for potential effects of visual salience on landmark fixation patterns. However, as different landmarks might be considered as unusual artifacts in rural or urban maps (e.g. a wind turbine in an urban area), plausibility of landmark pictograms in specific map areas might also affect fixation patterns. In order to prevent these potential effects on fixation patterns, landmarks that are plausible in rural as well as urban areas should be identified.

Based on our findings, we recommend to increase the margin regions around a displayed route with decreasing visual complexity of the region displayed in the map by either increasing the map size or decreasing the map scale. Follow-up experiments might investigate the implications for different map scale requirements (e.g. for pedestrians, cyclists or drivers) in the context of scale-driven map generalization (see Robinson (1953)), or try to identify an ideal margin width around displayed routes based on the visual complexity of the map.

5.6 Summary

The studies presented in this paper aimed to investigate how people use a map and map elements to memorize a displayed route. The results demonstrate that people primarily focus on the map area in close proximity to the route. The size of the surveyed area was found to depend on the visual complexity of the map. When a route was displayed in a map with low visual complexity, people looked at map elements (landmark representations) farther offside the route. This eye fixation pattern might be based on a requirement of spatial reference points for the formation of a mental representation of space. As the density of spatial reference points is lower in maps with low visual complexity, people need to scan wider areas in order to identify suitable spatial reference points. These findings can support task-oriented map design of web mapping services by coupling map scale or the size of displayed margin regions around a route to the visual complexity of the map.

6 Structural salience of landmark pictograms in maps as a predictor for object location memory performance

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Abstract

Landmarks, salient spatial elements, are often argued to play an important role in the formation of mental representations of space. They are likely to be perceived due to their salience and they can be used as spatial reference points to memorize the locations of other spatial elements. In maps, landmarks are often represented as pictograms. Similar to real-world objects, their likelihood to be perceived and used as spatial reference points depends on salience characteristics. In this paper, we investigate the structural salience of landmark pictograms in maps, based on their location relative to a task-relevant object. Using eye tracking, we aimed to identify distance parameters that predict the structural salience of landmark pictograms in an object location memory task. Additionally, we investigated whether the availability of structurally salient landmark pictograms improves object location memory. Our results show that landmark pictograms close to a to-be-learned object and the cardinal axes of the to-be-learned object were fixated more often. However, only the distance to the to-be-learned object was found to be related to object location memory performance. An increased location memory performance was observed when landmark pictograms were available close to the to-be-learned object. We argue that proximity of a landmark pictogram to a task-relevant object location and its cardinal axes can be used as parameters for its structural salience. We also found some first evidence that the availability of structurally salient landmark pictograms may improve object location memory performance.

Keywords

Landmarks; Location Memory; Structural Salience; Eye Tracking; Cognitive Cartography

6.1 Introduction

People live and act within geographic space. They regularly change their current location, which requires orientation and navigation. Effective and efficient orientation and navigation depend on knowledge about the geographic space, as people need to compare visually perceived spatial elements to a spatial model (Field et al., 2011; Kitchin & Blades, 2002). Identifying spatial elements and the spatial relation between these elements allows people to determine their current location and to triangulate the direction of their target location (Foo et al., 2005; Gunzelmann & Anderson, 2006).

In unfamiliar environments or in cases when knowledge about remote spaces needs to be acquired, people rely on external representations of space, i.e. maps (Roskos-Ewoldsen et al., 1998). Maps are abstract representations of geographic space used to communicate spatial information (Montello, 2002) either without or in combination with direct experience of the represented geographic space (Uttal & Wellman, 1989). By interacting with geographic space and maps, people gradually build a mental representation of space (Millonig & Schechtner, 2007; Montello et al., 2004; Sorrows & Hirtle, 1999). Such mental representations of space (also called cognitive maps or cognitive collages, cf. Tversky, 1993) are knowledge about spatial elements and the spatial relation between these elements (Kuipers, 1982; Morris & Parslow, 2004; Tversky, 2003). Although spatial knowledge can be structurally distorted in terms of distances and directions (Dickmann et al., 2013; Mark, Freksa, Hirtle, Lloyd, & Tversky, 1999; Montello, 1998; Tversky, 1993), it allows people to navigate through geographic space without relying on external representations of space (Millonig & Schechtner, 2007), thus making the use of maps obsolete after the mental representation of space is sufficiently complex and detailed to support orientation and navigation.

Concerning the complexity of mental representations of space, it is important to realize that it is not useful to obtain 'complete' spatial knowledge, as the temporal spatial permanence can greatly vary between spatial elements. A parking car for example may change its location multiple times per day whereas a building may exist in the same location for hundreds of years. Storing objects with a low temporal spatial permanence in a mental representation of space could lead to confusion and might impair orientation and navigation if these objects disappear or change their location (cf. Keil et al., 2018). Therefore, a certain level of temporal spatial permanence seems to be required for objects to be used as anchor points for a mental representation of space.

A group of spatial elements that has been repeatedly argued to play an important role in the formation of mental representations of space are landmarks (Foo et al., 2005; Millonig & Schechtner, 2007; Sorrows & Hirtle, 1999). Defined as salient spatial elements associated with a specific location (Anacta et al., 2017; Basiri et al., 2014; Bestgen, Edler, Kuchinke, & Dickmann, 2017), landmarks not only remain in a specific location for long enough to be used as spatial reference points for a mental representation of space. Their salience also makes them more likely to receive attention than other surrounding objects (Caduff & Timpf, 2008; Röser, 2017). Additionally, locations of salient objects are more likely to be memorized accurately (Fine & Minnery, 2009). Therefore, highly salient landmarks are assumed to be ideal spatial reference points for the formation of mental representations of space.

In maps, landmarks are often represented as pictograms. The salience levels of these pictograms depend on three sub-characteristics: their visual, semantic and structural salience. Visual salience is defined by visual characteristics of an object compared to surrounding elements, e.g. color contrast or size (Duckham et al., 2010; Klippel & Winter, 2005). Semantic salience comprises individual associations with an object, as attached emotions or knowledge about its origin, purpose or relevance (Duckham et al., 2010; Raubal & Winter, 2002). Therefore, the semantic salience of an object can vary greatly between individuals. Structural salience is context dependent. The structural salience of an object is determined based on its location relative to a currently (task-) relevant object or location (Claramunt & Winter, 2007; Röser et al., 2012). Previous research concerning the structural salience of landmarks and landmark pictograms in maps has mostly focused on navigation and route memory scenarios (e.g. Keil, Edler, Kuchinke, & Dickmann, 2020; Klippel & Winter, 2005; Röser et al., 2012; Röser et al., 2013). However, the investigation of the structural salience of landmarks in the context of a location memory scenario has been neglected so far. This paper is meant to narrow this gap based on experimental investigation of the role of landmark pictograms in maps for memorizing locations. More specifically, we aim to identify spatial distance parameters for the structural salience of landmark pictograms in an object location memory scenario. As argued above, highly salient landmarks may be more likely to be integrated into mental representations of space. Therefore, we also assess whether the availability of structurally salient landmark pictograms can be used to predict location memory performance. Accordingly, we formulate the following two research questions:

1. Which spatial distance characteristics predict the structural salience of landmark pictograms in maps when object locations are learned?

2. Does the availability of structurally salient landmark pictograms in maps improve location memory performance?

The experiment described in the following sections is meant to answer these research questions and to broaden our understanding of how maps are perceived and used to build mental representations of space. If, as suggested, relative locations of landmark pictograms can be used to predict their structural salience and their relevance for memorizing object locations, this information could be used to dynamically adjust map contents based on task requirements. For example, landmark pictograms could be displayed or hidden based on their structural salience, as derived from a selected map location.

6.2 Background

Maps are (in most cases) visual stimuli consisting of a multitude of visual elements. Based on their salience, some map elements will receive more visual attention than other elements (Caduff & Timpf, 2008). Therefore, information about the distribution of visual attention across all elements in the map can be used to deduce the salience of specific map elements. Eye fixations recorded with eye trackers have been argued to be an indicator of the attentional processing of visual stimuli (J. Henderson, 2003; Just & Carpenter, 1976; Poole & Ball, 2006; Tsai et al., 2011). Therefore, they are commonly used as a measure for the salience of specific visual stimuli (e.g. Edler, Keil, Tuller, Bestgen, & Dickmann, 2020; Fabrikant et al., 2010; Keil et al., 2019; Kuchinke et al., 2016). In combination with locational information, fixation data may also be used to assess structural salience differences of landmark pictograms in maps. The underlying assumption is: if landmark pictograms in a specific location (relative to a task's relevant object location) have a higher structural salience, these landmark pictograms receive more visual attention.

In order to compare structural salience differences between landmark pictograms and to assess potential effects of structurally salient landmark pictograms on object location memory performance, it is necessary to define potential spatial parameters for structural salience. Such parameters usually reflect the proximity to a specific location. In the context of a navigation or route memory scenario, structural salience is usually argued to depend on its distance to a decision point (e.g. an intersection along the route) or the route in general (Claramunt & Winter, 2007; Keil et al., 2020; Röser et al., 2012). However, in the context of a map-based location memory scenario, these route dependent distances do not exist. The most intuitive distance parameter might be the distance between a landmark pictogram and the to-be-learned object location. Winter et al. (2008) argue that the dominance of (real-world) landmarks is inverse to its distance to a specified location. We assume that this distance may also be a relevant parameter for the structural salience of a landmark pictogram. In our second research question, we speculate that the availability of structurally salient landmark pictograms improves location memory performance. If this is the case, and if the distance between landmark pictograms and a to-be-learned object is a relevant parameter for the structural salience of landmark pictograms, recall performance of to-be-learned objects should be better if landmark pictograms are displayed close to the to-be-learned objects. This assumption is supported by the results of related studies showing that location memory is better when spatial cues used to memorize a location are closer to the to-be-learned location (Fitting, Wedell, & Allen, 2007, 2009).

A second spatial parameter of landmark pictograms that we chose to investigate in the context of structural salience and location memory performance is derived from angular information about the spatial relation between landmark pictograms and the to-be-learned object. When people perceive images, they tend to assign a coordinate system based on its rotation and shape (Rock, 1997; Tversky, 1981). Both paper maps and digital maps usually have a rectangular shape. When such maps are perceived, two cardinal axes (horizontal and vertical) are expected to be deduced parallel to the borders of the maps. These cardinal axes may affect how specific map areas and elements are processed. Dickmann, Edler, Bestgen, and Kuchinke (2017) found that grids in maps support object location memory performance even if considerable parts of the grids are covered by topographic objects. They argue that people use Gestalt principles to connect visible grid fractions with illusory grid lines that are used as an additional layer of spatial reference. Similar to such illusory grid lines, 'illusory cardinal axes' originating from a to-be-learned object location may act as reference frames to improve object location memory performance. If the location of landmark pictograms is aligned with or close to one cardinal axis of the to-be-learned object, people can focus on the distance between the two objects for memorizing the to-be-learned object location and neglect to memorize the angular relation between the two objects. E.g. memorizing a location 1 cm 'above' a specific landmark pictogram is assumed to be easier than memorizing a location that is 1 cm away from a specific landmark pictogram, but 37° clockwise from the top of the landmark pictogram. Therefore, the distance between landmark pictograms and the cardinal axes of the to-be-learned object is proposed to affect location memory performance of the to-be-learned object. Given that visual attention is partially guided by top-down attentional control (Connor et al., 2004; Hopfinger, Buonocore, & Mangun, 2000; Oliva, Torralba, Castelhano, & Henderson, 2003), people may deliberately direct visual attention towards spatial elements that are expected to be helpful for a given spatial task. Thus, if people are aware (or just expect) that landmarks close to the cardinal axes of the to-be-learned object should be preferably used as reference points for memorizing the location of the to-be-learned object, these landmarks should also have a higher structural salience (cf. Corbetta & Shulman, 2002).

Attempts to predict the spatial perception of specific map elements (in this case landmark pictograms) also need to take potential biases of spatial perception into account. When people scan visual stimuli in a specific pattern, this might affect which landmark pictograms are visually perceived and used as spatial reference points for location memory. Studies have shown that people use more horizontal than vertical saccades to scan images (Foulsham & Kingstone, 2010; Gilchrist & Harvey, 2006). This perceptual bias may be caused by habits trained by the native reading direction (cf. Afsari, Ossandón, & König, 2016). Based on these findings, we assume that the distance to the horizontal cardinal axis of the to-be-learned object is a better predictor for the structural salience of landmark pictograms than the distance to the vertical cardinal axis. Consequentially, if landmark pictograms close to the horizontal cardinal axis receive more visual attention, they should be more important as reference points for location memory than landmark pictograms close to the vertical cardinal axis.

Patterns of spatial perception can also be affected by the content of an image (Foulsham, Kingstone, & Underwood, 2008). In route memory tasks, areas offside the route have been shown to receive more visual attention when the map has a lower visual complexity, i.e. contains less spatial elements (Keil et al., 2020). Thus, low visual complexity seems to enlarge the scanned map area, assumedly because the area close to the route does not contain sufficient spatial reference points to memorize the route. As location memory also depends on the availability of spatial reference points (Montello et al., 2004), we expect that more distant landmark pictograms relative to the to-be-learned object location are fixated when the displayed maps have a low visual complexity. Conversely, as demonstrated in multiple studies (Bestgen, Edler, Müller, et al., 2017; Edler, Bestgen, et al., 2014; Edler, Dickmann, et al., 2014), location memory should be better in maps with high visual complexity, because more spatial reference points are available close to the to-be-learned object location.

In summary, we assume that the distance of landmark pictograms to a to-be-learned object and its cardinal axes affects their structural salience and relevance for memorizing the location of the to-be-learned object in a map. Visual complexity of the map is expected to be a mediator variable for these effects. For the experimental investigation of our assumptions, we formulate the following hypotheses:

H1: Landmark pictograms close to the to-be-learned object location receive more visual attention.

H2: Landmark pictograms close to cardinal axes of the to-be-learned object, especially the horizontal axis, receive more visual attention.

H3: In maps with low visual complexity, landmark pictograms farther away from the to-be-learned object location receive visual attention.

H4: Map-based object location memory is more accurate when landmark pictograms are available close to the to-be-learned object location.

H5: Map-based object location memory is more accurate when landmark pictograms are available close to the cardinal axes of the to-be-learned object, especially the horizontal axis.

H6: Map-based object location memory is more accurate in maps with higher visual complexity.

6.3 Methods

The presented study was controlled and approved by the ethics committee of the Faculty of Geosciences at the Ruhr University Bochum (February 25, 2019).

6.3.1 Participants

The sample size was selected based on a power analysis with the assumption of a moderate effect size of 0.5 (cf. Sawilowsky, 2009), a significance level of 0.05 and a power level of 0.9. Based on these values, a required sample size of 38 was calculated. In a previous eye tracking study, we had to exclude 13.6% of the participants from statistical analyses, because gaze data losses were too high (Keil et al., 2020). Based on these considerations a required sample size of $n = 43$ was computed using G*Power (v.3.1.9.3). Accordingly, 43 volunteers from Ruhr University Bochum (11 females, 32 males) were recruited for participation in the study. Their age ranged between 20 and 36 years ($M = 24.5$, $SD = 3.7$). None of the participants was informed about the study purpose until the experiment was completed.

6.3.2 Materials

Nine stimulus maps were derived from OpenStreetMap (OSM) data using Maperitive. Opposed to map data from commercially oriented map providers, OSM data is based on volunteered geographic information and free access is provided to the underlying data structure. This allowed us to completely control the map design and to remove all street name labels, as their semantical load could have affected map perception. One of the nine maps was used as a training stimulus. From the other eight maps, a second version was created. The central area of the map (one fifth of the width and height) was selected and stretched to the original size of the map (see Figure 6.1). The stretched maps had a lower visual complexity, as less elements were displayed per unit of length.

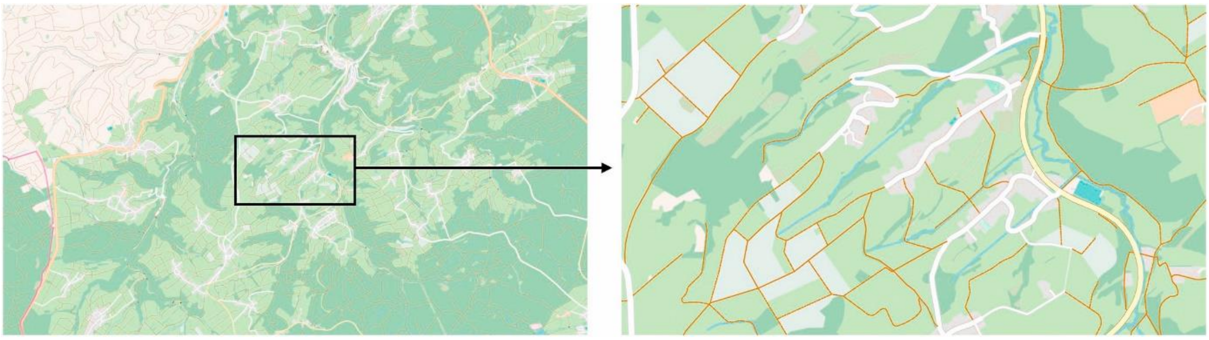

Figure 6.1. *Creation of maps with low visual complexity. In order to build map versions with lower visual complexity, the central area of eight stimulus maps was stretched to the original map size.*

Creating a second version of eight of the original maps resulted in a total of 17 maps (see example stimulus in Figure 6.2). All maps were scaled to 1920 × 1080 px and all point symbols (including landmark pictograms) were removed from the maps. Instead, 20 landmark pictograms retrieved from the OSM repository were placed with a size of 25 × 25 px on random locations in each map. To prevent effects of visual salience on the visual perception of specific landmark pictograms, all landmark pictograms were displayed black. Additionally, one red pictogram with black outlines representing a camera was added with a size of 25 × 25 px to a random location of each map. This pictogram marked a to-be-learned object location ("good location for taking a photo").

Figure 6.2. *Stimulus map example. Each stimulus map contained 20 black landmark pictograms serving as potential spatial reference points and one red pictogram that marked a to-be-learned object location.*

6.3.3 Procedure

The study comprised one training trial and 16 experimental trials. Each trial consisted of a study phase, a distractor task and a recall phase. During the study phase, one of the stimulus maps was displayed for 20 s. The order of stimulus maps was randomized. Participants had to memorize the location of the red camera pictogram ("A map containing a red camera symbol will be shown for 20 s. Please memorize the location of the camera symbol."). The subsequent distractor task consisted of two questions concerning alphabetical order (e.g. "What letter comes two positions after the letter P?"). Participants had to answer these questions using the keyboard ("Two questions concerning the order of letters in the alphabet will appear on the screen consecutively. Please answer these questions by pressing the respective letter on the keyboard."). In the recall phase, the same map as in the preceding study phase was presented. However, the red camera pictogram was not visible. Participants had to press on the memorized location using the mouse cursor and the left mouse button ("The map from the study phase will be shown, but without the camera symbol. Please click on the memorized location of the camera symbol using the left mouse button.").

6.3.4 Measures

6.3.4.1 Salience

Salience of landmark pictograms was measured based on total fixation durations assessed during the study phase with a Tobii TX300 eye tracker (23 in, 1920 × 1080 px, 300 Hz gaze recording). Round areas of interest (AOIs) with a diameter of 60 px were placed on all 20 landmark pictograms. The size difference between the landmark pictograms and the AOIs was due to the fact that no eye tracker can provide perfectly accurate gaze data. Therefore, a small buffer around the landmark pictograms was required to ensure that not too many fixations on landmark pictograms are missed (cf. Keil et al., 2020).

To investigate the proposed predictors for the structural salience of landmark pictograms, we measured the distance of each landmark pictogram to the to-be-learned object location, as well as their distance to the two cardinal axes of the to-be-learned object location (see Figure 6.3). Measuring the distance to both cardinal axes (horizontal and vertical) also allowed to assess the distance to the closer cardinal axis of the to-be-learned object. The cardinal axes were not displayed visually in the stimulus maps.

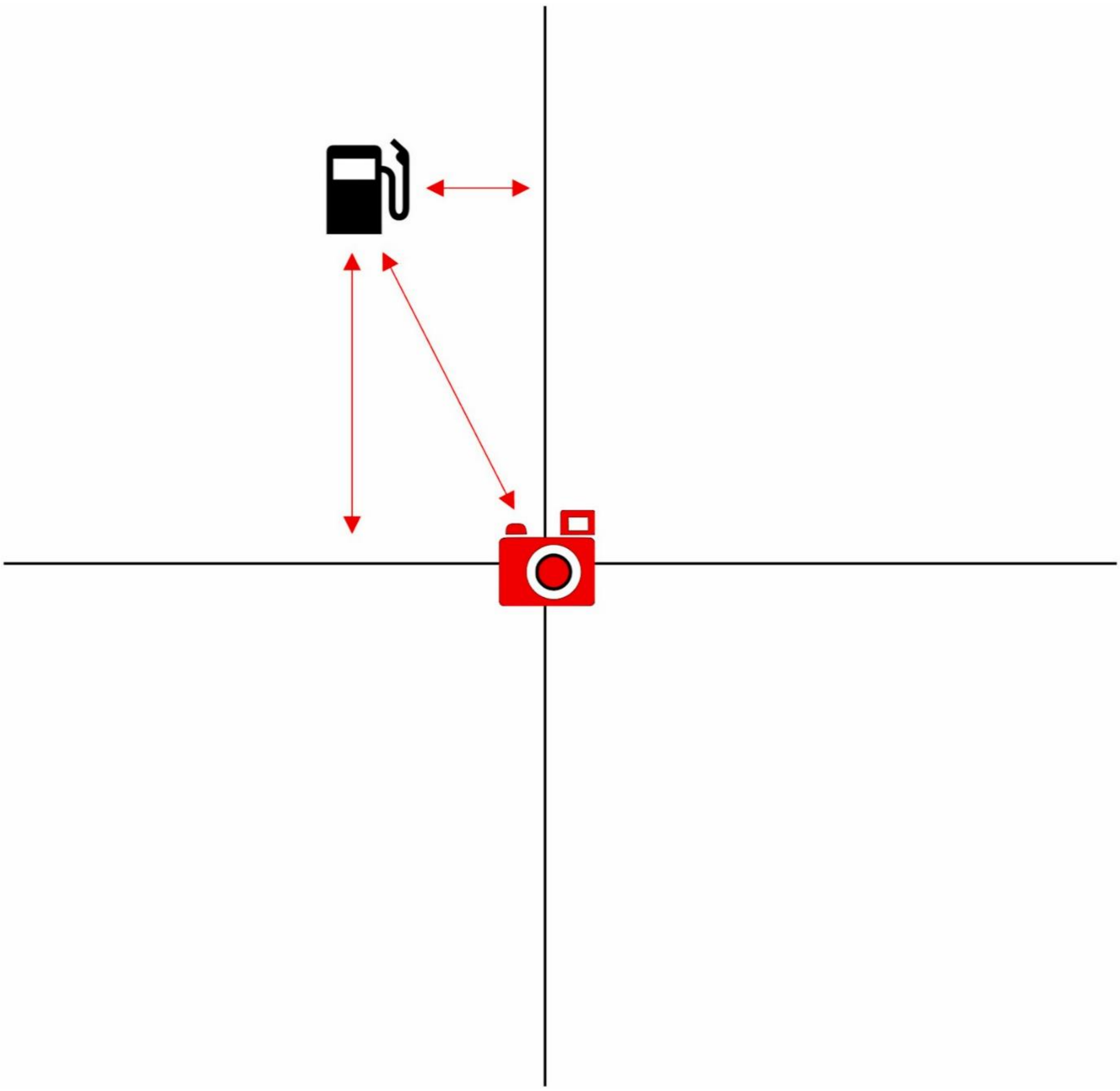

Figure 6.3. *Proposed predictors for structural salience. The distance of landmark pictograms to the to-be-learned object and its imaginary cardinal axes was assumed to predict their structural salience.*

6.3.4.2 Object location memory

Performance in the object location recall task was assessed based on the pixel distance between the correct location of the to-be-learned object and the recalled object location. The recalled object location was defined as the pixel coordinates of the mouse cursor at the moment when the left mouse key was pressed during the recall phase.

6.3.4.3 Visual complexity

As described above, eight stretched (thus visually less complex) maps were created from the OSM-based stimulus maps. In order to validate that stretching maps actually reduced their visual complexity, we saved the stimulus maps in the JPEG file format and compared the file sizes between the original maps and the stretched maps ($M_{Original}$ = 718 kB, $M_{Stretched}$ = 360 kB). JPEG file sizes are regularly used as a measure for visual complexity of image files, because the JPEG algorithm can compress the visual information into smaller files if less elements are presented in the file (Donderi & McFadden, 2005). Additionally, JPEG file sizes have been found to correlate positively with subjective user ratings of visual complexity (Stickel et al., 2010). In order to test whether the stretched maps indeed also have a lower subjective visual complexity, we asked a small sample of participants (12 participants that were not included in the sample of the main experiments) to rate the visual complexity of the 16 maps on a scale from 0 to 100 ("Please rate the visual complexity of the maps by selecting a value on the scale with the left mouse button. The left area of the scale represents a low visual complexity. The middle area of the scale represents an average visual complexity. The right area of the scale represents a high visual complexity."). A t-test showed that the stretched maps were rated as significantly less visually complex than the original maps ($M_{Original}$ = 65.54, $M_{Stretched}$ = 34.73, 95% CI [24.57, 37.06], $p < .001$). Additionally, a high and significant correlation was found between the subjective rating and the JPEG file size of the maps ($r = 0.97$, 95% CI [0.913, 0.99], $p < .001$). Thus, we replicated the findings of Stickel et al. (2010). Additionally, we showed that the stretched maps were indeed visually less complex.

6.3.5 Statistics

When recorded eye movements are statistically investigated, it is important to consider gaze data losses. Rates of gaze data losses can vary greatly between participants, because the ability of an eye tracker to track eye movements depends on criteria as eye color, eye openness and head pose (Al-Rahayfeh & Faezipour, 2013; Zhu et al., 2002). Gaze data losses are problematic, as important information may get lost and the remaining recorded gaze pattern can be distorted. Therefore, a maximum threshold for gaze data losses should be defined. Based on the suggestion of Bojko (2013), we set this threshold to 25%. This required us to exclude nine participants from analysis, which reduced the sample size from 43 to 34 participants.

In order to investigate whether the position of landmark pictograms relative to the to-be-learned-object affected visual attention towards these pictograms (H1 and H2), fixations on each pictogram were aggregated across participants. Subsequently, correlations were calculated between the fixation values and the distances of landmark pictograms to the to-be learned object and its cardinal axes. Spearman's rank correlation coefficient was used, because the fixation data contained several outliers.

A potential effect of visual map complexity on landmark pictogram fixation patterns (H3) was investigated by comparing the distances of the to-be-learned object location to all landmark pictograms that were fixated at least once between the two map conditions (original maps with high visual complexity/stretched maps with low visual complexity). Fixation data was aggregated per participant and map condition. As the data was not normally distributed in both conditions, potential differences were assessed using the Wilcoxon-signed rank test for paired data.

Whether map-based object location memory was related to the relative position of the surrounding landmark pictograms (H4 and H5) was assessed based on correlations between the object location recall performance and the distance values of the closest landmark pictogram relative to the to-be-learned object location. Four distance values were considered: distance to the to-be-learned object location, distance to the two cardinal axes of the to-be learned object location and distance to the closer cardinal axis of the to be learned object location. Additionally, correlations between the object location memory performance and the distance of the second- and third-closest landmark pictogram to the to-be-learned object location were calculated with the intention to investigate whether more than one landmark pictogram are used for memorizing the object location. As all participants saw the same landmark pictogram distributions, each distance measure contained 16 values (number of stimulus maps). Therefore, recall performance values were aggregated per map. Spearman correlation coefficients were applied, because the object location recall errors were right skewed. This is not uncommon for performance data in an object location recall task, because most participants are usually able to recall the correct location fairly accurate.

In order to assess whether visual map complexity may affect object location memory performance, recall errors were aggregated per participant and map condition (original maps with high visual complexity/stretched maps with low visual complexity), resulting in two paired values per participant. The paired values were then compared using the Wilcoxon-signed rank test, because the data was right skewed.

6.4 Results

The investigation of potential effects of the relative landmark pictogram position on the visual attention directed towards these landmark pictograms revealed a significant negative correlation between the total fixation duration on landmark pictograms and their distance to the to-be-learned object location ($r_s(318) = -0.617$, 95% CI [-0.698, −0.536], $p < .001$, see Figure

6.4, left side). Additionally, the total fixation duration on landmark pictograms was found to be negatively and significantly correlated to their distance to the closer cardinal axis ($r_s(318) = -0.513$, 95% CI [-0.597, −0.429], $p < .001$, see Figure 6.4, right side), to the horizontal cardinal axis ($r_s(318) = -0.54$, 95% CI [-0.624, −0.455], $p < .001$), and to the vertical cardinal axis of the to-be-learned object location ($r_s(318) = -0.396$, 95% CI [-0.49, −0.302], $p < .001$).

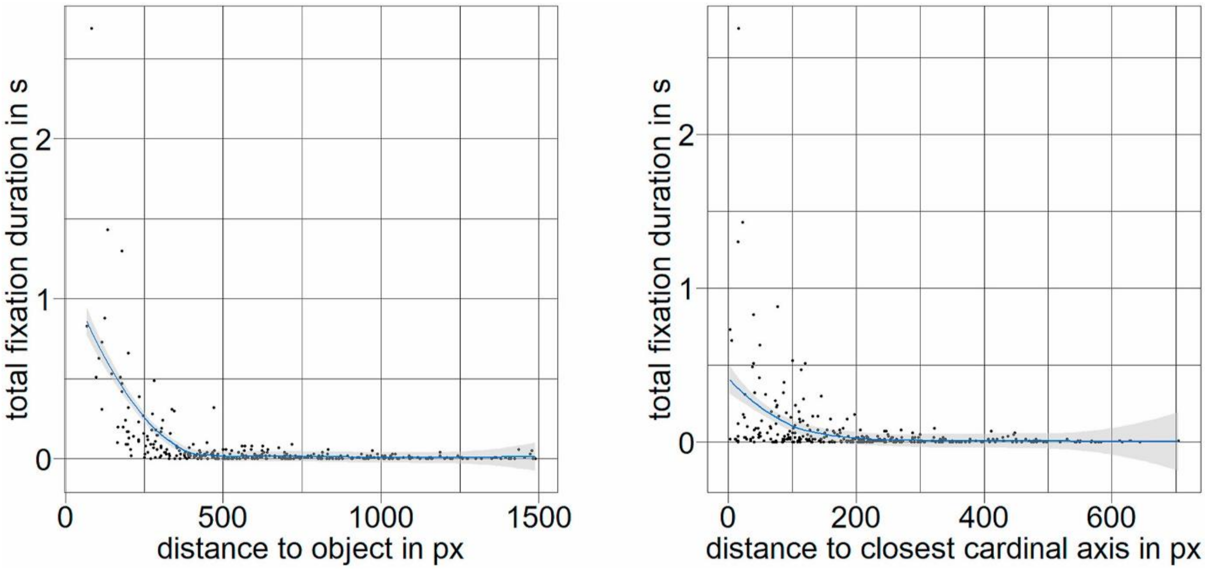

Figure 6.4. *Duration of fixations on landmark pictograms. Landmark pictograms close to the to-be-learned object (left scatterplot) and its cardinal axes (right scatterplot) were fixated more often.*

The Wilcoxon signed-rank test used to compare the average distance of the to-be-learned object location to all fixated landmark pictograms between the two map conditions (original maps with high visual complexity/stretched maps with low visual complexity) revealed no difference between the two conditions ($M_{High} = 360.21$ px, $M_{Low} = 361.9$ px, $SD_{High} = 102.77$ px, $SD_{Low} = 87.47$ px, $W = 295$, 95% CI [-38.31, 34.18], $p = .973$).

When object location memory performance is investigated, it is important to consider the risk of massive outliers caused by inattentiveness of the participants (cf. Meade & Craig, 2012). However, not every outlier should be discarded. As mentioned above, the recall performance data was right skewed. This naturally leads to outliers on the right side of the data, which need not reflect inattentiveness of the participant. Instead, many outliers may only reflect that participants differ concerning their ability to memorize object locations. Therefore, we plotted the object location recall errors for visual inspection (see Figure 6.5). The figure shows that even though most recall errors were smaller than 50 px, no considerable gap can be seen in the data distribution of recall errors smaller than 220 px. Given that 220 px corresponds to just 11.5% of the map width, we argue that response errors below this threshold are realistic and cannot be ascribed explicitly to inattentiveness. However, large gaps exist between the only two recall error values larger than 220 px (361.45 px and 738.88 px) and all other values. These massive outliers cannot be explained by the distribution of participant performance and were therefore removed from the following analyses.

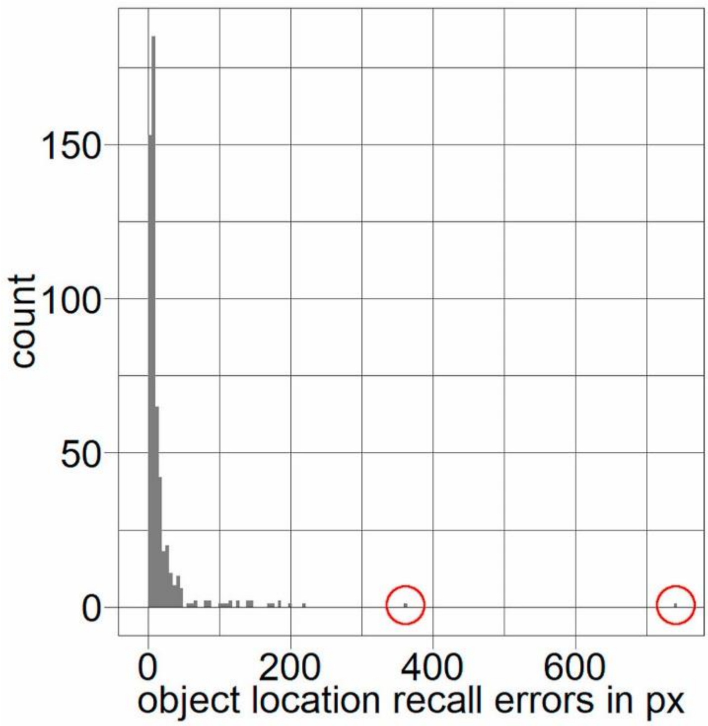

Figure 6.5. *Distribution of recall errors. Two recall error values (361.45 px and 738.88 px) cannot be explained based on the distribution of participant performance. They might have been caused by inattentiveness and were therefore excluded from the statistical analyses.*

Object location recall errors were significantly correlated to the distance of the to-be-learned object location to the closest landmark pictogram ($r_s(14) = 0.532$, 95% CI [0.05, 0.813], $p = .036$). However, correlations between the object location recall errors and the distance of the to-be-learned object location to the second-closest landmark pictogram ($r_s(14) = 0.406$, 95% CI [-0.112, 0.751], $p = .12$) or to the third-closest landmark pictogram ($r_s(14) = 0.206$, 95% CI [-0.323, 0.637], $p = .443$) were not significant.

No statistically significant correlations were found between the object location recall errors and the distance of the closest landmark pictogram to the closer cardinal axis ($r_s(14) = -0.119$, 95% CI [-0.782, 0.547], $p = .66$), to the horizontal axis ($r_s(14) = 0.315$, 95% CI [-0.214, 0.701], $p = .235$), or to the vertical axis ($r_s(14) = -0.041$, 95% CI [-0.464, 0.526], $p = .882$) of the to-be-learned object location.

Comparing the object location memory performance between the two map conditions (original maps with high visual complexity/stretched maps with low visual complexity) with the Wilcoxon signed-rank test showed that recall errors were significantly lower in maps with high visual complexity (M_{High} = 14.26 px, M_{Low} = 17.18 px, SD_{High} = 14.21 px, SD_{Low} = 9.02 px, W = 182, 95% CI [-6.87, −0.02], p = .048).

6.5 Discussion

Based on our results, we were able to confirm our first hypothesis. Landmark pictograms close to the to-be-learned object received more visual attention. This is in agreement with the statement by Winter et al. (2008) that the dominance of landmarks is inverse to its distance. We assume that the visual salience of the to-be-learned object (high color contrast of the black and red camera) directed visual attention towards its location quickly after stimulus onset. Hereafter, people seem to have looked for potential spatial reference points in the proximate area of this location. Thus, similar to real-world landmarks, distance to a task—relevant object (the to-be-learned object) is argued to be an appropriate spatial parameter of the structural salience of landmark pictograms in maps.

Similar results have been found for the second proposed spatial parameter of structural landmark pictogram salience in object location memory tasks. Landmark pictograms received more visual attention when they were located close to the cardinal axes of the to-be-learned object. Therefore, we can confirm our second hypothesis. As hypothesized by Rock (1997) and Tversky (1981) people seem to apply an invisible coordinate system to perceived images. However, it remains uncertain whether the cardinal axes were applied based on the egocentric coordinate system ("long axis of the observer's head and body", p.142) as proposed by Rock (1997), or based on the borders of the displayed image. To answer this question, future experiments could apply random rotations to the rectangular maps or the monitor.

Additional insights were obtained when the relation between fixations on landmark pictograms and their distance to the cardinal axes of the to-be-learned object was investigated separately for the horizontal and the vertical cardinal axis. Although all correlations were statistically highly significant, differences in the effect size were found (according to Cohen, 1988, correlations can be interpreted as effect sizes). The effect size for the distance to the horizontal axis was larger than the effect size for the distance to the closer cardinal axis of the to-be-learned object. The effect size for the distance to the vertical axis was smaller than the effect size for the distance to the closer cardinal axis of the to-be-learned object. Thus, as landmark pictograms close to the horizontal cardinal axis were more likely to be fixated, we found a first indication that a bias towards horizontal scanning patterns may affects the visual perception of specific landmark pictograms. This is in agreement with previous findings regarding biases of spatial perception (Foulsham & Kingstone, 2010; Gilchrist & Harvey, 2006) and may be a reflection of behavioral patterns trained based on the native reading direction, as reported by Afsari et al. (2016). Another explanation for the higher salience of landmark pictograms close to the horizontal cardinal axis of the to-be-learned object could be the screen aspect ratio. As conventional for modern computer screens, the maps were displayed on a screen with a landscape format. Thus, participants could expect to find more landmark pictograms and other spatial reference points along the horizontal axis. Whether such an expectation can affect fixation patterns could be investigated by comparing fixation patterns between maps displayed on landscape and portrait format screens. As the smartphone, a device that can be used in both landscape and portrait format, has become an important medium for map use (Schmidt & Weiser, 2012), investigating potential effects of screen format on map perception patterns could help to improve how people perceive and use maps.

Previous findings indicate that the visual complexity of a map affects fixation patterns. Keil et al. (2020) conducted a route memory task and found that people fixate numerous landmark pictograms farther offside the route when the map has a low visual complexity. Contradictory to this finding, we found no effects of visual map complexity on fixation patterns in this study. In both complexity conditions, almost all fixations were targeted on landmark pictograms close to the to-be-learned object. Therefore, we were not able to confirm our third hypothesis. We argue that the contradiction with the findings of Keil et al. (2020) may reflect different requirements for memorizing a route and memorizing a location. Routes consist of multiple locations (start point, decision points, end point). Therefore, multiple suitable reference points are required to memorize each of these locations and their sequence. Location memory however is knowledge of only one isolated location without directional information. Therefore, memorizing the location of a to-be-learned object relative to the closest suitable spatial reference point seems to be sufficient.

It is important to note that the identified fixation patterns related to the relative location of landmark pictograms and map complexity reflect the acquisition of spatial knowledge purely based on map information. It is uncertain to what extent the findings are transferrable to map use in a real-world environment. In the real world, proximal landmarks may be hidden behind other objects, whereas some distant landmarks may be visible (cf. Stülpnagel & Frankenstein, 2015). Therefore, when people try to compare real-world objects to their representations in maps, visibility of landmarks in the world is assumed to affect fixations on its representation in the map.

Our second research question implied that the availability of structurally salient landmark pictograms might affect object location memory. Indeed, in agreement with our fourth hypothesis, we found that location memory was better when landmark pictograms were available close to the to-be-learned object location. However, significant effects were found only for the closest landmark pictogram. Significance and effect size gradually decreased when effects of more distant landmark pictograms were investigated. As the effects of the second- and third-closest landmark pictograms were not statistically significant, we cannot infer that they affected object location memory. These results are in agreement with findings of Fitting et al. (2007, 2009), who reported that proximity of spatial reference points affects object location recall performance. It also supports our assumption that location memory requires less spatial reference points (maybe even only one) than route memory. As reported above, the closest landmark pictograms relative to the to-be-learned object location were also fixated more often. Thus, people seem to focus their attention on spatial reference points that support the acquisition of accurate spatial memory. A question that has not been addressed in this study is whether the location of a landmark pictogram relative to other landmark pictograms affects its relevance for location memory. For example, if one landmark pictogram is located very close to another landmark pictogram, it can be assumed that only one of the two is used as a spatial reference point for a memorized location. If such interactions between landmark pictograms exist, they could affect the structural salience of landmark pictograms.

In contrast to the distance of landmark pictograms to the to-be-learned object, no statistically significant relation was found between object location recall performance and the distance of the closest landmark pictogram to the closer cardinal axis of the to-be-learned object. A trend can be seen when the horizontal and vertical cardinal axes are investigated separately. Distance to the horizontal axis shows a stronger relation to location memory performance. However, the test results are not significant. Therefore, we cannot confirm our fifth hypothesis. Our results are in line with findings of Waller, Loomis, Golledge, and Beall (2000), who reported that people memorizing locations in the real world rely more on distance information than on angular information of spatial reference points. Although spatial memory effects in 3D space cannot automatically be transferred to spatial memory in 2D maps, we found some evidence that, similar to real-world location memory, distance information seems to be more important for map-based location memory. Both the distance of landmark pictograms to a to-be-learned object and the distance to its cardinal axes have been argued to affect the structural salience of landmark pictograms, but only the distance to the to-be-learned object seems to affect location memory performance. However, based on the weak trend seen when the results are compared between the horizontal and vertical cardinal axis, further studies with larger sample sizes may be required to rule out a type II error.

Finally, in agreement with previous findings (Bestgen, Edler, Müller, et al., 2017; Edler, Bestgen, et al., 2014; Edler, Dickmann, et al., 2014), we found that location memory performance was better in maps with higher visual complexity. Therefore, we can confirm our sixth hypothesis. We argue that the additional spatial elements provided in maps with higher visual complexity can be used as spatial reference points and thereby support object location memory. One might argue that the availability of additional spatial reference points close to the to-be-learned object may reduce the relevance of landmark pictograms for object location memory. However, this is not reflected in our data, as no differences in fixation patterns on landmark pictograms were found between the two map complexity conditions. Therefore, we conclude that people seem to use landmark pictograms in maps for approximation of memorized object locations. If a landmark pictogram is displayed close to the to-be-learned object, accurate location memory should be enabled based on the landmark pictogram alone (Fitting et al., 2007, 2009). If no landmark pictograms are available in close proximity of the to-be-learned object location, people may expand the spatial reference frame provided by landmark pictograms with other spatial reference points. However, if the map complexity is low and insufficient spatial reference points are available in close proximity to the to-be-learned object location, location memory performance is expected to be less accurate.

6.6 Summary and outlook

Based on our findings, we were able to verify two spatial distance parameters for the structural salience of landmark pictograms in the context of a map-based object location memory task: a) distance of landmark pictograms to a to-be-learned object, and b) distance of landmark pictograms to the projected cardinal axes of a to-be-learned object. Landmark pictograms close to a to-be-learned object and its cardinal axes (especially the horizontal axis) were fixated more often and are therefore argued to have a higher structural salience. Additionally, object location memory performance was found to be better when landmark pictograms were available close to a to-be-learned object. Thus, people seem to focus their visual attention on spatial reference points that support location memory particularly well. Future research needs to inspect how the tendency to fixate landmark pictograms close to the cardinal axes of a to-be-learned object relates to the orientation and format of the used screen or map, as rotations could affect the subjective coordinate system applied by the perceiver. Additionally, a replication of the study in a real-world scenario or a virtual 3D environment is required to investigate how landmark visibility in 3D space affects the salience of their representations in a map.

7 General Discussion

The background section and the studies reported in the foregoing chapters aimed to investigate to what extent the predictions of visual landmark perception based on established salience characteristics as semantic, visual and structural salience can be transferred to landmark representation in maps and potentially other map elements. Furthermore, it was assessed whether landmark representations rated as salient based on these characteristics support the acquisition of spatial memory. The aim was to extend insights of cognitive landmark processing and their effects on spatial memory from real-world landmarks to landmark representations in maps. The findings were also meant to help map designers to predict and control the distribution of visual attention across maps, to identify task-relevant map elements, and to direct visual attention towards these elements. In the following sub-sections, the experimental results of the reported studies are discussed. Similarities and differences between the visual attention directed towards real-world landmarks, landmark representations in maps and other map elements, as well as their effects on spatial memory are addressed. Constructive approaches and objectives for further research are suggested. Finally, based on the reported findings and gained knowledge, implications for task-oriented map design are derived.

7.1 Measuring Salience

In the experiments reported in this thesis, salience of landmark pictograms in maps and other map elements has been assessed based on visual attention directed towards these map elements, because salience has been defined as the tendency of a stimulus to attract visual attention (Caduff & Timpf, 2008). Visual attention in turn was measured based on fixations recorded with an eye tracker. Fixations, short “moments when the eyes are relatively stationary” (Poole & Ball, 2006), are associated with the cognitive processing of the visual stimuli in the foveal area of the eyes and are commonly used as a measure for visual attention (Franke & Schweikart, 2017; Just & Carpenter, 1980; Poole & Ball, 2006; Tsai et al., 2011; Wenczel et al., 2017). However, it is important to consider that cognitive processing and visual attention are not strictly limited to the narrow foveal area (Irwin, 2004). The useful field of view describes the area around the central fixation point in which visual stimuli can be visually processed (Mackworth, 1976). This area has been found to be larger than the foveal area (Williams, 1982). Thus, visual stimuli may be processed that are not located directly on the central fixation point (Just & Carpenter, 1976). Due to potential occurrences of covert attention, shifts of attention without moving the eyes (Carrasco & McElree, 2001), recorded fixations may not unambiguously reflect the allocation of visual attention. Still, performance on detecting critical visual detail has been found to be inverse to the distance to the nearest fixation (Nelson & Loftus, 1980). Therefore, although there is no direct and distinct causation between fixations and cognitive processing, in absence of a better measure, recording fixations is still the best option for assessing the distribution of visual attention and deducing salience based on the measured distribution of visual attention.

7.2 Semantic Salience

It has already been discussed in the background section that the semantic salience of real-world landmarks differs from the semantic salience of landmark representations in maps. The former depends on the cultural relevance of a landmark (Nothegger et al., 2004; Raubal & Winter, 2002) and individual semantic associations with it (Nuhn & Timpf, 2017; Quesnot & Roche, 2015a). The latter is argued to be affected by the generalization and abstraction processes associated with map making. Landmarks that are semantically highly salient to some individuals may not be represented in a map, or at least not highlighted with a landmark representation. Furthermore, the common use of abstract pictograms as landmark representations can affect semantic salience. The grouping of landmarks into semantic groups that are represented by the same pictogram makes landmarks less distinguishable. For example, people cannot identify their favorite restaurant in a map solely based on a pictogram, because the same pictogram is used to represent every other restaurant as well. Another threat for semantic salience is the limited ability to deduce semantic characteristics from pictograms used to represent landmarks in maps. Spinillo (2012) argued that the interpretation of pictograms depends on the cultural background of the observer. Furthermore, individual knowledge and design qualities may affect to what extent the correct semantic characteristics of a pictogram can be deduced (meaningfulness). Thus, semantic salience of landmark representations in maps was assumed to vary between pictograms and observers.

The first study reported in chapter 3 investigated such potential differences of the meaningfulness of pictograms used to represent landmarks in OSM maps. The results demonstrated that there is indeed great variation of meaningfulness between pictograms. These differences can be partially ascribed to the design quality. For example, the pictogram used to represent embankments is extremely minimalistic and abstract (see Figure 3.3). The inability to interpret such a pictogram without additional legend information suggests poor design choices. In agreement with Spinillo (2012), additional differences are likely to be attributable to the cultural background of the observers. This can be illustrated well by comparing meaningfulness ratings of pictograms representing religious buildings. The participants in the study sample gathered in Germany, thus in a mostly Christian country, rated the landmark pictogram that represents Christian churches as highly meaningful, whereas the landmark pictogram representing a Sikh temple received extremely low meaningfulness ratings. As both pictograms use symbolism that is highly established in the respective religious tradition, differences in the meaningfulness must be ascribed to the cultural background of the observer instead of design choices.

A second goal of the study reported in chapter 3 was to assess to what extent semantic characteristics of landmark pictograms affect the distribution of visual attention. In other words, it was investigated whether semantic salience effects can be demonstrated for landmark representations. According to Duckham et al. (2010), familiar (thus meaningful) spatial elements are better landmark candidates. Furthermore, Quesnot and Roche (2015a) found that highly semantic objects attract more attention if the perceiver is a local, who would be more likely to be familiar with the purpose or meaning of the objects. Thus, objects are only assumed to be semantically salient and to be used as landmarks if the perceiver has specific semantic associations with it, provided that the objects have no other (e.g. visually) salient properties. Interestingly, in the study reported in chapter 3, landmark pictograms with an extremely low meaningfulness rating were fixated more often. This is in contradiction with Duckham et al. (2010) and Quesnot and Roche (2015a), but it fits to studies demonstrating that unfamiliar objects can attract visual attention, potentially due to an increased interest in the object (Jurkat, Köster, Yovsi, & Kärtner, 2020; Leckart, 1966). This indicates that semantic salience is not necessarily only high if the meaningfulness of a landmark representation is high. The relation between object meaningfulness and semantic salience seems to be U-shaped with semantic salience also being high if an object is much less meaningful to the perceiver than surrounding objects. Similar to visual salience, the semantic salience of objects seems to be a relative characteristic that depends on the semantic properties of surrounding objects (Klippel & Winter, 2005). Thus, a large semantic contrast to surrounding objects seems to be a suitable predictor for the likelihood of a pictogram to attract visual attention. However, concerning the generalizability of the reported results, it is important to consider that in this study, pictograms were presented without a contextual background as a 2D map. Therefore, semantic contrast was solely based on semantic differences between these pictograms, most of which have at least a moderately high meaningfulness. In a map context, the semantic salience of landmark pictograms with a low meaningfulness might be less pronounced. As most map elements are semantically relatively neutral (e.g. roads, buildings, green spaces), the semantic contrast of pictograms with a low meaningfulness is assumed to be low, whereas pictograms with a high meaningfulness are assumed to have a high semantic contrast, thus a higher semantic salience and should attract more visual attention.

In addition to an increased visual attention, memory for previously presented landmark pictograms with a low meaningfulness was more accurate. As pictograms with a low meaningfulness have been argued to have a high sematic salience due to their high semantic contrast, this indicates a higher likelihood to memorize semantically salient landmark pictograms. This is in agreement with Santangelo (2015), who reported that semantics can affect memory performance. It also supports the assumption of Snodgrass and Vanderwart (1980) that unfamiliar picture stimuli are more easily recognized. This could be ascribed to the fact that familiar stimuli might have been experienced on multiple occasions and under different circumstances. For example, landmark pictograms representing supermarkets or restaurants are used and perceived in maps quite frequently. Therefore, it is more difficult to correctly recall specific occasions of where and when these landmark representations were perceived. However, as no statistically significant relation was found between visual attention and memory performance, variations of visual attention between pictograms can be ascribed to semantic properties, but not to a semantic salience based on these properties. Therefore, it cannot be answered conclusively whether semantic salience based on a semantic contrast leads to improved memory performance. As indicated by the high visual attention directed towards visually complex pictograms, visual salience effects may have partially covered up semantic salience effects on visual attention and consequentially on spatial memory.

In order to uncover how semantic salience of landmark pictograms interacts with other map elements, further studies are required. Nevertheless, the study reported in chapter 3 provided first evidence that, similar to real world landmarks, semantic associations with landmark pictograms affect the distribution of visual attention. Therefore, similar to real-world space, semantic salience has been found to be a suitable predictor for the visual attention directed towards single landmark pictograms in maps. Future studies aimed to investigate potential effects of semantic salience on the memory for landmark pictograms need to control potential visual salience effects based on pictogram complexity.

7.3 Visual Salience

The visual salience of landmark pictograms in maps has been argued to differ from the visual salience of the real-world objects they represent, because they are usually abstract and do not share the visual characteristics of the represented objects. Furthermore, pictogram colors are often standardized based on a semantic category they are sorted into. The same is true for surrounding map elements and background layers representing streets, houses, parks, forests etc. As visual salience depends on the visual contrast between an object and surrounding objects (Claramunt & Winter, 2007; Klippel & Winter, 2005), selecting colors of map elements based on semantic categories leads to a blending of visual and semantic characteristics.

The use of semantic color schemes can affect how visual attention is distributed across a map and what landmarks are most likely to attract visual attention (cf. Itti, 2005). For example, both Google Maps and OSM display landmark pictograms representing medical facilities red, a color rarely used for other landmark pictograms or map elements. Thus, the visual salience of pictograms representing medical facilities is usually high, making them more likely to attract visual attention. In addition to the use of contrast rich color schemes, the visual attention directed towards map elements can be manipulated by applying transparency. Sutherland, McQuiggan, Ryan, and Mather (2017) found that transparency reduces visual salience and can be used to direct visual attention away from visual stimuli. The study reported in chapter 4 aimed to extend these findings to the map context. As expected, making specific map areas transparent directed visual attention away from these map areas.

The ability to control the distribution of visual attention across a map based on the strategic use of visual salience characteristics as color or transparency offers great potential for task-oriented map design. Visual attention can be directed towards task-relevant map elements and away from irrelevant or distracting map elements (cf. Wolfe, Birnkrant, Kunar, & Horowitz, 2005). In digital maps, color and transparency schemes could be applied based on a specified task. For example, if a route is selected and displayed in a map, elements in the map that support route memory and navigation could be highlighted with a high contrast color. An example for such a task-oriented adjustment of visual salience is demonstrated in the study in chapter 4. The application of transparency to map areas offside a displayed route was meant to direct visual attention towards the map area close to the route, as elements in this area were assumed to be more relevant for route memory. However, supporting spatial tasks with the strategic adjustment of visual salience of map elements requires exact knowledge about which elements are relevant in specific tasks. Otherwise, visual attention could be directed towards irrelevant map elements and away from important map elements.

Although theoretically possible, popular web mapping services as Google Maps and OSM do not apply task-oriented adjustments of visual salience characteristics. Therefore, the distribution of visual attention across the map will be more or less appropriate based on the standardized predefined design rules and a specified spatial task. This can be illustrated based on the already mentioned visually highly salient pictograms representing medical facilities in Google Maps and OSM. Although medical facilities are certainly a highly important semantic category in medical emergency situations, some of them (e.g. a visually inconspicuous physician's office) may be less relevant for everyday spatial tasks as orientation, navigation and the formation of mental representations of space. Landmark pictograms highlighted in maps with contrast-rich colors based on their semantic properties need not represent the best landmarks for specific orientation and navigation tasks or for the formation of a mental representation of space. For the selection of landmarks in real-world space, semantic salience is not always a prerequisite. It has been repetitively demonstrated in studies that people preferably select spatial objects as landmarks that have visually salient characteristics such as a large visibility and uniqueness (Burnett, Smith, & May, 2001; Clarke et al., 2013; Röser, 2017; Stülpnagel & Frankenstein, 2015). Furthermore, Dong et al. (2020) found first evidence that visual salience is the dominant predictor for landmark selection in wayfinding tasks. Thus, a particularly large or colorful spatial object can be a good landmark without being sorted into a specific semantic category. As the selection of landmarks to be displayed in maps is usually based on semantic properties alone, spatial elements that qualify as suitable landmarks for spatial tasks only based on visual characteristics are often not appropriately represented in maps. Their visual salience can be overwritten by sorting them into subcategories that are represented in maps with inconspicuous colors and shapes, if they are represented at all.

When people rely on map information to perform a spatial task, differences between the visual salience of real-world objects and their representations in maps might force them to use landmarks as spatial reference points that would not qualify as landmarks based on visual characteristics. Map-based spatial task performance depends on the ability to match real-world objects to their map representations (Kiefer et al., 2014). However, to what extent the discrepancy of visual salience between real-world objects and their map representations affects the performance in spatial task has not been investigated yet and goes beyond the scope of this thesis. Future studies should address the potential of representing and exaggerating visually salient characteristics of real-world landmarks in maps. It can be assumed that matching real-world landmarks and landmark representations in maps would be easier if they share visual characteristics. Consequentially, orientation and navigation performance should improve, because spatial information provided by the map can be easily linked to the corresponding real-world space and vice versa.

Taken together, visual salience has been identified as a suitable predictor for the direction of visual attention towards landmark representations, routes and specified areas in maps. Similar to real-world landmarks, these map elements may be more or less visually salient based on their visual characteristics relative to surrounding objects. However, the visual salience of real-world objects is usually not related to the visual salience of their representations in maps, because the color contrast of the latter often depends on color schemes applied based on semantic characteristics of the represented objects. Applying visual characteristics of real-world landmarks to their map representations might help to improve orientation and navigation performance, because landmarks can be easily matched to their map representations.

7.4 Structural Salience

In addition to semantic and visual salience, the visual attention directed towards landmarks can be affected by its relative location to task-relevant locations. The general assumption is that landmarks are structurally salient if they are located close to a route and its (potential) decision points (Elias & Paelke, 2008; Klippel & Winter, 2005; Lovelace et al., 1999; Röser et al., 2011). Previous studies have reported on the effects of structural salience on visual attention, navigation, route memory and wayfinding instructions (Albrecht & Stuelpnagel, 2018; Blades & Medlicott, 1992; Michon & Denis, 2001; Röser et al., 2013; Wenczel et al., 2017). These studies focus on the structural salience of landmarks in real-world or virtual 3D space. The four studies reported in the chapters 4, 5 and 6 aimed to extend these findings by investigating to what extent parameters and effects of structural salience are applicable to landmark representations in maps and map elements in general.

The study reported in chapter 4 gave first insights into the effects of structural salience on the distribution of visual attention across maps. It was demonstrated that not only landmark representations, but the whole map area close to a displayed route received more visual attention than map areas offside the route. These findings demonstrate that, similar to real world perception, structural salience affects the distribution of visual attention across maps. Distance to a displayed route was identified as a first parameter for the structural salience of a map element.

The application of transparency to areas offside the route demonstrated that visual, structural and semantic salience can either reinforce each other or work against each other. By reducing the visual salience of areas offside the route with transparency, even more visual attention was directed towards the areas around the route containing structurally salient landmarks. Thus, due to a seemingly appropriate design decision, both visual and structural salience directed visual attention to the same map area. However, inappropriate design decisions could also lead to visually and structurally salient map elements competing for visual attention. For example, making areas around the displayed route transparent should direct visual attention away from structurally salient map elements. In the described study, such a competition for visual attention has been demonstrated between visual salience and semantic salience. Although the semantic landmark pictograms offside the route were not affected by the transparency filter, almost no fixations were directed towards the areas offside the route when the rest of the map elements in this area were transparent. These findings illustrate how important an understanding of the effects of design choices on salience and the direction of visual attention is for the generation of task-oriented maps.

The fact that making areas offside the displayed route transparent did not affect route memory performance demonstrates that structurally salient objects play a central role in memorizing routes in maps. Given that map elements in the transparent areas received almost no visual attention, it is unlikely that they were used as reference points for memorizing the route. Nevertheless, route memory performance was similar to the non-transparent condition associated with more visual attention directed towards map areas offside the route. Apparently, map elements offside the route brought no further benefit for route memory. This is in agreement with findings of Albrecht and Stuelpnagel (2018) that demonstrate the importance of structurally salient landmarks for route memory in 3D space.

In addition to the distance to a displayed route, the two studies reported in chapter 5 identified two more parameters for the structural salience of landmark representations: distance to decision points and distance to potential decision points as crossroads. Landmark representations close to decision points and potential decision points were found to attract more visual attention. The findings demonstrate that the parameters predicting the structural salience of landmark representations in maps relative to a route are similar to the parameters identified for real-world navigation tasks (cf. Elias & Paelke, 2008; Lovelace et al., 1999).

The effects of different map complexities on the distribution of visual attention reported in the second study in chapter 5 illustrates that the structural salience of landmark representations depends on the general map context. Visually more complex maps contain more elements that could be used as reference points to memorize a displayed route. Some of these map elements will have a higher structural salience than the available landmark representations, because they are closer to the route and its (potential) decision points. This is reflected in the fact that landmark representations further offside the route received less visual attention when the map was visually more complex.

That the availability of more spatial reference points in the visually more complex maps did not affect the generally high route memory performance indicates a ceiling effect. Either, memorizing the routes was too easy or the visually less complex maps already contained sufficient spatial reference points to memorize the route. In order to investigate potential effects of structural salience on map-based route memory, task difficulty should be increased by adding more turnoff points to the routes. Furthermore, varying the positions of landmark representations relative to the routes instead of varying the general map complexity would help to relate memory performance directly to the identified structural salience parameters distance to the route and distance to (potential) decision points. If such a relation between structural salience and route memory performance can be identified, follow-up studies could investigate potential effects of displaying structurally salient landmarks in maps on real-world navigation performance.

As mentioned above, structural salience is usually defined based on the location of a landmark relative to a defined route (Klippel & Winter, 2005; Röser et al., 2011). Relative locations to other single locations are only considered if these are relevant for a specific route, for example a (potential) decision point at a crossroad or junction. However, in orientation tasks, the structural salience of landmarks could also be defined based on their relative location to single task-relevant locations that are not relevant for a specific route. According to Golledge (1999a), landmarks “may have visible dominance such that surrounding features can be most easily described by relating their locations to the nearby landmarks or reference nodes”. In other words, landmarks could act as reference points for less salient objects nearby. If this is the case, landmarks should attract more visual attention if they can act as reference points for task-relevant object locations. Furthermore, the availability of structurally salient landmarks should support object location memory, because object locations should be easier to conceptualize.

The final study reported in chapter 6 was designed to address the assumption that structural salience can be defined independent of a specific route. The focus was placed on the structural salience of landmark representations in maps based on the location relative to a task-relevant object location. Based on the findings, two parameters for structural salience were identified, because they were related to the attraction of visual attention: distance to the task-relevant object location and distance to the cardinal (horizontal and vertical) axes of the task-relevant object location. The availability of landmark representations close to the to-be-learned object location was also associated with a more accurate object location recall. This supports the assumption that structurally salient spatial reference points support object location memory in maps.

It can be concluded that structural salience in maps is indeed not necessarily route-dependent. Landmark representations can also affect the distribution of visual attention across a map in object location memory tasks. Interestingly, with the distance of landmarks to the cardinal axes of a task-relevant object, a parameter for structural salience has been identified that is applicable to the map context, but not to real-world objects. The usually rectangular shape of maps and the angular orientation of map elements based on the viewing perspective imposes the availability of an up, down, left and right direction, as well as a horizontal and vertical axis (cf. Tversky, 1981). Therefore, object locations can be memorized as being located up, down, left or right from a spatial reference points as a landmark representation. In a real-world scenario however, explicit cardinal axes are not available, making them irrelevant as means for structuring space and consequentially as parameters for structural salience.

The four studies reported in the chapters 4, 5 and 6 demonstrate that structural salience affects the distribution of visual attention across maps. Furthermore, similarities and differences concerning the parameters of structural salience in real-world space and in maps have been identified. The parameters distance to the route and distance to (potential) decision points used in real-world space have been demonstrated to be also applicable in maps. In addition to these parameters, structural salience of map elements has been shown to be affected by their location relative to a task-relevant object location and its cardinal axes. Whereas the distance to the cardinal axes has been argued to not be transferable to real-world space, future studies need to assess whether the structural salience of real-world objects can be predicted based on their distance to task relevant object locations.

7.5 Implications for Map Design

As already mentioned above, the aim of the reported studies in specific and this thesis in general was to assess how semantic, visual and structural salience can be used to predict and direct the distribution of visual attention across a map. In an ideal task-oriented map, design-based salience characteristics direct visual attention towards map elements that are associated with an improved acquisition of task-relevant spatial knowledge. Therefore, effects of salient map elements on spatial memory were also assessed. Based on the acquired findings, new guidelines for the effective and efficient communication of map information can be deduced. Each study reported in this thesis provides additional insights into similarities and differences of salience effects in real-world space and in maps and effects on spatial memory that can be used to improve the task-oriented communication of spatial information with maps.

The investigation of landmark representations in maps played a central role in this thesis. The decision of map creators to represent specific landmarks as accentuated pictograms in a map reflects the assumption that these specific representations are important for the communication of spatial information. This raises the question to what extent the pre-selection of landmarks is in line with task-dependent requirements. Based on the results of the reported studies, the following paragraphs address this question and emphasize the importance of context for the selection of landmarks to be highlighted in maps. Furthermore, common limitations of landmark display in established maps are discussed and more reasonable alternatives are suggested.

Several models have been proposed for the selection of landmarks to be used in spatial tasks. The criteria used in these models include spatial permanence, visibility, relative location, uniqueness, size, shape, density of objects in the direct neighborhood, orientation, and historical or cultural significance (Elias, 2003; Elias & Sester, 2006; Quesnot & Roche, 2015a; Winter, 2003). All these criteria except spatial permanence can be linked to visual, structural and semantic salience characteristics and are context dependent (see chapter 2.3). Opposed to classical paper maps, modern digital maps allow to dynamically adjust the displayed map content based on predefined conditions. These possibilities could be used to create more task-oriented maps. Despite this potential and the proposed models, most salience characteristics and the context they depend on are usually ignored in the selection process of landmarks to be represented in maps. Instead, most digital maps only represent landmarks that fit into predefined semantic categories. Thus, important task-dependent salience characteristics that predict the use of spatial elements as landmarks are ignored. Consequentially, unimportant map elements may be visually highlighted and important map elements may be visually underrepresented. Of course, it has to be considered that previously proposed models for landmark selection in real-world space are not applicable to maps if the salience parameters that affect the distribution of visual attention differ between real-world space and maps. Therefore, in order to support the acquisition of spatial knowledge from maps, map creators need to account for the differences between the selection of landmarks used to make sense of real-world space and the selection of landmarks in maps. In the following sections, map design suggestions are provided based on the identified similarities and differences of the selection of real-world landmarks and landmark representations in maps and their effects on the acquisition of spatial memory and spatial task performance.

Consider the semantic knowledge of the map's target users

One of the most important recommendations for the representation of landmarks in maps is related to the communication of semantic information. If abstract pictograms are used to represent landmarks, it is essential that map readers are able to interpret these pictograms correctly. Otherwise the representation cannot be matched to the represented real-world object. The first study demonstrated that not only the lack of specific culture-dependent knowledge can affect the ability to interpret a landmark pictogram correctly. Some pictograms used in maps were found to be generally difficult to interpret, because the contained semantic information is not effectively conveyed by the selected pictogram design. This illustrates the importance of usability studies. Target users should be included in the design process of landmark pictograms. If the target group cannot be narrowed down to a coherent cultural group, pictograms should be either based on globally coherent symbols or pictograms should instead reflect visual characteristics of the represented landmarks.

Reflect visual characteristics of a landmark in its map representation

If, as proposed for culturally mixed user groups, semantic characteristics are excluded from the map representation of a landmark, the selection of landmarks to be represented in a map should also not be limited to semantically salient landmarks. Due to the different semantic associations, semantic salience of real-world landmarks will differ between individuals and between members from different cultural groups. Visual salience however is assumed to be relatively similar between individuals and cultural groups, because it is only based on visual contrast. Therefore, selecting landmarks to be represented in maps based on their visual salience should lead to a greater correspondence with the selection mechanisms used by different individuals and different cultural groups. Furthermore, if instead of using abstract pictograms visual characteristics of a landmark are reflected in its map representation, landmark representations could be more easily matched to the represented real-world object. Technically, identifying real-world landmarks based on their visual salience and applying salient visual characteristics to their representations in maps is already possible. Map services like Google Street View or KartaView gather and provide georeferenced street level image data that could be analyzed to create saliency maps. The extraction of saliency maps based on image data has been applied in numerous studies and such saliency maps have been demonstrated to be reliable predictors for the distribution of visual attention (e.g. Cerf, Harel, Einhäuser, & Koch, 2008; Foulsham & Underwood, 2008; Itti et al., 1998; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Thus, based on available image data and saliency maps, visually salient real-world landmarks could be identified automatically and visual characteristics as color and texture could be extracted from the images and applied to the map representations.

Only task-relevant landmark representations should be displayed in task-oriented maps

In addition to the ability to interpret landmark representations and to match them to the represented real-world object, it is important to consider the task-dependent relevance of landmark representations. In order to be selected as spatial reference points, landmark representations need to be visually salient, stand out from the map background and attract visual attention. However, if they are not task-relevant, these landmark representations will distract from important map elements and could impair task performance (Rosenholtz et al., 2005). Therefore, only task-relevant landmark representations should be displayed in a map. The studies reported in chapter 4 and 5 demonstrated that the structural salience of map elements relative to a displayed route depends on the same parameters that have been identified for landmark selection during real-world navigation (cf. Lovelace et al., 1999). Landmarks close to the route and its (potential) decision points attracted more visual attention and directing visual attention away from other map elements did not negatively affect route memory performance. As only structurally salient map elements seem to be relevant for route memory, landmark representations and other visually salient map elements offside a displayed route should be removed or their visual salience should be reduced.

Routing algorithms should incorporate the availability of visually salient landmarks at decision points

Conversely, route selection algorithms of digital mapping services could consider the availability of visually salient landmarks at decision points. Modern web mapping services as Google Maps or Microsoft Bing already provide the option to select from multiple alternative routes based on preferences as means of transportation, route length or travel duration. Providing an additional alternative route that is selected based on the availability of visually salient landmarks at decision points could help to improve the acquisition of route memory and reduce navigation errors, especially for non-local map users.

Adjust the dimensions of maps used for navigation based on their visual complexity

Besides the possibility to reduce the visual salience of structurally less salient map elements, another option for directing more visual attention towards structurally highly salient (and thus task-relevant) map elements is to adjust the dimensions of real-world space to be displayed in a map. As areas far offside the route are apparently not important for memorizing a route, these areas should not be represented in a map. However, as demonstrated by the second study reported in chapter 5, visual map complexity needs to be considered when the spatial dimensions to be displayed in a map are selected. In order to provide a sufficient number of spatial reference points, regions containing less landmarks and other spatial elements require broader areas around the route. To identify optimal values for the map margins around a displayed route, future studies need to compare route memory and navigation performance based on maps with a variety of spatial dimensions displayed around a route and different levels of visual complexity. If such optimal values could be deduced, digital maps could automatically identify the visual complexity around a selected route and dynamically adjust the map margins around the route.

Visually highlight landmark representations close to the cardinal axes of a task-relevant location

The study reported in chapter 6 demonstrated that the selection of spatial reference points in maps may differ from the selection of landmarks as spatial reference points in real-world space. The high structural salience of landmark representations close to the cardinal axes of a task-relevant map location implies that the layout and orientation of the map provides structural (up, down, left and right) information that is not available in real-world space. This structural information could support the capturing of spatial relations and the formation of a survey model of geographic space. Therefore, it is recommended to visually highlight landmark representations close to the cardinal axes of task-relevant (e.g. manually selected) map locations. Digital maps could easily and automatically select landmark representations to be highlighted based on their location relative to the cardinal axes of a selected location and a predefined maximum distance value. Up to what distance to the cardinal axes landmark representations should be highlighted and to what extent the cardinal structural information can be transferred to real-world space needs to be addressed in future studies.

In summary, although digital maps could be dynamically adapted to the requirements of selected spatial tasks, this opportunity is usually not fully utilized by popular map services. Applying the proposed approaches for dynamic and interactive map design would allow to create task-oriented maps that support the acquisition of spatial information and could improve spatial memory and the performance in spatial tasks as orientation and navigation. By accounting for different salience characteristics as semantic, visual and structural salience and interactions between these characteristics, the distribution of visual attention across a map can be controlled and directed towards tasks relevant map elements. At a glance, this thesis extended the available knowledge concerning the effects of salience in real-world space on visual attention to maps and map-based spatial memory. The logical next step would be to shift the research focus back onto real-world space by investigating how spatial orientation and navigation are influenced by specific controlled adjustments of salience characteristics in maps.

Summary

Landmarks are essential components of spatial perception. They serve as spatial reference points for orientation, navigation and the development of mental representations of space. Important properties that qualify a spatial object as a landmark are the permanence of the object's position and its salience. Salience describes the tendency of an object to attract visual attention based on its contrast to surrounding objects. With regard to landmarks, three different salience categories can be distinguished: visual, structural and semantic salience. Visual salience is based on contrast of visual object characteristics such as size, color, texture, shape or lighting. Structural salience describes the relative position of a spatial object to a route and its potential decision points, such as junctions and intersections. Semantic salience is based on semantic properties of a spatial object, such as its purpose, cultural meaning, or individual associations.

The effects of the described salience categories on visual attention and the performance in spatial tasks, has already been intensively researched. Eye tracking studies have shown that visual, structural and semantic landmarks are fixed more frequently than surrounding objects. Furthermore, the representation and use of salient landmarks have been associated with an improvement in orientation, navigation, spatial memory and the communication of spatial information. Thus, by identifying salient landmarks, people seem to focus visually on spatial objects that are conducive to the acquisition, use and communication of spatial information.

Maps can be used as external spatial representation models to acquire new spatial information, as well as to expand and structure spatial information already recorded in a mental representation of space. Selected landmarks are often represented in the form of pictograms and visually highlighted in maps. In contrast to landmarks in real space, the salience of map elements and their effects on spatial tasks has not yet been systematically investigated. The aim of this work was to investigate to what extent the mentioned salience categories can be applied to landmark representations in maps and other map elements. Similarities and differences between landmarks in real space and landmarks representations in maps were assessed. Furthermore, it was experimentally investigated to what extent the availability of salient map elements can be used as a predictor for spatial memory performance. The findings were supposed to expand our knowledge of cognitive landmark processing and to be used to derive recommendations for map design that promote effective and task-oriented communication of spatial information.

Five experimental studies demonstrated that visual, structural, and semantic characteristics can direct visual attention to specific landmark representations in maps. Parallels as well as differences between the selection of salient landmarks in real space and in maps were identified.

In contrast to landmarks in real space, landmark representations in maps are not individually selected, but are pre-selected during the creation of the maps and usually represented as pictograms. Since semantic landmarks are usually prioritized, visually salient landmarks are neglected. Color schemes of the represented map elements based on semantic categories override visual salience characteristics of the represented space. Pictograms used to represent landmarks are mostly abstract and classify landmarks into predefined semantic categories. The ability to interpret such partly culturally shaped pictograms can vary between pictograms and observers. In the first study, large differences in the ability to interpret certain landmark representations (meaningfulness) were demonstrated, which can be attributed to both design characteristics of the pictograms and culturally shaped prior knowledge. In addition, the results of the study indicate that the structural salience of landmark representations in maps may influence both visual attention and memory performance.

Despite the overriding of visual characteristics when transferring spatial objects into a map representation, the influence of visual salience on the direction of visual attention towards specific map elements must be considered. In a second study, it was shown that the application of transparency can reduce the visual salience of selected map areas and direct visual attention to other map areas. The use of predefined color schemes for groups of map elements can also direct visual attention. Since, unlike objects in real space, the visual salience of individual map elements can be easily adjusted, it is possible to use transparency and color contrasts to direct visual attention to map elements identified as relevant for specific spatial tasks.

Three studies on the display of routes in maps demonstrated that landmark representations and other map elements attract more visual attention when they are close to the route and its potential decision points. An additional study investigated to which extent structural salience characteristics, which are usually defined based on locations relative to a route, can be transferred to the location of map elements relative to a relevant object position. The evaluation of fixations shows that both the distance to the relevant object position and the distance to its cardinal axes are suitable predictors for the structural salience of map elements. Based on an egocentric coordinate system or the rectangular shape of the map, map users seem to assign a mental structure in the form of two directional axes. Map elements could then be categorized based on their position relative to these directional axes. Furthermore, correlations were found between structural salience and object location memory. The results of the four studies show that structural salience, comparable to objects in real space, can influence both the distribution of visual attention in maps and spatial memory.

The described studies illustrate differences and similarities between salience effects in real space and in maps. By taking the identified salience characteristics into account during the creation of maps, visual attention can be regulated and spatial memory can be supported. In future research, the gained insights should be extended by investigating the influence of salient landmarks in maps on orientation and navigation in real-world space.

Zusammenfassung

Landmarken sind essenzielle Komponenten der räumlichen Wahrnehmung. Sie dienen als räumliche Referenzpunkte für die Orientierung, Navigation, und die Entwicklung mentaler Raummodelle. Wichtige Eigenschaften, die ein räumlich verortetes Objekt als Landmarke qualifizieren, sind eine Permanenz der Objektposition und ein Mindestmaß an Salienz. Salienz beschreibt die Tendenz eines Objektes durch Kontrast zu umliegenden Objekten visuelle Aufmerksamkeit zu erregen. Bezüglich Landmarken wird zwischen drei verschiedenen Salienzkategorien unterschieden: visuelle, strukturelle und semantische Salienz. Visuelle Salienz entsteht durch einen Kontrast visuelle Objektcharakteristika, wie Größe, Farbe, Textur, Form oder Beleuchtung. Strukturelle Salienz beschreibt die relative Position eines räumlichen Objektes zu einer Route und dessen potenziellen Entscheidungspunkten, wie Abzweigungen und Kreuzungen. Semantische Salienz basiert auf semantischen Eigenschaften eines räumlichen Objektes, wie Zweck, kulturelle Bedeutung, oder individuelle Assoziationen.

Die Wirkung der beschriebenen Salienzkategorien auf die visuelle Aufmerksamkeit, sowie der Nutzen basierend auf diesen Kategorien ausgewählter Landmarken für räumliche Aufgaben wurde bereits intensiv erforscht. Eyetracking-Studien haben gezeigt, dass visuelle, strukturelle und semantische Landmarken häufiger fixiert werden als umliegende Objekte. Die Darstellung und Verwendung solcher Landmarken konnten mit einer Verbesserung von Orientierung und Navigation, sowie der Einprägung und Vermittlung räumlicher Informationen in Zusammenhang gebracht werden. Folglich scheinen sich Menschen durch die Identifizierung von Landmarken visuell auf räumliche Objekte zu fokussieren, die für die Erfassung, Nutzung und Kommunikation räumlicher Informationen förderlich sind.

Zur Aneignung neuer räumlicher Informationen, sowie zur Erweiterung und Strukturierung von in mentalen Raummodellen bereits erfassten räumlichen Informationen können Karten als externe räumliche Repräsentationsmodelle verwendet werden. In Karten werden ausgewählte Landmarken häufig in Form von Piktogrammen repräsentiert und visuell hervorgehoben. Im Gegensatz zu Landmarken im realen Raum wurde die Salienz von Kartenelementen und dessen Wirkung auf räumliche Aufgaben bisher nicht systematisch untersucht. Das Ziel dieser Arbeit war es zu überprüfen, inwiefern die beschriebenen Salienzkategorien auf Landmarkenrepräsentationen in Karten und sonstige Kartenelemente anwendbar sind. Gemeinsamkeiten und Unterschiede zwischen Landmarken im realen Raum und Landmarkenrepräsentationen in Karten sollten hierbei herausgearbeitet werden. Zusätzlich sollte experimentell untersucht werden, inwiefern die Verfügbarkeit salienter Kartenelemente

als Prädiktor für die Gedächtnisleistung bei der Einprägung räumlicher Informationen verwendet werden kann. Ziel der Studien was die Erweiterung des Verständnisses der kognitiven Verarbeitung von Landmarken. Außerdem sollten aus den gewonnenen Erkenntnissen Empfehlungen für die Kartengestaltung abgeleitet werden, die eine effektive und aufgabenorientierte Vermittlung räumlicher Informationen fördern.

Im Rahmen von insgesamt fünf experimentellen Studien konnte demonstriert werden, dass visuelle, strukturelle und semantische Charakteristiken die visuelle Aufmerksamkeit auf bestimmte Landmarkenrepräsentationen in Karten lenken können. Hierbei konnten sowohl Parallelen, als auch Unterschiede zwischen der Auswahl salienter Landmarken im realen Raum und in Karten identifiziert werden.

Im Gegensatz zu Landmarken im realen Raum werden Landmarkenrepräsentationen in Karten nicht individuell ausgewählt, sondern bei der Erstellung der Karten vorausgewählt und meist als Piktogramme repräsentiert. Da semantische Landmarken meist priorisiert werden, werden visuell saliente Landmarken vernachlässigt. Durch auf semantischen Kategorien basierende Farbschemata der dargestellten Kartenelemente werden visuelle Salienzcharakteristika des repräsentierten Raumes überschrieben. Die zur Repräsentation von Landmarken verwendeten Piktogramme sind meist abstrakt und ordnen Landmarken in vordefinierte semantische Kategorien ein. Die Fähigkeit solche teils kulturell geprägte Piktogramme zu interpretieren kann zwischen Piktogrammen und Betrachtern variieren. In der ersten Studie konnten große Unterschiede in der Fähigkeit bestimmte Landmarkenrepräsentationen zu interpretieren (Bedeutsamkeit) nachgewiesen werden, die sowohl auf Designcharakteristiken der Piktogramme, als auch auf kulturell geprägte Vorkenntnisse zurückgeführt werden können. Zusätzlich stützen die Ergebnisse der Studie die Vermutung, dass die strukturelle Salienz von Landmarkenrepräsentationen in Karten sowohl die visuelle Aufmerksamkeit, als auch die Gedächtnisleistung beeinflusst.

Trotz der Überschreibung visueller Charakteristiken bei der Übertragung von Objekten in eine Kartenrepräsentation muss der Einfluss visueller Salienz auf die Ausrichtung visueller Aufmerksamkeit auf bestimmte Kartenelemente beachtet werden. In einer zweiten Studie konnte gezeigt werden, dass die Anwendung von Transparenz die visuelle Salienz einzelner Kartenbereiche reduzieren und die visuelle Aufmerksamkeit auf andere Kartenbereiche lenken kann. Auch die Verwendung vordefinierter Farbschemata für Gruppen von Kartenelementen kann die visuelle Aufmerksamkeit lenken. Da im Gegensatz zu Objekten im realen Raum die visuelle Salienz einzelner Kartenelemente leicht angepasst werden kann, ist es möglich durch

Transparenz und Farbkontraste visuelle Aufmerksamkeit auf für spezielle räumliche Aufgaben als relevant identifizierte Kartenelemente zu richten.

In drei Studien zur Darstellung von Routen in Karten konnte nachgewiesen werden, dass Landmarkenrepräsentationen und sonstige Kartenelemente mehr visuelle Aufmerksamkeit erregen, wenn sie nah an der Route und dessen potenziellen Entscheidungspunkten liegen. In einer zusätzlichen Studie wurde untersucht, inwiefern die üblicherweise relativ zu einer Route erfasste strukturelle Salienz auf die Position von Kartenelementen relativ zu einer relevanten Objektposition übertragbar ist. Die Auswertung von Fixationen zeigt, dass sowohl die Distanz zur relevanten Objektposition, als auch die Distanz zu dessen Kardinalachsen sich als Prädiktoren für die strukturelle Salienz von Kartenelementen eignen. Kartennutzer scheinen, basierend auf einem egozentrischen Koordinatensystem oder der rechteckigen Form der Karte, eine mentale Strukturierungsebene in Form von zwei Richtungsachsen zuzuordnen und Kartenelemente anhand ihrer Position relativ zu diesen Richtungsachsen zu kategorisieren. Des Weiteren wurden Zusammenhänge zwischen der strukturellen Salienz und dem Objektpositionsgedächtnis gefunden. Die Ergebnisse der vier Studien zeigen, dass strukturelle Salienz, vergleichbar mit Objekten im realen Raum, sowohl die Verteilung visueller Aufmerksamkeit in Karten, als auch das räumliche Gedächtnis beeinflussen kann.

Die beschriebenen Studien verdeutlichen Unterschiede und Gemeinsamkeiten zwischen Salienzeffekten im realen Raum und in Karten. Durch Beachtung der identifizierten Salienzcharakteristika kann bei der Erstellung von Karten die visuelle Aufmerksamkeit gezielt gesteuert, und das räumliche Gedächtnis unterstützt werden. Im Rahmen zukünftiger Forschung sollten die gesammelten Erkenntnisse um die Untersuchung von Einflüssen dieser Saliencharakteristika auf die Orientierung und Navigation im realen Raum erweitert werden.

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Curriculum vitae

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02/2014 – 07/2015	University of Twente, Enschede, Netherlands **Degree: Master of Science (Human Factors & Engineering Psychology)**
09/2009 – 01/2014	University of Twente, Enschede, Netherlands **Degree: Bachelor of Science (Psychology)**
10/2008 – 08/2009	Ruhr University Bochum, Bochum, Germany IT-Security / Information Technology
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Academic employment history

Since 06/2017	Ruhr University Bochum, Bochum, Germany Research associate Research projects: Volunteered Geographic Information: Interpretation, Visualisation and Social Computing (DFG); Curriculum 4.0 - Die Potenziale und die Auswirkungen der Digitalisierung (Stifterverband & state NRW)
03/2016 – 05/2017	TU Dortmund University, Dortmund, Germany Research associate Research projects: Model-Based Optimizing Control - From a Vision to Industrial Reality (EU); Real-time Monitoring and Optimization of Resource Efficiency in Integrated Processing Plants (EU)
10/2013 – 10/2014	University of Twente, Enschede, Netherlands Student assistant, processing of statistical data sets and qualitative data

Academic teaching

2018	Introduction to scientific work
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