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Wayfinding Through Orientation

Angela Schwering[a], Jakub Krukar[a], Rui Li[b], Vanessa Joy Anacta[a], and Stefan Fuest[a]

[a]Institute for Geoinformatics, University of Muenster, Muenster, Germany; [b]Department of Geography and Planning, State University of New York at Albany, Albany, NY, USA

ABSTRACT
Dominant approaches in computer-assisted wayfinding support adhere to the deeply problematic principles of turn-by-turn navigation. In this article, we suggest a new approach called "Wayfinding Through Orientation," which supports the acquisition of spatial knowledge and cognitive mapping for advancing the user's spatial orientation. Being oriented on one's way is a prerequisite to enabling people to verify instructions and to incorporate new spatial information into their existing knowledge structure. In three studies described in this article we first present empirical evidence that people can be supported in survey knowledge acquisition through suitable wayfinding instructions. Consequently, we explore orientation information in human wayfinding instructions. Finally, we outline how orientation information can be communicated within a prototypically implemented navigation assistance system.

KEYWORDS
wayfinding; spatial orientation; survey knowledge; global landmarks

1. Introduction and motivation

Wayfinding is a task that we conduct every day while going to work, visiting friends, or going on vacation. Being such a vital part of our everyday activity, it has been studied within diverse academic perspectives. Contemporary wayfinding research in the cognitive sciences aims to understand the structure of internal knowledge and mental processes involved during wayfinding and during related activities (such as learning the layout of an unknown area before travelling to it). Unsurprisingly, it is the movement to and through environments unexperienced before which people traditionally aimed to make easier for themselves, for instance by designing wayfinding support systems (e.g., maps, signage, global positioning system). With the emergence of consumer-grade car and pedestrian navigation systems, we gained omnipresent support for wayfinding tasks in unfamiliar environments. Although this technology has gone through tremendous development, with cognitive aspects attracting particular interest, it still suffers from some fundamental shortcomings: State-of-the-art wayfinding support follows the principles of

CONTACT Angela Schwering schwering@uni-muenster.de Institute for Geoinformatics, University of Muenster, Heisenbergstr. 2, 48149 Münster, Germany.

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turn-by-turn navigation. It guides users towards the destination by giving them direction instructions at each decision point one after another. The user's entire task is thus broken down into executing these instructions.

Turn-by-turn navigation was successfully used for many wayfinding problems, for example to communicate escaping routes, to guide travelers through the tunnels of a subway station, or to help passengers find their way at the airport. With turn-by-turn navigation, a user can reach the destination through the best (e.g., fastest, simplest, easiest, safest) way; however, s/he might have no broader orientation and no overview of the route. Turn-by-turn instructions are incompatible with the naturally employed ways of engaging with spatial information nor with natural means of communicating such information to other people. Humans do not execute instructions separately, one after another, but integrate their information, spontaneously learn the spatial configuration during wayfinding, and build up cognitive maps to orient themselves in their environments. Because turn-by-turn navigation solely communicates directions at decision points, it only supports users in the acquisition of route knowledge, but not in the user's spontaneous ability to gain orientation in an unfamiliar environment.

Consequently, the goal of this research is to suggest a new means of wayfinding support, based on orientation. Recent research enhanced navigation systems by making navigation instructions easier to understand through intuitive landmark information, through simpler decision points, and through easier routes (c.f. Section 2). However, this research does not tackle the fundamental problems of turn-by-turn navigation listed here.

The remainder of this article is structured as follows: In Section 2 we outline state-of-the-art wayfinding research in the cognitive sciences. We specifically review related work on knowledge acquisition during wayfinding. Section 3 describes the principles of "Wayfinding Through Orientation" and relates it to the taxonomy of wayfinding tasks. In Section 4 we give an overview of three studies exploring different aspects of wayfinding through orientation: Study 1 examines knowledge acquired with different wayfinding instructions. Study 2 explores the nature of orientation information in human wayfinding. Study 3 investigates visualization techniques to communicate orientation wayfinding instructions. Section 5 relates this work to broader wayfinding research, and Section 6 concludes the article and outlines directions for future work.

2. Related studies

Related work includes two major components. First, broader wayfinding research investigates factors which influence the acquisition of survey knowledge during assisted navigation. Second, the current progress in the cognitive sciences relevant for designing navigation support systems investigates how to improve route instructions, how to identify relevant decision points, and how to compute a better route.

2.1. *Survey knowledge acquisition during assisted wayfinding*

Recently, researchers investigated the acquisition of survey knowledge with assisted turn-by-turn navigation. We review those findings below and suggest that more survey knowledge could be acquired if wayfinding instructions are designed to support spatial learning.

2.1.1. *Tools affecting acquisition of survey knowledge*

Maps and verbal directions have been compared to clarify which type of wayfinding knowledge is acquired when using these tools. Meilinger (2005) found that the complexity of the route determines the usefulness of each source of information. The results in his study showed that participants who used a map in a simple route often got lost while those following a complex route got typically lost with verbal directions. Nowadays, mobile navigation systems take over guidance in real environments. This has detrimental effects on spatial learning: Münzer et al. compared computer-assisted navigation to traditional map-based navigation and found differences in incidental knowledge acquisition (Münzer, Zimmer, & Baus, 2012; Münzer et al., 2006). Users of navigation systems showed good route memory but bad survey knowledge. Ishikawa et al. (2008) investigated how turn-by-turn navigation with different tools affect the acquisition of survey knowledge. They compared navigation with GPS devices to navigation with paper maps and to the direct experience, finding empirical evidence that users travelling with GPS devices acquire less survey knowledge.

2.1.2. *Visualizations affecting acquisition of survey knowledge*

Münzer et al. (2012) examined the effect of different visualization modes on incidental route and survey knowledge acquisition during an assisted tour through a real environment. When wayfinding instructions were presented in a "guidance mode" (turn-by-turn instructions from the egocentric perspective), then route memory was strengthened at the cost of survey knowledge. When wayfinding instruction was embedded in an allocentric representation providing a metric-map overview or the sole directional information without the layout, then survey knowledge was strengthened, but route memory was weaker and more wayfinding errors were made during the tour.

Several researchers investigated the effect of small displays on spatial information communication and learning. Richter et al. found that an adaptive pan and zoom with the automatic overlay of the route is beneficial to wayfinding, while an adaptable pan & zoom is supporting spatial learning better (Richter, Dara-Abrams, & Raubal, 2010). Schmid et al. (2010b) developed a map that provides local and global orientation (similar to the prototype presented further in Section 4) and showed that it has a positive effect on speed and accuracy during a self-localization task. They did not investigate survey knowledge acquisition.

2.1.3. *Type of navigation affecting acquisition of survey knowledge*

Maguire and colleagues compared taxi drivers navigating around the city throughout the day (without navigation systems) to bus drivers travelling a comparable distance by route-following (Maguire, Woollett, & Spiers, 2006). Neuropsychological analysis showed that taxi drivers who have an extremely large capacity to acquire and use knowledge about their environment, have a larger gray matter volume in their hippocampus. These results suggest that navigation abilities increase by training, while route-following does not train navigation abilities and survey knowledge.

Research reviewed here demonstrates that people acquire relatively little survey knowledge when using turn-by-turn navigation support. It has also been shown that continuous training increases capabilities of learning survey knowledge. The approach presented in this article aims to train and thus increase the acquisition of survey knowledge during assisted navigation.

2.2. *Cognitive aspects of wayfinding support systems*

Cognitive wayfinding research has had a critical impact on the improvement of navigation support systems. Although deserving acknowledgment, their key limitation remains a prevailing reliance on turn-by-turn routes communicated as a sequence of instructions to be performed by a user in a step-by-step fashion.

2.2.1. *Decision points and landmarks*

Landmarks are important features in route directions. Michon and Denis (2001) showed that participants refer to landmarks for reorientation on the route. They emphasized that the absence of landmarks makes it difficult for people to progress on their way when there are possible choices of directions. Lovelace et al. (1999) emphasized the importance of landmarks for giving route directions and differentiated landmarks on the route at choice points from those at nondecision points, and those off route. Like most other researchers, Michon's and Lovelace's research concentrates on local landmarks for decision point identification in turn-by-turn navigation. Few researchers further investigated hierarchical communication of space referring to global landmarks (Winter, Tomko, Elias, & Sester, 2008), and global landmarks' potential benefit for navigation performance (Steck & Mallot, 2000) but not in the context of spatial learning of unfamiliar environments.

2.2.2. *Route instructions*

Cognitive principles were investigated to enhance both visual and verbal route instructions. For example, schematization is intentionally applied to map design to improve visual route instructions by overemphasizing important aspects while underemphasizing others (Klippel, Richter, Barkowsky, & Freksa, 2005a; Peters & Richter, 2008). Subway maps are probably the oldest examples of schematic maps purposefully designed to capture only the topologic structure of the environment. Focus maps are maps designed to draw the user's attention towards one specific area of the map by emphasizing relevant information (Richter, Peters, Kuhnmünch, & Schmid, 2008).

Klippel et al. (Klippel, Richter, & Hansen, 2006; Klippel, Tappe, & Habel, 2003; Klippel, Tappe, Kulik, & Lee, 2005) proposed a set of wayfinding choremes as "mental conceptualizations of functional wayfinding and route direction elements" (Klippel et al., 2005b, p. 311). They are used to visualize turn information in a simplified way. Klippel and Richter applied wayfinding choremes to focus maps in order to combine functional and structural focus in choreomatic focus maps (Klippel & Richter, 2004).

Other research on verbal route instructions focused on linguistic expressions. Klippel and Montello (2007) used mental concepts of direction changes to find better expressions for describing turn directions. Appropriate spatial relations also depend on the context and structure of the environment. For example, spatial relations to landmarks can be enhanced by taking into account their locations at or between decision points (Hansen, Richter, & Klippel, 2006). Other methods reduced the complexity of wayfinding instructions via spatial chunking (Klippel et al., 2003). Spatial chunking reduces the number of instructions by merging instructions of unnecessary or obvious directions (e.g., three "turn-left" instructions are merged into "turn left three times").

This process is similar to segmentation proposed by Dale, Geldof, & Prost (2003), which refers to partitioning route instructions and generating a meaningful summary of each segment. This hierarchical or regional information approach aims at reducing the cognitive load imposed on wayfinders as well as enhancing their recall of route directions.

2.2.3. *Route choice*

Researchers investigate how criteria such as the presence of landmarks and decision points affect the complexity of turn-by-turn routes. Decision points with low complexity are easy to identify, thus preferred in route directions. Landmarks at decision points also decrease the complexity of route directions. The Simplest Path Algorithm (Duckham & Kulik, 2003) evaluates a route according to the complexity of its turns. A simple route minimizes the number of decision points and maximizes decision points of low complexity. GUARD (Generation of Unambiguous, Adapted Route Directions) (Richter, 2007) uses environmental characteristics such as landmarks to compute unambiguous routes.

The Easy-to-Follow Routes algorithm (Richter & Duckham, 2008) accounts for decision point complexity, references to landmarks, and spatial chunking. Other cognitively motivated routing algorithms are the least-angle strategy (Collins & Loftus, 1975), longest leg strategy (Hochmair & Karlsson, 2004), and hierarchical path finding (Wiener & Mallot, 2003). Kopf et al. developed a system to produce destination maps using some of the aforementioned algorithms by extracting only the relevant road networks that will be more effective and informative in wayfinding compared to a fixed metric map (Kopf et al., 2010). Tomko et al. (2008) investigated hierarchies in streets reflecting the experience of navigators in cities. This provides navigation instructions on different levels of hierarchy. At the current state, the hierarchy is restricted to streets only, but could be extended to the general structure of a city.

2.2.4. *Limitations of the existing work*

Although deserving acknowledgment, and most likely driven by the implicit understanding of the shortcomings of the existing navigation support systems, the work reviewed above shares a similar assumption. Their key limitation remains a prevailing reliance on turn-by-turn routes communicated as a sequence of instructions to be performed by a user in a step-by-step fashion at predefined decision points.

Consequently, related research focuses on pointlike landmarks, neglecting regional landmarks that are useful for communicating survey knowledge. Studies of route instructions seem to advance only turn-by-turn instructions. Orientation and survey knowledge acquisition do not seem to play a prioritized role in this research. This seems to be reflected in the development of routing algorithms. For example, the Easy-to-Follow Routes algorithm uses landmarks to identify the spatial decision points, but does not use landmarks to enhance orientation and cognitive mapping.

3. Wayfinding through orientation and the taxonomy of wayfinding tasks

The problem of wayfinding can be divided into different wayfinding tasks, which are supported by separate navigation assistance systems. First, we outline different wayfinding tasks together with corresponding assistance systems and identify an existing gap: a wayfinding assistance system supporting the task of "oriented path following." In the second subsection, we explain the basic ideas underlying such a navigation assistance system.

3.1. *Wayfinding tasks with and without navigation assistance*

Wiener et al. (2009) proposed a taxonomy of human wayfinding tasks based on the knowledge structures involved and the underlying cognitive differences

(Figure 1). The taxonomy focuses only on tasks performed without navigation assistance. Below, we explain the taxonomy and introduce a new wayfinding task called "oriented path following." In the next step, we attempt to extend the taxonomy by the part "navigation with navigation assistance" and discuss how "oriented path following" corresponds to the navigation assistance system proposed in this article.

3.1.1. *Directed wayfinding without navigation assistance*

Based on the type of knowledge involved in the task, Wiener et al. suggest five different wayfinding tasks. In *uninformed search* the wayfinder has no survey nor destination knowledge (e.g., a firefighter searching for a person in a burning house without knowledge of their exact location). In *informed search* the environment is known to the user but the exact destination is not (e.g., "searching for a friend who is in one of the restaurants in the downtown area of your hometown"; Wiener et al., 2009, p. 159).

In *path search*, the wayfinder is approximating the target location without route or survey knowledge (e.g., navigating towards the church tower). In *path planning*, the wayfinder uses her knowledge of the environment to plan the path to the destination beforehand. In *passive path following* (called simply *path following* in the Wiener's version of the taxonomy) the wayfinder has route knowledge and executes "the appropriate sequence of actions" (Wiener et al., 2009, p. 160). This task does not require much attention or spatial reasoning and runs nearly automatically as during the daily drive to work.

We propose to extend this taxonomy by a sixth task called *oriented path following*. In it, the wayfinder has the destination, route, and survey knowledge about the environment, which s/he uses during the navigation task to decide on the best route to follow. A typical situation in which *oriented path following* can occur, is while travelling to a well-known shop in the city center. There are different alternative routes that s/he could take and is aware of (survey knowledge and knowledge of multiple routes is available).

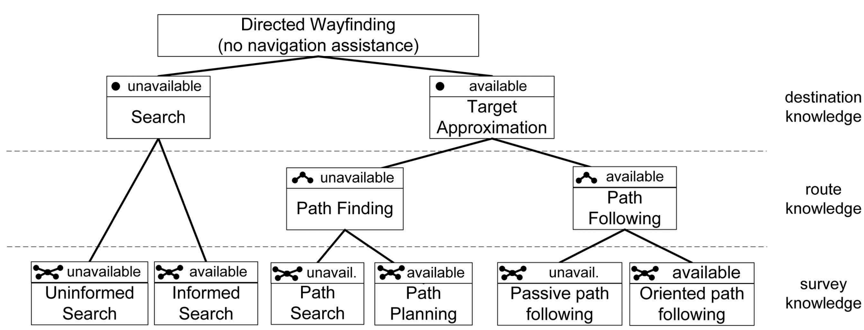


Figure 1. Directed Wayfinding Taxonomy (without navigation assistance) extended by the task "Oriented path following" (Wiener et al., 2009).

While approaching the destination s/he decides spontaneously to take one route or the other. This wayfinding strategy is supported by empirical data of more recent studies by Hölscher et al., who found that wayfinders re-plan their preplanned route during navigation (Hölscher, Tenbrink, & Wiener, 2011): Even a preplanned route involves elements of adjusting and re-planning with the continuous use of survey knowledge. In *oriented path following*, the navigator reacts to visual input on the way and re-plans the route using the information s/he has about the broader environment.

This situation could be described as simple *passive path following* adjusted "online" (i.e., during navigation as opposed to being planned ahead). However, framing it this way assumes that when route knowledge is available, the presence *or* lack of survey knowledge is irrelevant to the navigation task. This is untrue. Humans spontaneously and continuously integrate knowledge gained on separate routes to build up survey understanding of the broader environment (Ishikawa & Montello, 2006). They also use survey knowledge of the broader environment to update their location *en route* with respect to other objects not directly visually accessible from the route (Montello, 2005). Therefore, even when route knowledge is available to us, the presence or lack of survey knowledge of the broader surrounding has an impact on the cognitive processes involved in the act of wayfinding.

Consider the opposite example of knowing two correct routes to the shop without any other knowledge of the city center. The act of such *passive path following* might look and seem identical on the behavioral level (the shopper executes turns at decision points) but different cognitive processes are at play. For instance, the "oriented" shopper might realize that s/he is passing nearby her favorite sandwich place (without knowing the exact route to it) and choose to have a snack. This is an insight unavailable to the "passive" shopper, and yet so tightly embedded in the natural strategy of performing this task that it is automatized. It might not have a tangible impact on the behavioral performance in this task (how fast or accurately the body of either of the shoppers reached their destination)—but demonstrates the qualitative difference between the two experiences on the cognitive level.

"Navigate to the shop on the route you are familiar with" can constitute two cognitively distinct tasks. Depending on the presence *or* lack of relevant survey knowledge (and keeping all other things equal), navigators might (a) plan to execute them differently, (b) demonstrate varying openness to changing their strategy *en route*, (c) report diverse satisfaction after completing the task (to name but a few potential differences). Figure 1 presents the Taxonomy expanded by this distinction.

3.1.2. *Directed wayfinding with navigation assistance*

Navigation assistance nowadays is commonly used for a wide range of wayfinding tasks. The taxonomy proposed by Wiener et al. (intentionally) does not discuss directed wayfinding tasks when navigational aid is used. As the authors noted, the cognitive processes involved are likely to be different when a navigation assistant system is used. However, it bears noting that the primary reason to build navigation systems is to supplement deficiencies in different types of human knowledge.

Although the authors focus on the cognitive processes during directed wayfinding tasks without navigation assistance, we would like to review existing navigation assistance that supports users in performing these distinct tasks. The cognitive processes involved when using navigation assistance – as well as the way how cognitive processes might interact – are not discussed here and are out of the scope of this article. Based on the taxonomy of wayfinding tasks, we identified different navigational assistance that were developed to support each task. We distinguish navigational assistance systems by the type of *information provided* by the system (Figure 2).

For *uninformed* search, no navigational assistance system exists, since neither destination, nor route or survey information is provided.

A *navigation assistance for the informed search task* provides survey information in the form of a digital map. Usually the device can localize the user e.g., via the GPS and show their current position on the map. However, such system does not have the information about the destination (as this might be unknown) and thus does not show the route to the destination.

A *navigation assistance for the path search task* provides destination knowledge and tells the user in which direction s/he can find the destination based on their current position. No additional route or survey knowledge is provided. This scenario occurs for example when a person is hiking in the wild and no map or predefined paths exist. Another example for this application is a car-finding-app, in which a user can localize their car with GPS coordinates and the app will show the direction and distance to the car without a digital map (e.g., on a large airport car park).

A *navigation assistance for the path planning task* provides survey information in the form of a digital map and destination information as a location on the map.

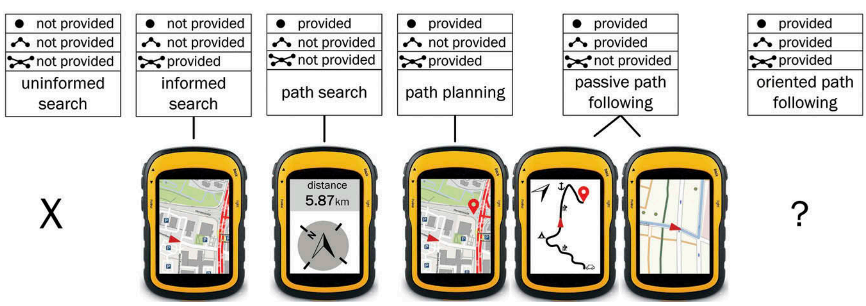


Figure 2. Navigation assistance for directed wayfinding tasks.

Sometimes the device shows the position of the user on the map as well, but it does not offer a route planning functionality; thus, the task of finding the route is up to the user. In practice, this is how users of mobile mapping apps often interact with them in an ad-hoc context: comparing the You-Are-Here indicator with the location of the searched destination (e.g., a nearby cafe) can be sufficient to adjust one's trajectory on-foot few hundred meters away from the destination, without using the app's routing algorithm.

A *navigation assistance for passive path following* shows today's car navigation systems which are usually supporting the passive path following task: Based on the destination information and the current position, it calculates the route and shows the relevant route information for the next decision point. Figure 2 shows two navigation assistance systems that fall into this category: the left one visualizes only the route and the destination, while the right one shows also the background digital map. However, due to the tradeoff between scales and levels of detail, this visualization is not suitable to communicate both at the same time. Consequently, the survey information communicated is very limited. The user can zoom out to obtain more survey information, however, the information on the route then becomes too small to be useful for navigation. This approach does not facilitate the acquisition of route knowledge *and* survey knowledge in an integrated manner.

A *navigation assistance for oriented path following* would provide destination, route and survey information in a way that is easily perceivable by the user. Such a system does not exist at the moment, although the information that we typically receive from other sources - for instance, from other people's wayfinding descriptions - is orientation information. With this research, we are aiming to develop such a system, potentially looking like the one shown in Figure 3. (right side).

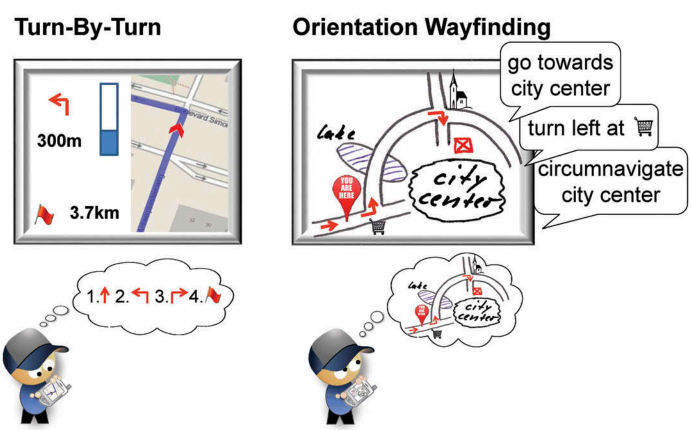


Figure 3. Turn-by-turn wayfinding gives direction instructions at decision points supporting users in the acquisition of route knowledge, while orientation wayfinding uses orientation information supporting users to build up a cognitive map.

3.2. *Wayfinding Through Orientation*

Wayfinding systems nowadays represent the route as a sequence of turns. Each time we change the direction, the navigation system gives a turning instruction such as "take a sharp left" or "take a right." There already are studies that attempt to provide both local and global orientation through means such as route aware maps (Schmid, Richter, & Peters, 2010b). They are a combination of strip maps and survey maps that visualize different levels of granularity during wayfinding. Although there is similarity in terms of context, the Wayfinding Through Orientation approach aims to use (global) landmarks to support (global) orientation. It is based on the acknowledgement that landmarks serve a crucial role in determining the relative location of a feature to another feature in the environment (Gunzelmann & Anderson, 2006).

Furthermore, the location of landmarks with regard to the route should be considered. Denis (1997) suggested that wayfinders often use landmarks for the purpose of reorientation which happens at decision points where change of direction is necessary to reach the destination. Lovelace and colleagues (1999) suggested that landmarks are not only important at locations where reorientation is needed, but also crucial at points where change of direction *can be possible*. At these potential decision points, wayfinders need to maintain their orientation by continuing towards the same heading direction. Limited studies have addressed the role of distant landmarks. Those distant landmarks are important for providing general orientation and confirming heading direction (Couclelis, 1996).

Wayfinding Through Orientation intends to give instructions in a more holistic way and at a higher level of abstraction. Instead of communicating single turns only, it aims to relate the immediate route information to the broader environmental context and to define larger route segments that comprise a meaningful sequence of turn instructions. This is also reflected in the visualization: Instead of visualizing each turn one after another, a larger section of the route is shown and focused on cognitively important aspects through schematization. Schematization is used to overemphasize information which helps to build up cognitive maps (e.g., structure of a city, major hierarchical structures), and simplification to delete or underemphasize information that is not necessary for orientation (e.g., many small streets located off-route).

Schematization and simplifications are intentionally applied to aid communication of orientation-supporting features such as global landmarks or the overall course of a route. For people who are familiar with the environment, a hierarchical structure of giving directions by selecting relevant elements in the area could be more effective (Tomko & Winter, 2006; Richter, 2008).

Figure 3 contrasts two exemplary instructions for the same route in the turn-by-turn and the orientation fashion. Orientation example includes instructions which give a more holistic picture of the surrounding environment. In the orientation instructions – "go towards the city center," "turn left at the supermarket, circumnavigate the city center" – we replaced, modified or simply extended turn-instructions with information about the surrounding environment, information about spatial relations to landmarks, and other types of information that helps the user to build up a cognitive map.

In addition, the visual representation aims to give a holistic overview by providing an overview of the surrounding environment, and of the route, as well as showing all important decision points on the route. Figure 3 also contrasts spatial knowledge learned from the two types of wayfinding approaches. From turn-by-turn wayfinding, users learn the sequence of turns that need to be taken (route knowledge). From orientation wayfinding, users learn survey knowledge which will allow them to gain an overview of the route and the surrounding environment. Evidence for this is provided in the next section.

4. Empirical evidence

In the following, we report on three studies. Study 1 provides empirical evidence for our hypotheses that orientation information supports users in acquiring survey knowledge and building-up a cognitive map. Study 2 further explores the concept of orientation information by examining human wayfinding instructions. Study 3 proposes a preliminary design of visualization for orientation wayfinding and tests its effect on users' spatial orientation.

4.1. *Study 1: Learning from route instructions*

To evaluate the effects of wayfinding instructions based on orientation information, we constructed three types of instructions: currently available turn-by-turn instructions provided through routing services, route instructions with orientation information, and skeletal instructions based on the methodology introduced by Denis (1997). Skeletal instructions contain landmark and orientation information but only if they are necessary for identifying the route with its turns.

The selected route starts at the railway station and ends at the authors' institute (Figure 4). The length of the selected route is approximately 3.9 km (air distance approximately 3 km). To avoid the influence of a person's familiarity with this environment, we changed the names of all streets and landmarks used in verbal descriptions (participants did not see any maps of the study area). For example, in the instructions given to participants, the origin of the route was named "cinema" (railway station in Figure 4) and the destination was named "library" (Institute in Figure 4). The city was introduced as a mid-size German city with an old town in its center and a ringlike arrangement of streets.

Table 1 provides examples of all types of instructions. The first type of route instructions is generated from Google Maps with names replaced.

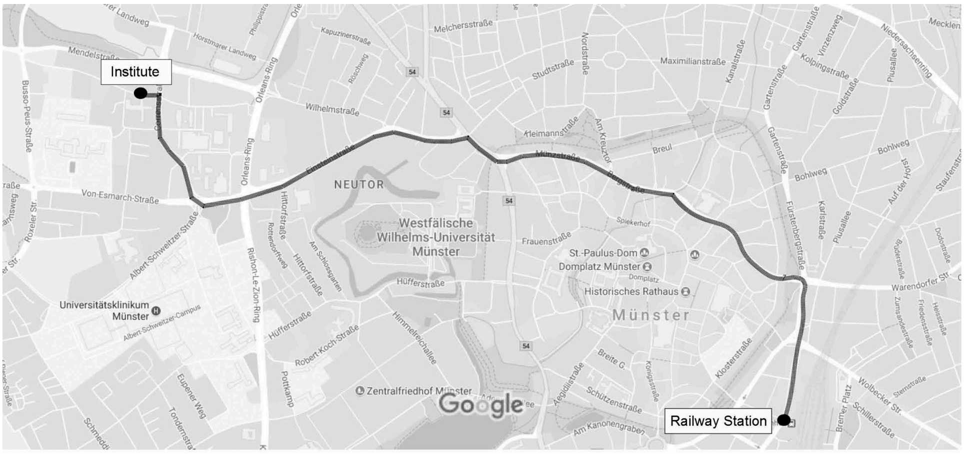


Figure 4. Study area and selected route. Source: Google Maps.

Table 1. Example instructions for the machine-generated, orientation-based, and skeletal wayfinding task ('orientation' elements emphasized in italics; participants saw all instructions in one font).

Type	*Instructions*
1. Machine-generated	• Turn left onto Empire Street and drive 350 m • Continue onto Hudson street for 650 m • Continue onto Main street for 140 m
2. Orientation-based	• Follow the street, which is heading *away from* the *city center* • You cross the intersection *on the inner ring road* that *runs around the city* • Right after you pass the *big church on your right-hand side*, you reach an intersection.
3. Skeletal	• Walk along the Empire Street • Right after you passed the big church, which is on the right side, you reach an intersection

The second type provides instructions based on orientation information with landmarks based on our previous finding (Schwering, Li, & Anacta, 2013) (i.e., not only at potential decision points). This type of instructions consists of local landmarks at potential decision points and alongside the route, as well as distant global landmarks.[1] The third type are the skeletal instructions. They are generated according to the strategy suggested in wayfinding studies by Denis et al. (Denis & Kosslyn, 1999; P.-E. Michon & M. Denis, 2001). For generating instructions for this specific route, the experimenters collected instructions through a survey and then generated the skeletal instructions, using the results of a previous study (Schwering et al., 2013) to verify its validity. All types of route instructions are provided in the form of verbal descriptions.

[1]We define global landmarks as landmarks being relevant and useful for navigation or orientation even when they are not adjacent to the route. Note that some landmarks might be local and gain a global function as the wayfinder progresses (e.g., a large church that you pass, but later refer to from a distance). Global landmarks can also be constituted by regions.

4.1.1. *Study procedure*

Thirty participants (Age: M = 29.75, SD = 10.65; 17 men and 13 women) were recruited for this study. They received one randomly chosen type of wayfinding instructions but with an approximately balanced number of female and male participants in each group.

After receiving one type of wayfinding instructions, participants completed a set of tasks using the wayfinding instructions. The first task was drawing a sketch map from the origin to the destination. The second task was estimating directions and distances at various locations along the route. This task included three subtasks. The first subtask was estimating the direction back from the destination to the origin of the route facing a predesignated direction in mind as well as judging the corresponding air distance.

In the second and the third subtasks, participants needed to mentally change their position to specific landmarks or intersections (depending on the type of wayfinding instructions) on the route, point to the origin and the destination, and then estimate the air distance in between. The third task was filling in two self-rated measures and one spatial ability test including the Santa Barbara Sense of Direction Scale (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), the Spatial Anxiety Scale (Lawton, 1994) and the Purdue Spatial Visualization Test for rotations (Guay, 1976).

4.1.2. *Results*

Sketch maps drawn based on different types of instructions show some distinctive characteristics. Sketch maps drawn based on machine-generated instructions show straight route segments with labelled street names (Figure 5). Only a very limited number of participants tried to avoid drawing only straight lines in order to provide a more realistic 2D map-like layout. What is most apparent in this type of sketch maps is that they only contain the route itself, indicated by a sequence of route segments. Thus, they resemble routes with few spatial features. As intersections and recognizable decision points are not part of these machine-generated instructions, not

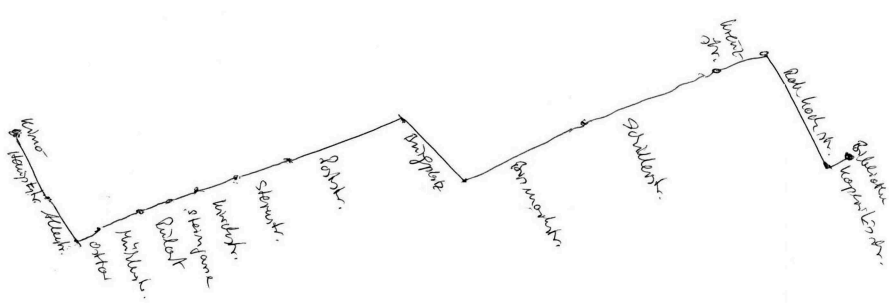


Figure 5. The sketch map drawn by a participant who received machine-generated instructions shows the learned route knowledge.

surprisingly, the only drawn spatial entities are streets, except some cases where the origin and the target have been included.

Sketched maps drawn based on orientation instructions, however, mostly indicate a spatial layout of the area, with not only the actual route drawn, but also intersections and additional street segments. This spatial representation is particularly achieved by including global landmarks in the sketches, like the city center and the ring road, as shown in Figure 6. The general observations of sketch maps suggested that orientation-based instructions contribute to more comprehensive spatial knowledge possessing both global and local orientation.

Sketch maps drawn based on skeletal instructions show the least variation. As shown in Figure 7, the most obvious recurring characteristic is the grid-like layout of these sketches. People drew fewer intersections, because this type of instructions contained only landmarks at decision points. Route segments were mostly drawn with similar length, due to the very limited information content in this type of instructions.

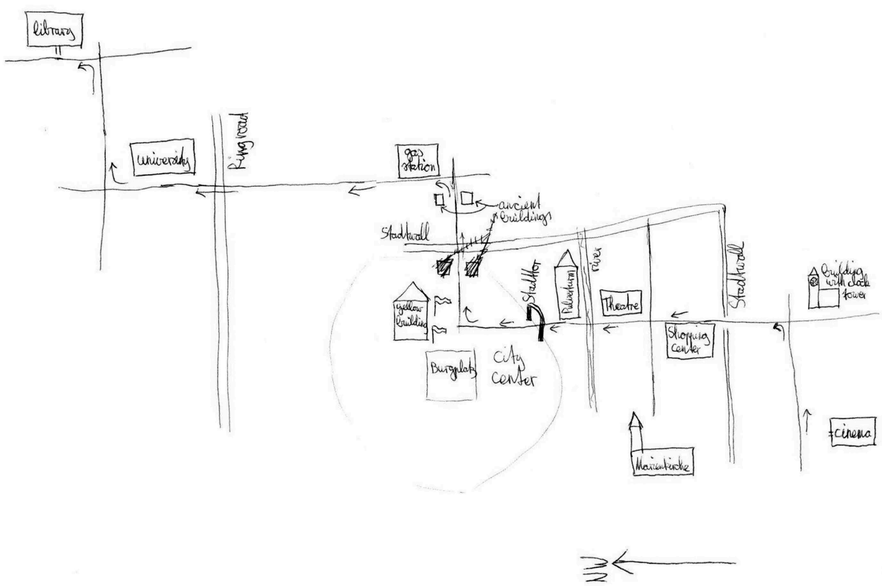


Figure 6. The sketch map drawn by a participant who received orientation instructions shows the learned survey knowledge.

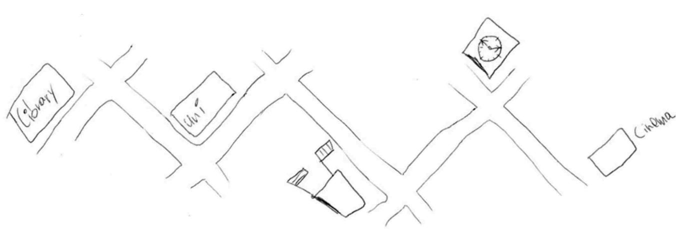


Figure 7. The sketch map drawn by a participant who received skeletal instructions shows a gridlike configuration.

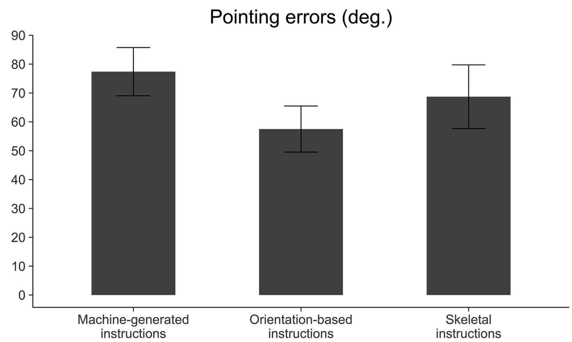


Figure 8. Directional estimation errors.

Figure 8 shows the average pointing errors within three groups. Participants using the orientation-based instructions made fewer errors in their estimation of direction (M = 57.50°, SD = 25.25). The average pointing error is much larger for the group using machine-generated instructions (M = 77.40°, SD = 26.43). The average pointing error for the group using skeletal instructions is slightly lower than that for the machine-generated instructions and higher than that for the group using orientation-based instructions (M = 68.72°, SD = 34.87). The main condition effect in a split-plot ANOVA did not achieve significance ($F(2, 24) = 1.56, p = .23$), although a t-test conducted directly between machine-generated and orientation instructions was approaching significance (prior to multiple-comparison correction; $t(17) = 1.72, p = .10$). Further work should verify these exploratory findings with a larger sample size.

The orientation-based instructions are the only type that includes the city center as a global landmark. Additionally, local landmarks are provided not only at decision points but also along the route. Compared to machine-generated wayfinding instructions, it seems easier for participants to mentally arrange the described route into a spatial configuration. These landmarks (both global and local ones) included in the instructions facilitate the acquisition of survey knowledge.

Distance estimation errors were assessed by calculating a single correlation value (between real and estimated distances) for each participant. These values were then converted with Fisher's r-to-z transformation and used in a one-way ANOVA. The analysis did not show significant differences in relative distance estimations between the three groups ($F(2,24) = 0.57, p = 0.572$) for our sample size.

4.2. *Study 2: Orientation information in route instructions*

As argued in the previous section, we believe that orientation information is very important in human communication and is a promising concept for navigation support. In this study, we aim to explore the usage of global and local landmarks in human wayfinding instructions. Our earlier study (Schwering et al., 2013) revealed that particularly global and local landmarks are actively used for orientation. As only one route and a small data set was used in the previous study, it is important that we further systematically explore routes with different relations to global landmarks.

In particular, city center seems to be a prominent global landmark. Thus, we chose routes which either start outside and end inside the city center, or start outside the city center, cross it and end outside, or pass by several cities with city centers. The task aims to collect wayfinding instructions and analyze whether participants will include information potentially used for orientation which is not necessarily on the route.

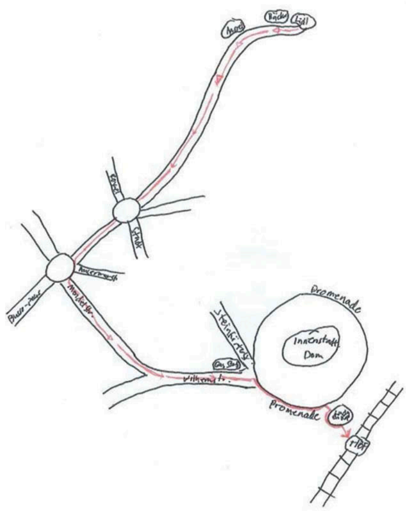
4.2.1. *Study procedure*

Twenty-one subjects aged between 19 and 30 years (M = 22.95 years, SD = 2.9, 11 women) were asked to describe routes through a familiar area with both sketch maps and verbal instructions. They received no additional instructions or tools for their descriptions. Participants were tested on three different routes which had different relations to spatial entities that we identified as global landmarks in our earlier studies. Each route passed by at least two global landmarks.

4.2.2. *Results*

The analysis of sketch maps revealed that participants included spatial overview information of the area in their wayfinding instructions. The intuitive use of landmarks was of particular interest. Although local landmarks were the most commonly mentioned spatial features in both verbal descriptions and sketch maps, results also showed that all of the participants included global landmarks. In verbal descriptions, 20% of the landmarks mentioned were global ones that support orientation, 19% of the landmarks were local ones with turning actions, and the majority of the landmarks were local landmarks along the route (61%) that also support spatial orientation. In sketch maps, about 30% of the landmarks were global landmarks, 22% were local landmarks at decision points and 48% were local landmarks along the route. We suggest that global landmarks and local landmarks along the route (i.e., not at decision points) are used for orientation.

Figure 9 shows an example of wayfinding instructions collected from our study. The participant used place information for local and global orientation. Information is reduced to relevant aspects, which leads to schematization and different levels of abstraction within one map, but also to repeated information reconfirming the route and supporting re-orientation. Although, there is still presence of turn-by-turn directions, in some instructions such as this shown in the sketch map, participants structured the route hierarchically by partitioning it into sections described at different levels of abstraction.



Leave LIDL parking lot, turn right and follow the street. At the end of the street, turn right again. Then follow the street until you reach a roundabout. Take the second exit. Now go towards the city center. At the next traffic lights (Coesfelder Kreuz) go straight. Then go always straight until you leave the current street (Wilhelmstr.) and turn left. There are no traffic lights, but a give way sign. Turn right at the next traffic lights and left at the next but one street. Then go straight until you see an ice cream shop on the right. Turn right before the ice cream shop; go up the hill. When you are on the top, go directly towards the cathedral.

Figure 9. Example sketch map and (translated) instructions of a participant.

Both types of route descriptions contained many landmarks (Figure 10). Global landmarks (GL) were more often drawn on sketch maps. It shows that local landmarks along the route (LLAR) are mentioned more frequently than landmarks at decision points (LLDP). Concerning local landmarks at decision points, these are more often mentioned in verbal descriptions. On the contrary, more local landmarks along the route were drawn in sketch maps.

There was no significant difference between the landmarks included in verbal descriptions and sketch maps. This indicates that both verbal descriptions and sketch maps are reliable sources for analyzing wayfinding instructions.

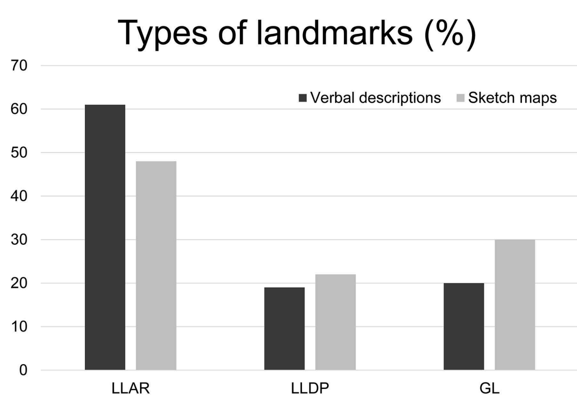


Figure 10. Types of landmarks in spatial descriptions.

4.3. *Study 3: Visualizing route instructions*

We identified the role of global landmarks in support of spatial orientation. In reality, however, due to their large distance to a route it is still an ongoing research agenda to identify effective ways to visualize them on small screens such as mobile phones. Studies have suggested ways of visualizing off-screen landmarks (Baudisch & Rosenholtz, 2003; Burigat et al., 2006; Gustafson et al., 2008), and here we designed a visualization using the similar theory but a different presentation.

Based on the global landmarks that were collected through a survey, we assign an invisible circle of a radius[2] to each landmark as a reference region. If the circle overlapped the area of display, this global landmark is visualized at the border of the screen (Figure 11, left side), because we assume that people would use this global landmark as reference once they are in the reference region. We use this to enable users to view a small area while zoomed in and simultaneously acquire information about global landmarks in a large extent.

4.3.1. *Methods and procedure*

Sixty participants were equally divided between the control group (no off-screen landmarks: *NOS*) and the experimental group (off-screen landmarks: *OS; N* = 30 each). The experiment took place on the streets of the city of Münster, Germany. After indicating verbally the familiarity with a list of major landmarks in the city, the participants were asked to walk a

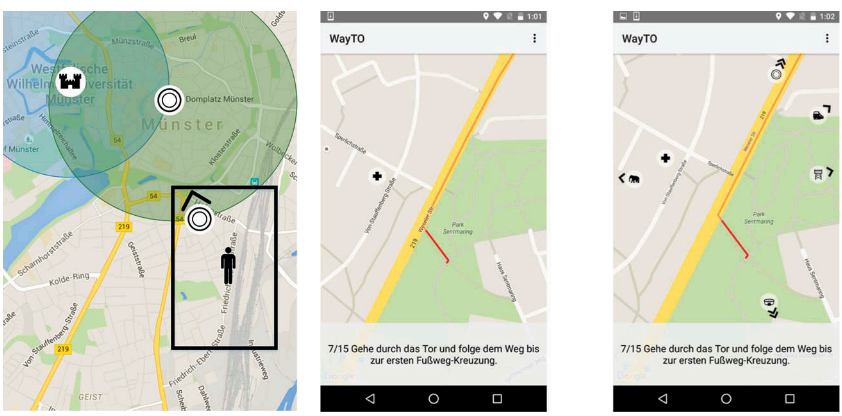


Figure 11. Left: Reference regions on the mobile device to detect off-screen landmarks. Right: Our prototype: User's view in the NOS group (left) and the corresponding view in the OS group (right). The instruction below reads: "Go through the gate and follow the road until the first intersection with a footpath."

[2]For the purpose of the experiment this radius has an arbitrary size (i.e., so that it covers the study area). This is a temporary solution which would cause issues if applied to other cases (e.g., the radius would need to flexibly change during zooming).

predefined route with the use of a provided smartphone application (Figure 11, right side). The application displayed a map of the area with a visualization of the next stretch of the required path, and a short textual route instruction. The visualization included icons emphasizing the location of some landmarks. The set of predefined visualized landmarks was the same, but the type of landmarks visible on the screen differed depending on the group. The *NOS group* only saw icons for landmarks that were located within the map section shown on the screen. The *OS group* additionally saw off-screen landmarks at the edge of the screen - highlighting the direction to distant locations in the city. To ensure participants' engagement with the application, every 2 minutes the screen displayed a pop-up message warning of the navigational device being unstable and urging the user to remain oriented.

After arriving at the final destination (unrevealed to the navigators before or during the travel), participants faced north and performed a pointing task towards the same landmarks they were asked for prior to the travel. Figure 12 presents the map of the study area, together with the route and the location of all pre-defined landmarks.

Participants were first asked about familiarity[3] with the location of each of the marked objects and, after the walk (route marked with a bold line in the center), to point in its direction. Labels "X" symbolize two landmarks, which were included in the task but were not visualized on the device. City Center, Train Station, Cinema, Stadium and Zoo were typically only seen on the screens of the *OS group*; the *NOS* participants would need to zoom out the map to see the icons, since displaying global landmarks at the edge of the screen was disabled.

4.3.2. *Hypotheses*

Following our previous work, we expected that additional off-screen information is beneficial to spatial learning. We hypothesized that *OS* version of the application will increase participants' ability to learn directions to unknown distant landmarks.

4.3.3. *Results*

Average pointing error was generally low compared to similar studies, reflecting the benefit of a map-supported navigation for this type of exercise. Overall average absolute pointing error was slightly larger in the *OS* group ($M_{OS} = 38°$, $SD_{OS} = 44°$; $M_{NOS} = 33°$, $SD_{NOS} = 43°$) but the difference was not significant. In 23 trials[4] participants refused to estimate the direction; the number of declining participants was higher in the *NOS* group. As these

[3]Familiarity was indicated verbally prior to the experiment: 0 - "I have never been there and don't know where it lies on the map," 1 – "I have never been but know where it lies on the map," 2 – "I have been there, but don't know where it lies on the map," 3 – "I have been there and I know where it lies on the map."

[4]Each of 60 participants was asked to point to 11 landmarks, so there were 660 trials in total.

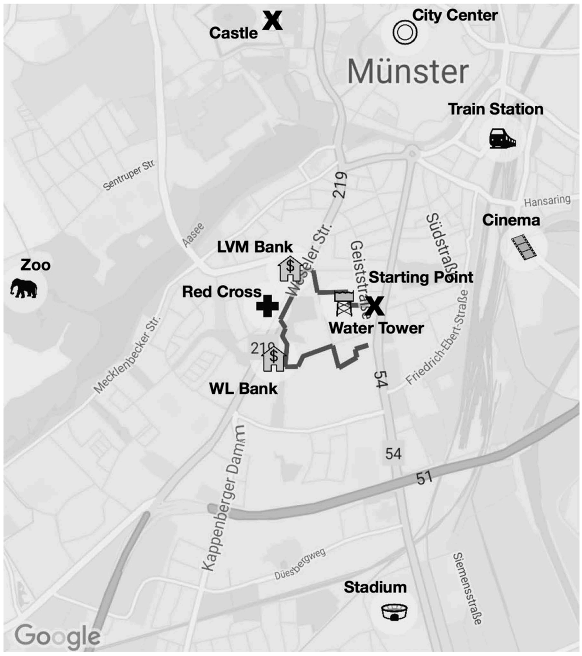


Figure 12. Map of the study area with all landmarks used in the experiment.

occurrences were excluded from further analysis, the *NOS group* results might be overestimated.

As presented in Figure 12, five off-screen landmarks were visualized in the *OS group*, which were not presented within the visualizations of the *NOS group*. One of them, the Zoo, is located South-West from the city center and West/North-West from the pointing location. Performance of the *OS group* with respect to this off-screen landmark was better (*absolute pointing error:* $M_{\mathrm{OS}} = 28.9°$, $SD_{OS} = 29°$; $M_{NOS} = 34.6°$, $SD_{NOS} = 18°$; $W = 525$, $p = 0.058$). To explain this improvement, we differentiate clockwise and counterclockwise bias in pointing. Although the pointing error of the *OS group* was randomly distributed around the direction to the Zoo, the distribution of the *NOS group's* error was binomial, biased either to the left or to the right of the target. Further investigation of the individual's prior familiarity with this landmark revealed, that those participants who declared partial knowledge of its location benefited from the *OS* visualization the most. Figure 13 demonstrates these results.

Another off-screen landmark of interest is the Cinema located North-East from the pointing location and South-East from the city center. Here, the difference between absolute pointing deviation means was negligible (absolute pointing error: $M_{\mathrm{OS}} = 30.2°$, $SD_{\mathrm{OS}} = 39.2°$; $M_{\mathrm{NOS}} = 28.4°$, $SD_{\mathrm{NOS}} = 31.6°$). However, a closer inspection of the circular distribution of errors again reveals a systematic bias in the *NOS group* — this time consequently in the counterclockwise direction. On the contrary, the distribution of errors in the *OS group* seems to be distributed around the correct direction in a manner resembling randomness (Figure 14).

Off-screen landmark visualizations might have an impact on the broader survey representation of the environment, going beyond individual cases. To assess this, we analyzed correlations between pointing errors to individual landmarks (see (Bryant, 1984) for a similar approach to studying mental representations underlying pointing errors). These correlations were much higher in the *OS group*, yielding an average Pearson's r value of 0.63, as opposed to r = 0.28 in the *NOS group* (Figure 15).

For example, the value between Stadium and WLBank in the *OS group* is 0.5. This indicates, that for all 30 participants in the *OS group*, the correlation of pointing errors to these two landmarks is r = 0.5. Note, that even if the error would be high (but similarly high for both landmarks), it would yield a high correlation value.

4.3.4. *Discussion*

The clockwise/counterclockwise bias observed in the pointing behavior of the *NOS* group (and its consistency to the Zoo and the Cinema) might result from a systematic error associated with performing a task requiring survey knowledge, when no such information is provided. Participants partially familiar with the location of the Zoo and the Cinema have a coarse understanding of where these targets might lie, but in the *NOS condition* they are forced to infer its exact location.

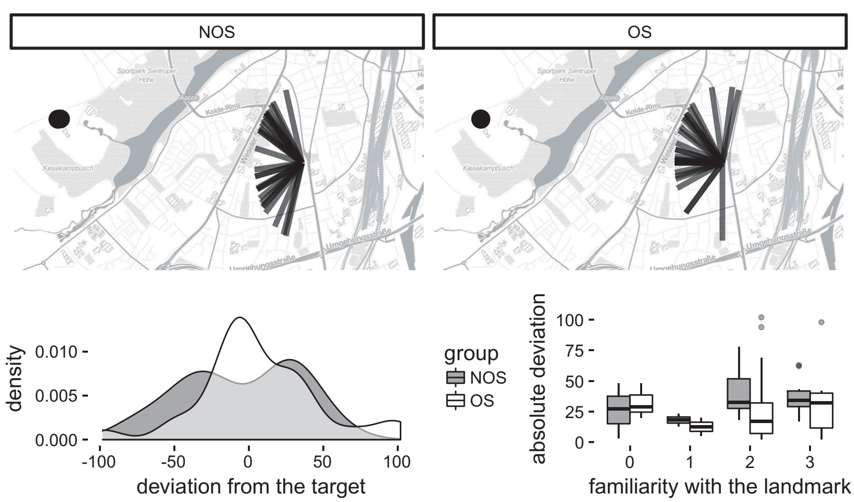


Figure 13. Top: All pointing vectors towards the Zoo (black dot) from the pointing task; bottom left: Distribution of counterclockwise/clockwise pointing errors; bottom right: Interaction of pointing performance and of familiarity with the target (Zoo). Due to low number of data points (60 split into 2×4 groups) we visualize raw distributions only.

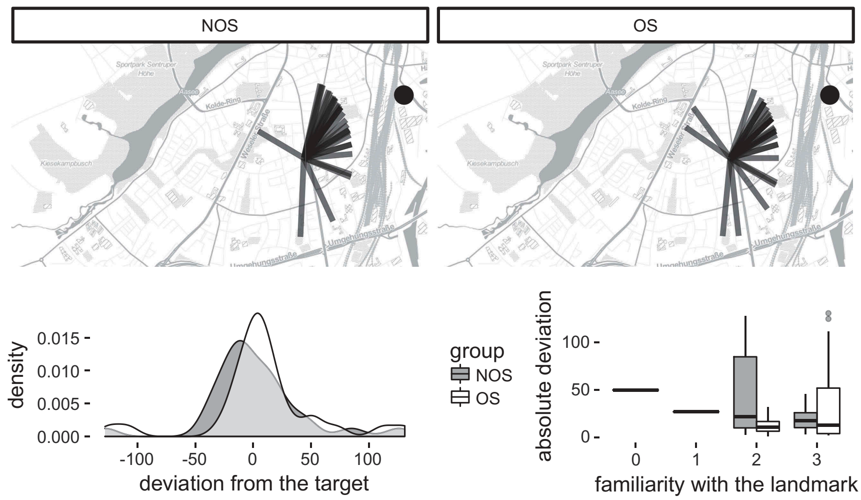


Figure 14. Top: All pointing vectors towards the Cinema (black dot) from the pointing task; bottom left: Distribution of counterclockwise/clockwise pointing errors; bottom right: Interaction of pointing performance and of familiarity with the Cinema; horizontal lines in the "0" and "1" group indicate that only one participant fell into this category.

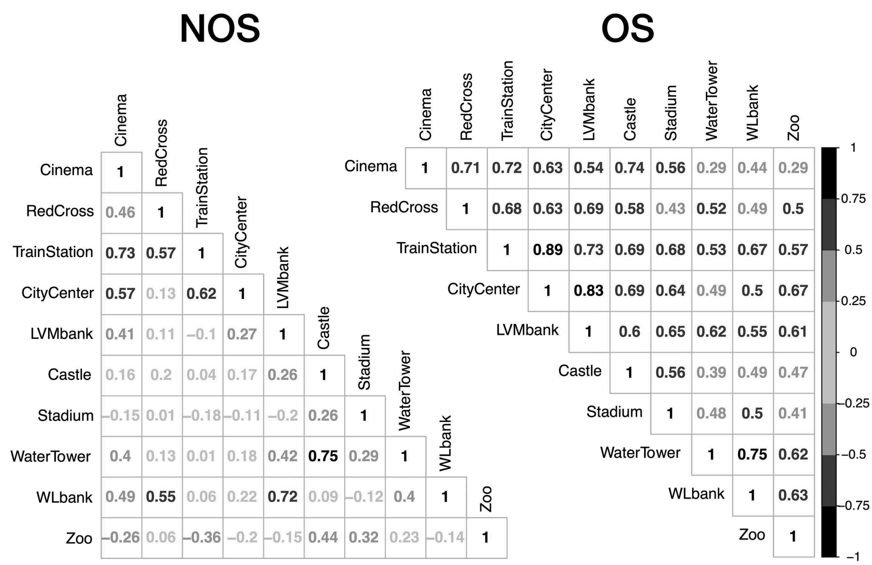


Figure 15. Correlations (Pearson's *r*) in pointing errors between landmark pairs. Lower correlations (closer to 0) are marked with a more transparent color.

One explanation of the observed biases might be an adjustment based on the already well-known routes to the targets. Existing spatial barriers between the pointing location and pointing target (the lake in between the pointing location and the Zoo and the railway track without crossings in between the pointing location and the Cinema) imply that following routes to these destinations would require making a northern or a southern detour (Zoo) or a northern detour (Cinema). Pointing of the *NOS group* showed exactly this northern or southern bias to the Zoo and the northern bias to the Cinema from the possible routes to the Zoo /Cinema.

It seems that the visualization of the off-screen landmarks was successful at correcting the bias occurring at the moment of inferring survey representation by participants who might have had no such representation beforehand. It bears noting that while generic heuristics responsible for such biases are relatively well-studied, current state of knowledge does not allow us to precisely predict which real-life environmental location will be subject to a specific heuristic in each given situations. Our analysis at this stage is limited to a single use-case.

Higher correlations in the pointing error within the *OS group* suggest that participants in this group made stronger connections between assumed locations of individual landmarks during their pointing performance. This indicates a more coherent representation of spatial relations between the targets (potentially due to placing them in a single reference frame defined by the global landmarks) (Meilinger, 2008). On the contrary, navigators in the *NOS group* seemed to point on an independent landmark-by-landmark basis, not taking into account the assumed direction to other landmarks. This strategy might be potentially beneficial when one's knowledge of target locations is heterogeneous. However, it seems that its occurrence can be varied by the display of additional (potentially auxiliary and unnecessary) orientation information.

Orientation instructions can promote spontaneous use of more survey-oriented strategies in tasks which require estimation of one's location in their broader environment. In our experiment, this seems to have happened without a clear benefit to pointing performance to all landmarks, but rather to an overall consistency of the built spatial representations and single-case biases. This might result from the fact that the visualization currently employed in the prototype application still treats distant landmarks as disjoint points on an extension of a metric map. Further work will focus on embedding survey-type information auxiliary to the route-centered instructions in an intuitively understandable manner corresponding to the natural ways of organizing and communicating such knowledge.

5. Revising the paradigm of wayfinding research

This article touched upon three distinct concepts: (A) *wayfinding* (a spontaneous activity people perform naturally, together with the related notions, such as the ways they communicate directions to each other), (B) *wayfinding research* (the study of these spontaneous activities through the proxy of established methods and tasks), and (C) *wayfinding support* (technological means to enhance human wayfinding capabilities in an unknown environment). The expected relation between these concepts is that: (A) *is studied by* (B) which *serves to inform the* *development of* (C). Despite this, the established methods of providing *wayfinding support* seem to be incompatible with the cognitive strategies involved in spontaneous human *wayfinding*.

Technological aids manage to assist our bodies in moving from origin to destination, but the cognitive experience they create does not empower the user to improve their unassisted navigation. It is also incomparable with anything humans do naturally, would advise to others, or would expect from other people in response to a question about directions. This section discusses two potential reasons for this state of affairs.

(1) It seems plausible to acknowledge that decades after their introduction, *wayfinding support* systems failed to integrate all relevant insight developed by *wayfinding research*. One feature of this fallacy is the overreliance on the goal of delivering the minimum required information in the simplest repeatable format. This problem is not unique to computer-assisted navigation. The field of human-computer interaction has long recognized the need for developing "calm" (Weiser & Brown, 1997), and (more recently) "human-like" (Dix, 2016) computer systems, operating according to an "etiquette" (Miller, 2004) in an effort to enhance natural means of interaction and empower users in their intrinsic cognitive tasks. Work reviewed in Section 2.2 demonstrates that this is already a recognized challenge in *wayfinding support* studies. However, despite embedment of this research in the cognitive sciences, the vast majority of improvements are proposed within unnatural and restrictive nature of the turn-by-turn approach.

(2) Further, the question we aim to pose is whether empowering users in their *spontaneous wayfinding* is ever achievable if built upon the findings stemming from the current paradigm of *wayfinding research*. The mere fact that the reviewed taxonomy does not distinguish between tasks probably performed *the most often* in our directed wayfinding activities seems to be a symptom of broader *wayfinding research* approach we argue against. People do not follow routes by blindly dissecting them into sequences of simplified instructions, but consciously operate within a broader environment, even if not immediately needing or using information about its more distant parts. And yet, research tends to study selected subsets of that experience, largely ignoring the impact of information seemingly irrelevant to the research question at hand. Has it not focused too much on artificial situations and processes which never appear in reality?

Naturally, this is how empirical research is typically done, and we do not claim that counterexamples do not exist, but the experimental means seem to have overshadowed the aim. One symptom of this issue is the overwhelming reliance on performance measures: it is the performance (in a limited number of tasks, indicative of limited subsets of knowledge, and of singled-out cognitive processes) that is used to judge the impact of variables affecting wayfinding. As a result, human activity is judged against the most optimal solution to a task while it tends to be forgotten that this optimal solution has to be operationalized within limited variables or concepts (e.g., metric vs topological space), which do not necessarily correspond to variables or concepts which human mind seems to prioritize during its everyday operation.

With this work, we call for reviewing the paradigm of *wayfinding research*: the means through which we learn about human spontaneous activity of *wayfinding* and the types of contributions we consider to be valuable extensions of that knowledge. This calls for (a) studying orientation as a situated cognitive phenomenon (Tversky, 2009), *always* involving multiple, interacting processes, and (b) moving away from studying *deviations-from-optimal* towards studying *deviations-from-natural*. We point to similar arguments made within the cognitive ethology approach (Kingstone, Smilek, & Eastwood, 2008).

6. Conclusions and future work

Existing research of wayfinding support improved navigation in various respects, but rarely questioned the turn-by-turn method itself. We propose the new method — Wayfinding Through Orientation – where the navigation system supports the user in orienting, spatial learning and cognitive mapping. Although researchers acknowledge that survey knowledge is equally important to route knowledge and that survey knowledge substantially contributes to cognitive mapping and orientation, so far survey or orientation information has not been typically used to improve computer-supported wayfinding.

Results of Study 1 confirm that the type of instructions received by participants affects survey knowledge acquisition measured with sketch maps and the pointing task. Study 2 demonstrated that people use orientation information naturally when asked to give route directions about a well-known environment. Finally, in Study 3 we implemented orientation information into a working prototype and showed its effect on spontaneous knowledge acquisition during computer-supported navigation in-the-wild. Users can acquire survey knowledge if they receive orientation wayfinding instructions together with route directions.

Wayfinding Through Orientation implies a novel understanding of a person's role in navigation. Orientation wayfinding actively involves users in the navigation process through addressing the users' learning and thinking abilities. It carries the potential of making its users less dependent on the navigation system, more self-confident in and aware of their environment. Users can make informed choices and are able to update their route according to unforeseen changes. Users are empowered to find shortcuts, circumnavigate new obstacles or spontaneously make detours. Being oriented and having the knowledge of environment's configuration is necessary to verify and understand wayfinding instructions. In contrast, users of turn-by-turn systems solely execute provided turn instructions.

6.1. *Challenges on the way to Wayfinding Through Orientation*

Research so far has overlooked the question of how wayfinding instructions and navigation systems can systematically increase spatial orientation in humans. What is spatial orientation in humans and what kind of information induces spatial orientation? How can we develop models to capture and process orientation information automatically? The studies presented in this article introduce preliminary ideas about how orientation instructions might look like and how they can be visualized in an effective manner. However, many fundamental questions have to be solved before Wayfinding Through Orientation can be realized. We believe that future work should address the following four challenges:

6.1.1. *Scientific understanding of orientation wayfinding*

Research needs to investigate what defines orientation in humans and what kind of information supports orientation in wayfinding. We need to demonstrate that the two goals of Wayfinding Through Orientation – wayfinding assistance on the one hand and supporting orientation on the other hand – are related and that good global and local orientation positively influences wayfinding abilities.

6.1.2. *Automatic generation of orientation information*

For computer-supported wayfinding assistance, we must be able to handle orientation information automatically. However, orientation information has some fundamentally different characteristics than conventional spatial data stored in geographic information systems. Orientation information does not have a consistent level of generalization, it is highly schematized and it refers to vernacular, vague places not included in traditional maps. Furthermore, the level of generalization and schematization of orientation information depends on the route.

6.1.3. *Communication of orientation information*

New visualizations will be required to account for the characteristics of orientation information: How can we represent schematized spatial objects with vague boundaries and inhomogeneous levels of generalization in a single map on small displays of mobile devices used for navigation? Which spatial characteristics of traditional maps may remain?

6.1.4. *Revising the paradigm of wayfinding*

Wayfinding Through Orientation supports human spatial learning and orientation. Thus, the success of orientation systems cannot be determined through traditional measures such as travel efficiency. We require new methods to determine the effect of orientation information on peoples' ability to solve wayfinding tasks that require orientation and cognitive mapping.

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