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The effect of orientation instructions on the recall and reuse of route and survey elements in wayfinding descriptions

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ABSTRACT

Turn-by-turn instructions of navigation systems do not fully correspond to the way in which people typically communicate spatial information to each other. Previous research demonstrated that the acquisition of survey knowledge from such instructions is challenging. In the present study we investigate whether it is possible to create wayfinding instructions that communicate survey information, without sacrificing the recall of route information. We explore whether the presentation of survey information can be easily mentally integrated with route information. To this end, we compared three different types of wayfinding instructions: *turn-by-turn* instructions, which include streets and metric distances; *spatial chunking* instructions which include local route information such as landmarks located at decision points and present instructions in cognitively logical chunks; and our *orientation instructions*, which combine local and global information of the route and integrate it within the environment's context. Instructions were presented in verbal and visual modes. Results showed that it is possible to improve the recall of survey information without sacrificing the recall of route-specific elements: visual *orientation instructions* resulted in significantly higher landmark recall rates, significantly higher quality sketch maps, and significantly more "survey-like" sketch map types. In the verbal mode, differences between *orientation instructions* and *spatial chunking* instructions were less clear, but the performance of both was better, compared to *turn-by-turn* instructions. These results contribute to the ongoing discussion on the potential reasons for the navigation systems' detrimental effect on spatial learning and demonstrate that people can learn both types of knowledge if the presentation style supports it. The overall amount of acquired knowledge could be improved through *orientation instructions.* Our study has practical implications for the future design of navigation systems.

1. Introduction

There is a significant gap between the way people give navigation instructions and the way computers do it: While navigation systems describe routes as a sequence of turning actions, human route descriptions additionally provide local and global orientation, provide confirmatory information by referring to non-turning actions, and describe the environmental context of the route (Anacta, Schwering, Li, & Muenzer, 2017). A large body of literature empirically confirmed the importance of landmarks in human navigation instructions (Lovelace, Hegarty, & Montello, 1999; Michon & Denis, 2001; Richter & Winter 2014) and found evidence for the relevance of landmarks in text corpora of navigational instructions (Tezuka & Tanaka, 2005).

Previous research investigated the influence of navigation instructions on wayfinding error rates, memorability of turns, and memorability of information along the route. However, we know relatively little about the effect of navigation instructions on spatial learning of both: route *and* survey information. In particular, it is unclear whether the presentation of survey information in navigation instructions can be easily mentally integrated with the route information, or whether survey information has a negative effect on route following and route information recall.

Turning actions at decision points referring to streets and distances are commonly communicated by turn-by-turn navigation systems but might not be used in strategies with which humans spontaneously acquire, store, retrieve, and communicate spatial information. Researchers found that such turn-by-turn navigation systems have a negative effect on spatial memory of environments (Hejtmánek, Oravcová, Motyl, Horáček, & Fajnerová, 2018; Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006; Parush, Ahuvia, & Erev, 2007; Sönmez

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& Önder, 2019; Willis, Hölscher, Wilbertz, & Li, 2009) and that such instructions with limited types of spatial descriptors are judged as ineffective (Padgitt & Hund, 2012). People may favor alternative spatial entities and relations in their supported navigation. Therefore, there is a need for a different navigation system that provides route instructions beyond a sequence of turning actions (route information) but includes survey information. In earlier work (Schwering, Krukar, Li, Anacta, & Fuest, 2017) we suggested a new paradigm of Wayfinding Through Orientation, and developed such alternative wayfinding instructions - called *orientation instructions*.

This paper provides evidence that it is possible to combine route and survey information in a route description without harming the recall of route information. We compare the performance of *orientation instructions* to the performance of *turn-by-turn* wayfinding instructions, as well as to the performance of spatial chunking, one existing extension of the traditional turn-by-turn approach proposed earlier by Klippel, Hansen, Richter, and Winter (2009).

This paper aims at different objectives in different disciplines. From a psychological perspective, we aim to investigate whether it is possible to improve the recall of survey information without harming the recall of route information. Is it possible to induce a spatial representation that combines both, survey and route information into one representation of a route embedded in the broader environment? This problem is not trivial, considering that survey information is not necessary to successfully complete a navigation task. It is possible that survey information is thus ignored by people focused on their wayfinding task. Furthermore, such instructions are more complex: it might therefore be a more challenging task to memorize them and the recall of survey information might be to the detriment of route information.

From a geoinformatics perspective, we would like to demonstrate that it is possible to construct *orientation instructions* combining both: route and survey information. In analogy to mnemonic strategies, which improve memory by relating new and old information aiming for a deeper understanding of the content - *orientation instructions* embed turning actions into the context of the environment and relate information to each other. A navigation instruction leading to a better recall of route and survey elements is a significant step towards solving the problem of turn-by-turn navigation systems and improving spatial learning during navigation.

2. Literature overview

The detrimental effect of navigation support on environmental learning might be justified by the primary role of these systems: it is not to support knowledge acquisition but rather to lead users to their destinations. The unanswered question is whether it is possible to design a system that would be as efficient and as intuitive as the current ones, while also being more supportive in environmental learning. One of the features that have been seen as crucial for this direction is the type of information that the system communicates in wayfinding instructions.

In the following sections we outline related work on spatial knowledge acquisition of route, survey, and landmark information. Afterwards we show how these types of information are communicated in wayfinding instructions and how navigation systems deal with them. Finally, we review work on recall and memorization of wayfinding instructions.

2.1. Spatial knowledge acquisition

Human spatial knowledge is organized into landmark knowledge, route knowledge, and survey knowledge (Siegel & White, 1975). Landmark knowledge includes information about salient places, without references to their locations; route knowledge includes information about the sequence of actions necessary to reach one point from another; and survey knowledge includes information about the configurational organization of locations in the environment. These types of information are built up simultaneously (Montello, 1998) and with large individual differences in the process (Ishikawa & Montello, 2006). While some participants may acquire survey knowledge from the first exposure to a new environment, others rely on route knowledge even after repeated visits to the same area (Ishikawa & Montello, 2006). Information relevant to route knowledge and to survey knowledge is combined, and it is possible to remain an effective navigator even with deficiencies in some knowledge type.

Human spatial knowledge does not consist solely of metric knowledge, but in large parts, it was built up from approximate spatial relations at varying degrees of certainty. Ishikawa and Montello (2006) suggested that the main unit of spatial knowledge is qualitative metric information - one that contains some metric relations (e.g., angles and distances), but often in a vague or approximate form. Tversky (1993) argued that the term “cognitive map” is misleading and proposed the metaphor of a “cognitive collage” instead.

Individual differences moderate the acquisition of spatial knowledge. These differences can be measured with different methods. The Questionnaire on Spatial Strategies is a self-report measure of preferred strategies in spatial knowledge acquisition (Münzer & Hölscher, 2011). It distinguishes between three factors: (1) global self-confidence related to egocentric spatial reference frame, (2) preference for an allocentric reference frame, and (3) preference for the knowledge of cardinal directions. This recognizes the diversity of strategies with which people prefer to learn spatial environments. It has been suggested that people with a higher preference for an allocentric reference frame should be better and more frequent users of paper maps (Münzer, Fehringer, & Kühl, 2016). However, the map's design often restricts the set of strategies that can be employed to understand and communicate spatial information. Of particular interest has been the problem of map orientation (Aretz, 1991; Montello, 2010) since mapped spatial relations often need to be rotated mentally in order to align them with the (imagined) egocentric perspective of the navigator. The Mental Rotation Test (Vandenberg & Kuse, 1978) is a common measure of objective spatial abilities related to such mental alignment. Higher results on this test have been linked to a better performance in map-reading tasks (Malinowski, 2001).

Given the diverse set of strategies with which spatial knowledge is acquired, it is critical to evaluate spatial knowledge acquisition with methods that recognize this diversity. One of such appropriate methods is sketch mapping (Kitchin, 2000; Montello, 2016). Krukar, Münzer, et al. (2018) and Krukar, Schwering, et al. (2018) emphasized that sketch maps might be evaluated not only through the prism of their *accuracy* but, separately, through the prism of their *type*. The authors provide a classification system that evaluates sketch maps on two independent dimensions: their *route-likeness* and their *survey-likeness*, depending on the diversity of information types used to communicate route-related and survey-related information. Whereas the accuracy of sketch maps is not a necessary precondition for their practical usefulness (Tversky, 2009), a more sophisticated sketch map *type* may be indicative of a more complex underlying cognitive map.

2.2. Communicating wayfinding instructions

Vague and approximate spatial knowledge is used to create wayfinding instructions for other people. When communicating wayfinding instructions (either verbally or by sketching), humans make use of a broad variety of spatial relations, often neither preserving nor explicitly communicating correct metric information. Human-generated instructions commonly contain landmarks at decision points (Denis, 1997; Klippel & Winter 2005; Lee, Tappe, & Klippel, 2002), landmarks along the route (Ishikawa & Nakamura, 2012; Lovelace et al., 1999), and global landmarks located off-route (Li, Fuest, & Schwering, 2014; Schwering, Li, & Anacta, 2013; Steck & Mallot, 2000). Good human-generated instructions routinely link actions with specific landmarks (Daniel, Tom, Manghi, & Denis, 2003) and increase the number of

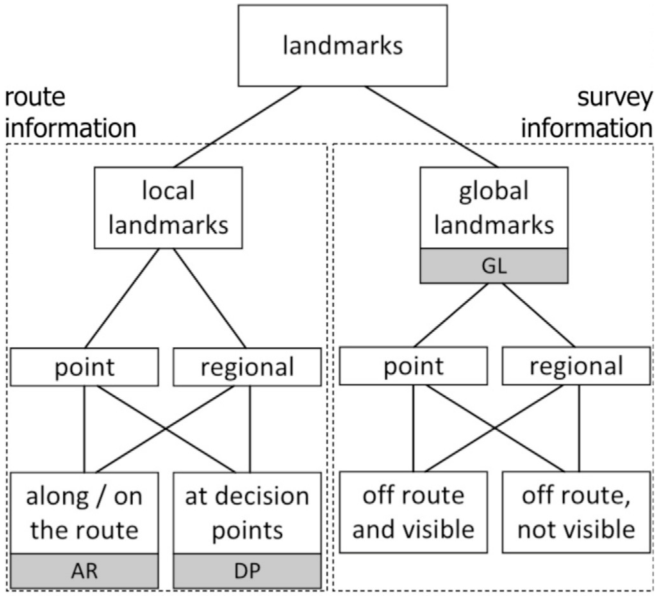

Fig. 1. Classification scheme of landmarks typically included in human-generated wayfinding instructions. Adapted from Anacta, Humayun, et al. (2017) and Anacta, Schwering, et al. (2017) with the added emphasis of route information and survey information, as used in the current manuscript.

landmarks around route fragments that are challenging for orientation (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999). Instructions also flexibly switch between different granularities of description, reflecting the hierarchical character of spatial knowledge, and communicating the level of hierarchy more relevant at the given part of the route (Tenbrink & Winter 2009).

Due to their flexibility, landmarks can be used as elements communicating route-relevant information or survey-relevant information. Anacta, Humayun, et al. (2017) and Anacta, Schwering, et al. (2017) provided a classification scheme for landmarks as used in human-generated wayfinding instructions (Fig. 1). The authors distinguished local and global landmarks with subtypes. Local landmarks are located along the route or at decision points - they serve to communicate route-relevant information since knowledge of landmarks' sequence helps to make and validate decisions about how to reach the destination using a single predefined path. Global landmarks are located off the route - either visible from the route (e.g., mountains on the horizon), or not (e.g., a city center). Global landmarks relate the current location and the route to the environmental context. They allow the person to remain oriented, and therefore help to integrate separately learned parts of the environment. In the current paper, we quantify route information through the number of local landmarks and survey information through the number of global landmarks.

2.3. Implementing wayfinding instructions in navigation systems

Disregarding human ability and preference for acquiring multiple types of spatial information, technological aids communicate route instructions in a uniform and minimalistic fashion. Researchers therefore attempted to make computationally-generated route instructions more similar to those preferred and used by humans.

One such development, introduced into commercial wayfinding systems relatively recently are landmarks (Richter & Winter 2014). Including landmarks in machine-generated route instructions includes the problem of selecting salient landmarks from a number of possible landmark candidates (Raubal & Winter 2002) and distinguishing landmark hierarchies in the context of the broader environment (Winter, Tomko, Elias, & Sester, 2008).

Another improvement for making computationally-generated route instructions more similar to those preferred by humans has been proposed by Klippel et al. (2009). They considered the problem of turn-by-turn division of wayfinding instructions. In his work, Klippel identified cognitively relevant "chunks" of the route, that he then used to structure the instructions. The resulting instructions consist of less "chunks" because many turn-by-turn instructions can be combined into one: For instance, when the navigator needs to go straight through three intersections in a row. Despite claiming its cognitive adequacy, so far, this approach has not been evaluated in empirical user studies.

2.4. Memorability of wayfinding instructions

Navigation systems have transformed wayfinding into a *passive path following* task (Schwering et al., 2017) where active information search, spatial updating, and decision making have been substituted by the demand of following a sequential set of turning actions at decision points (Krukar, Schwering, Löwen, Galvao, & Anacta, 2018; Schwering et al., 2017). This negatively affects spatial learning and people's ability to orient in the environment (Krüger, Aslan, & Zimmer, 2004; Münzer, Zimmer, & Baus, 2012; Ruginski, Creem-Regehr, Stefanucci, & Cashdan, 2019).

Although the traditional turn-by-turn, metric information-based approach has been considered an effective solution to supporting navigation and it follows justified principle-based practices (G. L. Allen, 2000), there are disadvantages to its usage (Field, O'Brien, & Beale, 2011; Ishikawa, Fujiwara, Imai, & Okabe, 2008). Using navigation assistance systems leads to poor spatial knowledge (Münzer et al., 2006) despite allowing the user to successfully reach their destination (Dickmann, 2012). One of the reasons is that such navigation instructions decrease the users' engagement with the environment (Fenech, Drews, & Bakdash, 2010; Leshed, Velden, Rieger, Kot, & Sengers, 2008). Another reason is the commonly adopted presentation modes which do not support building up a cognitive map of the environment (Gartner & Radoczky, 2005; Ishikawa & Takahashi, 2013; Münzer et al., 2012). Alternative presentation modes have been shown to result in a trade-off between providing an efficient wayfinding support and supporting effective environmental learning (Münzer et al., 2012).

However, making computer-generated instructions more similar to those spontaneously used by humans did improve their memorability. Including landmarks in wayfinding instructions has repeatedly been shown to affect what information is being learned during assisted navigation (Gramann, Hoeppner, & Karrer-Gauss, 2017; Oliver & Burnett, 2008). For example, Oliver and Burnett (2008) conducted an experiment in a virtual reality driving simulator, where participants used one of two navigation systems - a classical turn-by-turn system and a turn-by-turn system enhanced by the presence of landmarks at intersections. The authors demonstrated that the system with landmarks increased learning of some route details, while it did not increase the attentional demand (measured by the number of glances at the display). Gramann et al. (2017) tested three alternative wayfinding systems in a virtual driving simulator: a traditional turn-by-turn system, a system enhanced with landmarks, and one enhanced with landmarks of personalized meaning. Their results demonstrated that participants who saw the landmark-enhanced systems learned the route better: they recognized more landmarks in the subsequent test, their performed better in the rerouting task, and they correctly reproduced a higher proportion of landmarks and turns onto sketch maps. Importantly, authors' analyses did not reveal any negative impact of the landmark-enhanced wayfinding instructions on the mental workload and driving performance. The lack of these effects could be seen as counter-intuitive, if we consider that landmark-enhanced instructions are typically longer and more complex. Löwen, Krukar, and Schwering (2019) investigated spatial knowledge acquisition in a car driving scenario in a virtual world with different types of maps highlighting local features such as landmarks along the route and at decision points and/or highlighting structural features that provide global orientation. The results showed that accentuating local features supports peoples' acquisition of route knowledge, whereas accentuating global features supports peoples' acquisition of survey knowledge.

Memory literature shows that learning performance is higher if the information being learned is meaningful (Craik & Lockhart, 1972; Craik & Tulving, 1975). On the contrary, metric turn-by-turn information is a very challenging stimuli to learn: it is numeric, abstract, difficult to visualize, and similar to each other. The success of landmark-enhanced instructions can therefore be explained by the fact that landmarks are memorable cues. Associating memorable cues with difficult-to-learn information improves recall, and is common in numerous mnemonic strategies (Bellezza, 1996). Memory literature also demonstrates that information is learned better if it can be related to other knowledge that sets it in context (Morton, Sherrill, & Preston, 2017) and if it is presented simultaneously, rather than sequentially (R. J. Allen, Baddeley, & Hitch, 2006; Blalock & Clegg, 2010; Lecerf & de Ribaupierre, 2005).

The current paper introduces a new type of wayfinding instructions: orientation instructions that aim at relating route information to the context of the broader environment. These instructions are by necessity longer and more complex and therefore could be expected to be more difficult to memorize. However, due to the fact that they set route information in context and remain relevant to the task at hand, they may also expand people's learning potential by requiring a deeper level of cognitive processing and by promoting the integration of separately learned elements presented simultaneously.

3. The present study

The present study aims at investigating whether route instructions can trigger the recall of both route and survey information at a high level. The goal of the study is to explore whether people can recall additional (survey-like) information while keeping the amount of recalled route-like information at the same level. This is not a trivial task, given that instructions containing survey information are more complex and the amount of information people can recall from the learning phase is limited. The goal is therefore to explore what are the limits of spatial learning: how much additional survey-related information, and in what form, can we present to users without harming the route-related information acquisition. We compared three types of wayfinding instructions:

- *Turn-by-turn instructions* which presented only information on the route in a sequential way.
- *Spatial chunking instructions* inspired by Klippel et al. (2009), which merged cognitively relevant "chunks" of route information and used local landmarks for structuring the route.
- *Orientation instructions* which minimize the presented route information, but add additional survey information describing the route's relation to the environment (Anacta, Schwering, et al., 2017).

All three route instructions were tested in two modes: a combined visual-and-verbal mode (herafter: "visual") and in a purely verbal mode (herafter: "verbal"). The recall of route information was investigated in a sketch map drawing task: We analyzed sketch maps with respect to the quantity of recalled information, with respect to the quality of recalled information, and with respect to the type of the drawn sketch map based on the included route-related information (route-likeness) and survey-related information (survey-likeness).

From a psychological perspective, we hypothesized that *orientation instructions* will allow people to recall survey information without harming the recall of route information. In particular:

- H1: *Turn-by-turn*, *spatial chunking*, and *orientation instructions* will result in sketch maps that do not differ in the quantity of route-relevant information, but *orientation instructions* will result in additional recall of survey-related information.
  - H1a: *Orientation instructions* will not result in lower quantity of recalled local landmarks compared to *turn-by-turn* and *spatial chunking* instructions.
  - H1b: *Orientation instructions* will result in additional recall of global landmarks.
- H2: *Orientation instructions* will result in sketch maps that receive higher scores from raters judging their quality.
- H3: *Turn-by-turn*, *spatial chunking*, and *orientation instructions* will result in sketch maps that differ in their type: sketch maps will be equally "route-like", but *orientation instructions* will generate more "survey-like" sketch maps.

From the Geoinformatics perspective, we aimed to show that *orientation instructions* combining route and survey information can be constructed. If *orientation instructions* perform well in the evaluations related to quantity, quality, and type of the memorized information, we will have shown successfully that route and survey information can be combined into meaningful wayfinding instructions.

Large individual differences across participants can be anticipated in this process. We hypothesized that at least one of the two administered questionnaires will significantly correlate with landmark recall, sketch map quality and sketch map type. For each dependent variable we identify the individual difference measure that predicted it best. For example, it could be expected that participants with a higher preference for an allocentric reference frame, or with higher Mental Rotation Test scores will draw more survey-like maps. Conversely, it could be expected that participants will draw more route-like sketch maps if they self-report higher global self-confidence related to the egocentric reference frame.

4. Method

4.1. Participants

Eighty-four students and university staff (47 female, age range = 19–50 yrs, M = 25.77, SD = 5.01) participated in the experiment in return for a monetary compensation of €10. The duration of the experiment was approximately 1 h.

Power analysis: We conducted a power analysis using the simr R package (Green & Macleod, 2016) for simulated (not observed) results of the landmark quantity analysis (Section 5.1.1). According to the analysis, our sample size had a 60% power to detect a small effect size (i.e., assuming Odds Ratios = 0.59 for the *spatial chunking* condition) and a 99% power to detect a medium or large effect size (*spatial chunking* Odds Ratios = 0.29).

4.2. Experimental design

We tested the influence of instruction type on quantity, quality and type of sketch map in two modes of instructions: visual (route visualized in a map with text and audio instructions provided simultaneously) and verbal (textual and audio instructions only). We tested the between-participant effect of instruction type (*orientation instruction* vs *spatial chunking* vs *turn-by-turn*) in a 2x3 split-plot design (Table 1), but did not test the effect of instruction mode (visual vs verbal), nor its interaction. The reason was that the procedure and materials had to be modified across the two modes and they are not directly comparable

Table 1
Experimental design.

	turn-by-turn	spatial chunking	orientation instructions
visual	Participant A	Participant B	Participant C
verbal	Participant A	Participant B	Participant C

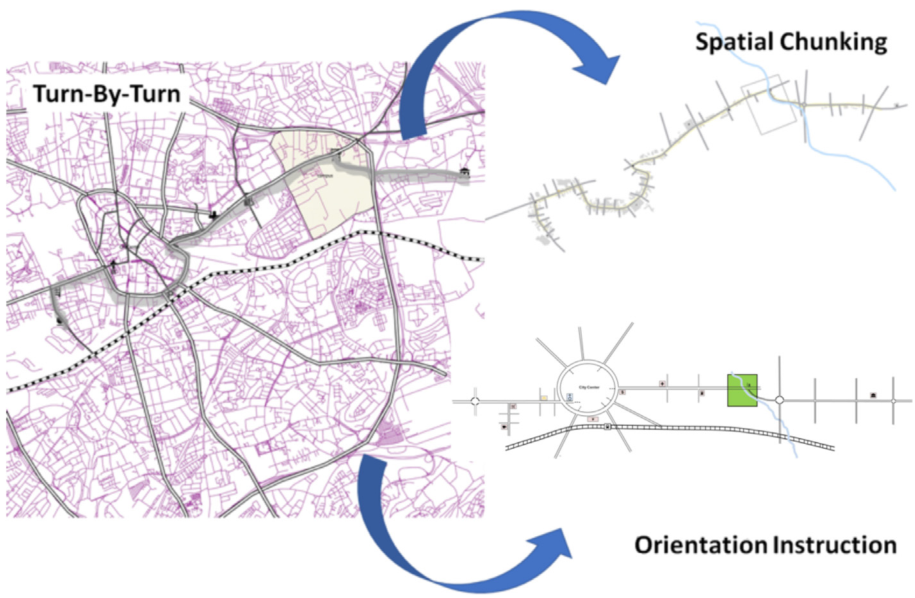

Fig. 2. Three maps of a single route used to generate instructions: in the turn-by-turn condition (left, with the route highlighted in bold grey), spatial chunking condition (top right) and orientation instructions condition (bottom right). Note that participants never saw the entire map in such a view, but only its fragments (in the visual mode) or textual descriptions of its segments (in the verbal mode).

(see explanation in the Materials section). Participants were randomly and equally distributed into three *instruction type* groups. There were 28 participants in each group. Each group performed first the visual and then the verbal mode tasks which resulted in 168 sketch maps. The dependent variables were: (1) the number of landmarks drawn, (2) sketch map quality judged by two independent raters, and (3) sketch map type (route-likeness/survey-likeness scores).

4.3. *Materials*

4.3.1. *Study area*

We used two fictional cities; one in the visual and one in the verbal mode. Both cities were nearly identical (number of landmarks differed by one), but we flipped the map along the vertical axis and changed labels of landmarks and streets to avoid learning effects. The route had a total length of 6160 m and consisted of 6 turns and one roundabout. Fig. 2 visualizes the route in three base maps used to generate wayfinding instructions.

4.3.2. *Types of wayfinding instructions and modes of presentation*

Table 2 shows the difference in the type of wayfinding instructions in both visual and verbal modes. *Turn-by-turn* instructions followed a typical navigation system paradigm mostly including street names and distances. *Spatial chunking* based on the work of Klippel et al. (2009) combined multiple subsequent route segments including mostly landmarks at intersections where a turn is made. *Orientation instructions* had components of spatial chunking but with references to all other types of landmarks. *Orientation instructions* were longer as they incorporated both route and survey information (thus, using more spatial relations) compared to *turn-by-turn* and *spatial chunking* instructions.

Visual Mode (visual map, text, and audio). Navigation systems communicate route instructions by highlighting routes in maps complemented by verbal instructions, which are read out to the user and sometimes also written on the display of the navigation system. Our visual mode was designed to resemble this look. In the *turn-by-turn* condition, the map was shown only at a fixed scale. In the *spatial chunking* condition, a simplified map was created by extracting the route from the *turn-by-turn* visualization while preserving the side streets. For the visualization of *orientation instructions*, the map was schematized and drawn not to scale. We adapted the results from our previous work on how people represent different types of landmarks on their sketch maps (Anacta, Humayun, et al., 2017; Anacta, Schwering, et al., 2017). In addition, landmark icons were shown in all maps independently of whether they were explicitly mentioned in the instructions or not. Appendix B gives examples of our wayfinding instructions. Fig. 3 shows an example of the same route segment with three different visualizations and the corresponding instructions. The map for *turn-by-turn* instructions presented a large fixed scale, while *spatial chunking* showed a simplified abstracted route at different scales. *Orientation instruction* maps, on the other hand, incorporated a schematized route of the *spatial chunking* map. In the animated visualization, a red dot indicated the user's changing location on the map. The animation in *orientation instructions* showed side streets of the *spatial chunking* map which faded away as soon as the red dot passed the particular route segment.

Verbal Mode (text and audio). The verbal mode consisted of textual and audio instructions for different instruction types as explained above, but without the visualization. We need to point out that wayfinding instructions contained different information in the visualization and in the verbal part of the instruction: *Turn-by-turn* instructions did not contain any landmark information in the verbal mode. Verbal instructions in the *spatial chunking* condition contained only landmarks, if they were a part of a spatial chunk, while the visualization contained the complete set of landmarks, independently of whether they were in a spatial chunk or not. Therefore, the *spatial chunking* condition in the verbal mode contained only 5 landmarks, while the *orientation instructions* condition presented all landmarks. With the verbal mode we wanted to test to what extent we can communicate effective orientation instructions without visualization. Since the amount and the type of information contained in the verbal and in the visual mode differed, we could not compare the results of both modes directly to each other.

4.3.3. *Individual differences questionnaires*

We administered the Mental Rotation Test (Vandenberg & Kuse, 1978) as an objective measure of spatial abilities and the Questionnaire on Spatial Strategies (Münzer et al., 2016; Münzer & Hölscher, 2011) as a subjective measure of preferred spatial strategies. Both questionnaires were provided in a paper-and-pencil form.

Mental Rotation Test consisted of two parts, with a time limit of 3 min for each part. The participant's goal was to select two (out of four displayed) three-dimensional figures that were rotated instances of the provided reference figure. There were 10 reference figures in each part of the test. The score for each part is calculated by dividing the number of incorrect responses by 4 and subtracting the resulting value from the number of correct responses (i.e., from the number of figures for which both of the matching rotated instances were identified). Correctly

Table 2
Design principles used to generate wayfinding instructions across the conditions.

	verbal mode	visual mode
turn-by-turn	• inspired by navigation systems • only street names, distances, cardinal directions • no landmarks • e.g. "Turn right onto Richard-Wagner-Str. and drive for 500 m"	• inspired by maps in navigation systems • street names • icons for landmarks • landmarks are shown but not mentioned in text and audio instructions • fixed scale of 1:1000 • north-up map
spatial chunking	• following Klippel et al. (2009) • spatial chunking (numerical-, landmark-, structural chunking) • landmarks at decision points • e.g. "Turn right at the second intersection/T-intersection; Follow the railroad track; Turn right at the church"	• adapted map visualization from Klippel et al. (2009) • simplified route (selected route segments and side streets) • no street names • icons for landmarks • no fixed scale such that the complete current segment is visible • north-up map
orientation instruction	• following Anacta, Schwering, et al. (2017) • local landmarks at decision points and along route • global landmarks off-route • spatial chunking • includes spatial relations to regions • e.g. "Go around the city center towards the church, then go through the park"	• adapted from Anacta, Schwering, et al. (2017) • simplified and schematized route with schematized surroundings • straightened streets, regularized shape for regional landmarks • no street names • icons for landmarks, labels for regions • no fixed scale so that the current and next segment are visible • north-up map

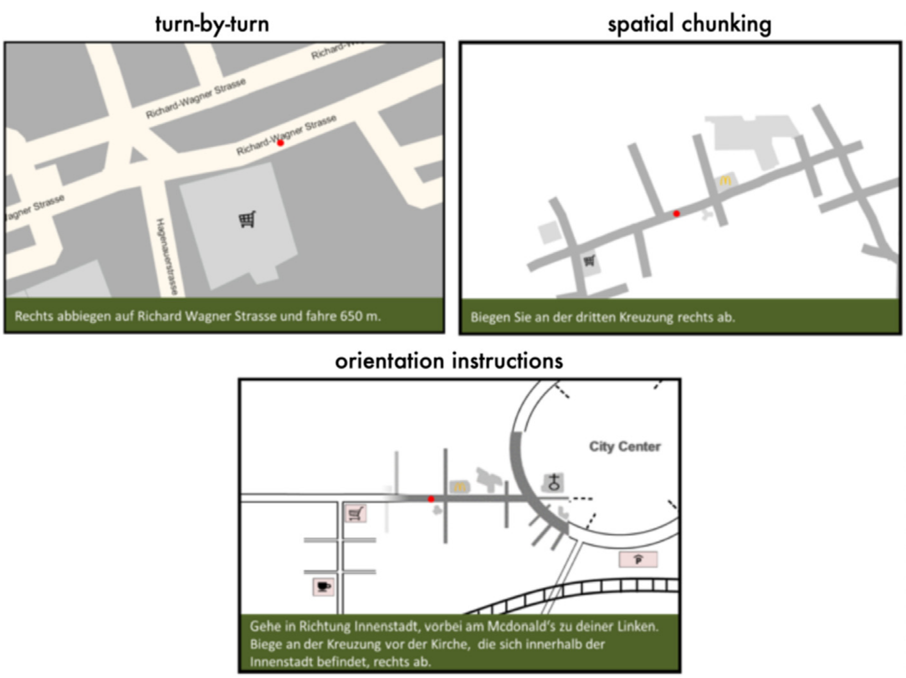

Fig. 3. Three types of visualizations used in the visual mode. Instructions were in German. Turn-by-turn: "Turn right at Richard Wagner street and drive for 650 m". Spatial chunking: "Turn right at the third intersection". Orientation instructions: "Go towards the city center, passing McDonald's on your left. Turn right before the church, located inside the city center".

responding to all figures resulted in the score of 10; providing incorrect responses to all figures resulted in the score of −2.5; not providing any responses resulted in the score of 0. Part 2 of the test was more challenging. Because of the observed floor effect in Part 2, we only analyze the results of Part 1. In it, responses ranged from −2.5 to 10 with $M = 4.80$, and $SD = 2.61$.

Questionnaire on Spatial Strategies (administered in German) consisted of 19 statements with Likert-scale answers ranging from 1 (strongly disagree) to 7 (strongly agree). Global self-confidence scale is loaded by 10 items, preference for an allocentric reference frame scale is loaded by 7 items, and preference for the knowledge of cardinal directions is loaded by 2 items (Münzer & Hölscher, 2011). The score for each scale is calculated by averaging the responses for the respective items, and can therefore range from 1 to 7. In our sample, global self-confidence ranged from 2.10 to 6.50 ($M = 4.40$, $SD = 1.02$); preference for an allocentric reference frame ranged from 1.14 to 6.00 ($M = 4.13$, $SD = 1.06$); and preference for the knowledge of cardinal directions ranged from 1.00 to 7.00 ($M = 3.04$, $SD = 1.72$).

4.4. Procedure

Participants were tested in a laboratory where they were seated in the same location and in the same facing direction. After signing the consent form, participants were asked to perform the Mental Rotation Test (Vandenberg & Kuse, 1978) and to fill in the Questionnaire on Spatial Strategies (Münzer et al., 2016; Münzer & Hölscher, 2011).

Next, participants were instructed to remember the route so that they could describe it to another person afterwards without specifying how they will be asked to describe the route. A laptop was used to present the tasks in first the verbal and then the visual mode. In the verbal mode, participants were given a scenario where they had to follow a route in textual instructions with audio from *a Pub to a Hotel shown on Microsoft Powerpoint slides.* Participants could move to the next instruction by pressing a button. After going through all instructions, they were allowed to repeat viewing the route instructions until they felt confident enough to proceed. Next, they were asked to sketch a map of the described route.

Afterwards, in the visual mode, participants were given a scenario where they had to follow a route from a *Café to a Museum*. Participants were instructed to remember the route as they would later be asked to describe the same route to someone new in the area. Written instructions, together with the map of the environment were presented in a Microsoft Powerpoint animation: a red dot highlighted the current location on the map which was moving continuously in the background. Audio instructions were played simultaneously. The route was divided into route segments: The animation continued with the next route instruction when the participant pressed a button.

The Microsoft Powerpoint animation had a screen frame size similar to navigation system devices, 5 × 3.3 inches. The animated map moved with the same speed for every condition, therefore, the total time spent on each animation differed depending on the length of the instruction and the map scale. Given that it is easier to sketch a map based on the visual representation than based on a verbal representation (as in the verbal mode), participants saw the animated route only once before drawing a sketch map. Both maps were drawn on an A4 sheet of paper with optional extra pages. There was no time limit for the sketch mapping activity.

5. Data analysis

We compared three conditions (*turn-by-turn* vs *spatial chunking* vs *orientation instructions*) on three measures: quantity, quality, and type. The visual and the verbal mode were analyzed separately.

5.1. Quantity of route- and survey-related information

We were interested in testing whether *orientation instructions* increased the likelihood that participants reuse landmarks in their subsequent descriptions of the route. In order to measure the significance of such differences, we used logit mixed models (Jaeger, 2008). Compared to ANOVA, this method has the advantage of considering all information in the dataset without aggregating it by-landmarks or by-participants, i.e., it considers which particular landmark was recalled by which participant, taking into account that some participants perform on average better than others and that some particular landmarks are on average more difficult to recall than others. Further, this method has the advantage of directly modelling the type of data which was collected (i.e., yes/no recall of each landmark). As such, it increases statistical power of the analysis, and respects the properties of the underlying data. The results are presented in the form of Odds Ratios, that can be interpreted like betting odds. For example, Odds Ratio of 1.5 indicate that there is a 1.5:1 chance for a particular outcome to happen (e.g., for a landmark to be recalled) in the given condition. This is equivalent to saying that the chance for a landmark to be recalled in the given condition is 50% higher, compared to the baseline condition. All reported odds are relative to the baseline condition; we used *orientation instructions* as the baseline condition, because we stated no hypotheses about the differences between *turn-by-turn* and *spatial chunking* conditions. Therefore, modeling odds between the baseline *orientation instructions* condition and the remaining two conditions suffices to answer all hypotheses stated in Section 2.

5.2. Quality of sketch maps

We used a common evaluation method for sketch map quality by rating "map goodness", based on a subjective judgment of how useful each sketch map could be to a potential navigator unfamiliar with the sketched environment (Billinghurst & Weghorst, 1995; Zanbaka, Lok, Babu, Ulinski, & Hodges, 2005). Two raters (blind to the purpose, procedure, design, and results of the study) were presented with all sketch maps, in a randomized order. They were asked to rate each sketch map independently on an ordinal scale from 0 to 3 (exact instruction: "Please classify these sketch maps based on their quality into the following categories"):

0 nonsense (it is not a map)
1 bad (it is a map but it would be impossible to use)
2 medium (this map is possible to use in parts, but it would be difficult to reach the destination using this map)
3 good (it would be possible to find the destination with this map; small parts might be missing, but they probably would be solvable by a navigator using the map in practice).

Raters first did a training set of 10 sketch maps, discussing the scores between themselves. They then scored the remaining 158 sketch maps independently. Finally, they reviewed their scores, identified diverging cases and were asked to jointly arrive at a single conclusion (there were 41 diverging cases out of 168 sketch maps, i.e., 24%).

In some cases, raters could not reach a decision without knowing whether specific metric or turning information in the sketch map is correct. For these cases, they were asked to agree on two scores: one if the relations in question are accurate and another if they are not. This was the case for 32 sketch maps out of 168, i.e., for 19% of sketch maps. The relations in sketch maps were subsequently checked for accuracy and the final score was selected. For all analyses, we used a single, final, agreed score of each sketch map (i.e., one on which both raters have agreed, and if necessary, selecting one of two alternatives based on the accuracy of the concerned spatial relations). Note that the entire procedure related to the rating of sketch maps' quality was conducted over a year after the main study. Two independent raters judging the sketch maps were not involved in any aspect of the data collection or earlier data analysis.

In order to statistically test the difference between experimental conditions, we modelled the influence of instruction type on sketch map quality by using a proportional odds model for ordinal data (Christensen, 2015). This model has the advantage of respecting the underlying nature of the ordinal scale, most importantly the fact that the conceptual distance between each score on the ordinal scale is unknown and needs to be modelled. This is reported in the output in the form of threshold values between the items of the ordinal scale. The results are presented in the form of Odds Ratios, as in the logit model described earlier.

5.3. Type of sketch maps: survey-likeness and route-likeness

We use the approach presented and evaluated by Krukar, Münzer, et al. (2018) and Krukar, Schwering, et al. (2018) to rate sketch maps according to the presence of elements related to route-like and survey-like map characteristic. The classification does not consider the accuracy of the sketch map, but the presence or absence of elements useful to a potential future user of the sketch. The analysis differentiates between two dimensions: survey-likeness and route-likeness of the sketch map (Fig. 4). Survey-likeness of a sketch map is scored based on the existence of:

S1 *global point landmarks*: any point-like feature located off-route or visible from multiple stretches of the route, e.g. a city hall;
S2 *global linear landmarks*: any linear-like feature (other than the street

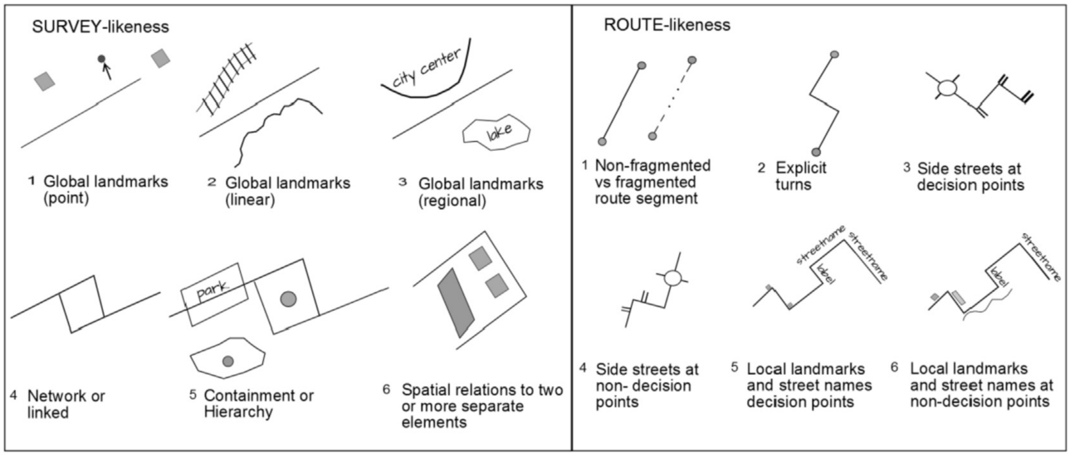

Fig. 4. Sketch configurations used in scoring the route-likeness and survey-likeness.

network) that carries a spatial relation to other objects, e.g. rivers or railway track located either along the path or off-route;

S3 *global regional landmarks*: any areal-like feature, possibly with vague boundaries, e.g. city center, district, lake, and park;

S4 a *network or linked street:* at least two streets are connected or forming a cycle-like structure so that it would be possible to identify an alternative route in the sketch drawing;

S5 a *hierarchy or containment*: at least one feature is depicted inside another feature, e.g. a building inside a regional landmark;

S6 *spatial relations between neighboring objects:* when two separate elements have spatial relations *to at least three separate elements* such as streets and landmarks.

Route-likeness of a sketch map is scored based on the existence of:

R1 a *non-fragmented route*: the entire path from start to destination is continuously drawn;

R2 route with explicit *turns:* when the path includes depiction of meaningful and explicitly drawn turns for the whole route;

R3 *side streets at decision points*: when some indication of alternative route are depicted at intersections or junctions;

R4 *side streets outside decision points (along the route):* when some indication of alternative route along the segment of a straight path;

R5 *local landmarks or street names at decision points:* when the sketch includes landmarks at intersections or junctions *(*street names should be labeled on both sides of the turn segments);

R6 *local landmarks or street names outside decision points*: when the sketch includes landmarks located along the street segment.

One point was scored for each criterion that was present in the sketch map. For R3 to R6, at least two examples were required in order to score a point. Sample-specific reliability for the data presented in this paper was 0.60 for route-likeness, and 0.82 for survey-likeness scale (measured by Guttman's Lambda 6, the interpretation of which is similar to Cronbach's alpha). All sketch maps were coded by a single rater, based on the training document from the original publication, available at https://osf.io/3d97m/(Krukar, Münzer, et al., 2018). In order to estimate the potential measurement error arising from the subjectivity of this coding, we let a second coder code a random subset of 17 sketch maps (10% of the dataset). Inter-rater agreement was assessed using a two-way random, agreement-based, average-measures intra-class correlation (Hallgren, 2012), calculated separately for the total route-likeness scores and for the total survey-likeness score using the irr R package (Gamer, Lemon, & Singh, 2012). The inter-rater agreement of the route-likeness and survey-likeness scores for these sketch maps was 1.0, indicating perfect agreement between the two raters at the level of cumulative scores. Please refer to the original publication (Krukar, Münzer, et al., 2018) for a discussion of potential cases where inter-rater agreement might be an issue.

Each sketch received one score for each dimension. The classification assumes that a map can score highly on both dimensions, if it describes the route in detail and contains survey information as well. Fig. 5 shows the two dimensions of sketch maps with examples and Appendix A shows further examples from the dataset. We perform statistical analyses on this data using proportional odds models for ordinal data, as described in Section 4.2.

5.4. Individual differences questionnaires

Individual differences were controlled in the statistical models by including the individual's results on the Mental Rotation Test (Vandenberg & Kuse, 1978) and in the Questionnaire on Spatial Strategies (Münzer & Hölscher, 2011). Because most of the results of these two individual differences questionnaires significantly correlated in our sample (Mental Rotation Test and global self-confidence scale of the

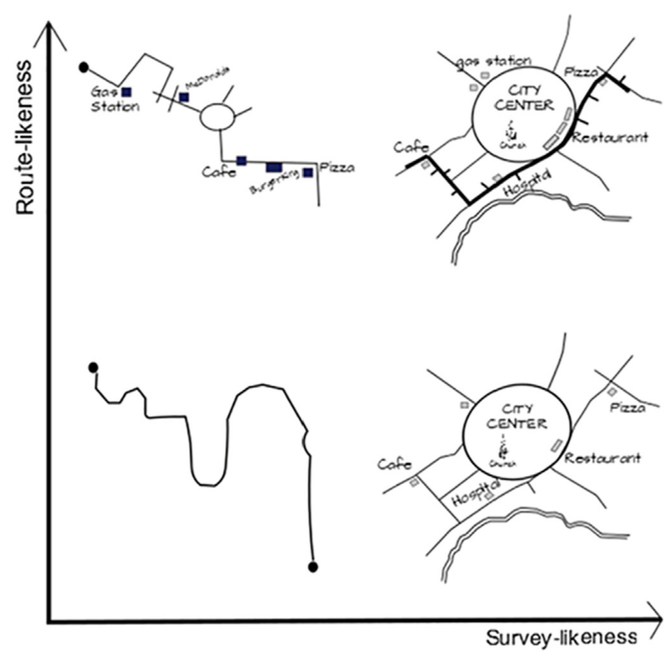

Fig. 5. Sample sketch maps demonstrating various combinations of route-likeness and survey-likeness: low route and low survey (bottom left), low route and high survey (bottom right), high route and low survey (top left), high survey and high route (top right).

Questionnaire on Spatial Strategies: $r = .24$, $p = .028$; Mental Rotation Test and the preference for an allocentric reference frame scale of the Questionnaire on Spatial Strategies: $r = .23$, $p = .034$; Mental Rotation Test and the preference for the knowledge of cardinal directions scale of the Questionnaire on Spatial Strategies: $r = .12$, $p = .289$), we do not use them simultaneously as predictors in our models in order to avoid the issue of multicollinearity. Instead, for each dependent variable, we only present models with the single individual differences measure that improved the model best. We evaluated model improvement by comparing the model without any individual differences measures (the null model) against four alternative models, each containing one measure of individual differences (either the Mental Rotation Test score, the global self-confidence scale, the preference for an allocentric reference frame scale, or the preference for the knowledge of cardinal directions scale). We selected the best model using the likelihood ratio tests. For simplicity, we only report the result of the likelihood ratio test between the best, and the null model and we only report the statistical summary of the best model.

6. Results

6.1. Quantity of route- and survey-related information

In order to verify our hypothesis H1, we tested whether participants recalled local landmarks at the same rate across the conditions, while additionally recalling global landmarks in the *orientation instructions* condition.

6.1.1. Visual mode

Descriptives. In the visual mode, the *turn-by-turn* instructions, the *spatial chunking* instructions, and the *orientation instructions* contained 12 local (route) landmarks. The *orientation* instructions additionally contained 3 global (survey-related) landmarks. Participants receiving *turn-by-turn* instructions, on average, included 2.9 local landmarks in their sketch maps; those in the *spatial chunking* condition reused an average of 6.9 local landmarks; and those who saw *orientation instructions* included 9 local landmarks on average plus an additional 2.2 global landmarks on average.

Inferential statistics. To test the differences in the local landmark recall rate, we fitted a logit mixed model, using the lme4 R package (Bates, Maechler, Bolker, & Walker, 2014) only using the local landmarks data, i.e., excluding the recall of global landmarks. The dependent variable was binomial: whether a given landmark was included in the sketch map (yes/no). The model for the visual mode data explained 25% of the variance, with significant differences between each type of instructions compared to *orientation instructions* (Table 3). Odds ratios can be interpreted as follows: The odds of reusing a landmark in the *spatial chunking* condition were 0.33 (or 1:3) compared to the baseline *orientation instructions* condition: Therefore including a landmark was estimated to be 3 times more likely in the *orientation instructions* condition.

To test the global landmark recall rate, we conducted a one-sample *t*-test, comparing the number of global landmarks recalled by participants in the *orientation instructions* condition ($M = 2.2$, $SD = 0.6$), to number 0. This test was significant $t(27) = 18.84$, $p < .001$.

Further, a positive change in 1 unit on the global self-confidence scale increased the odds of including a landmark by 37% (1.37:1). Alternative models including other measures of individual differences were tested, but only the global self-confidence scale significantly improved the model's fit compared to the null model ($\chi2(1) = 8.26$, $p = .004$).

Conclusion. These results confirm hypothesis H1: *orientation instructions* resulted in even a higher number of reused local landmarks and, additionally, in a large ($M = 2.2$ out of 3) proportion of reused global landmarks.

Table 3
A logit mixed model describing the impact of instruction type and the global self-confidence scale questionnaire score on the odds of including a landmark in the sketch map, in the visual mode.

Predictors	landmark included		
	Odds Ratios	*CI*	*p*
(Intercept)	1.09	0.29–4.18	0.896
spatial chunking	0.27	0.10–0.75	**0.012**
turn-by-turn	0.04	0.02–0.11	**< 0.001**
global self-confidence	1.40	1.12–1.75	**0.003**
Random Effects			
σ^2	3.29		
$\tau_{00\ \mathrm{part.ID}}$	0.61		
$\tau_{00\ \mathrm{landmark}}$	2.03		
$\tau_{11\ \mathrm{landmark.instr.typeSC}}$	2.11		
$\tau_{11\ \mathrm{landmark.instr.typeTbT}}$	1.62		
$\rho_{01\ \mathrm{landmark.instr.typeSC}}$	−0.24		
$\rho_{01\ \mathrm{landmark.instr.typeTbT}}$	−0.62		
ICC	0.46		
$N_{\mathrm{part.ID}}$	84		
N_{landmark}	12		
Observations	1008		
Marginal R^2/Conditional R^2	0.234/0.586		

6.1.2. Verbal mode

Descriptives. In the verbal mode, the *turn-by-turn* instructions did not mention any landmarks, the *spatial chunking* instructions contained 5 local landmarks, and the *orientation instructions* contained 11 local and 2 global landmarks. Since no landmarks were presented in the *turn-by-turn* condition, it is not included in the analysis. *Spatial chunking* participants included on average 4.9 (out of 5) local landmarks, and the *orientation instructions* participants included on average 8.9 (out of 11) local landmarks, plus an additional 1.9 global landmarks (out of 2), on average.

Inferential statistics. Similarly to the analysis of the visual mode, we fitted a logit mixed model (only using the local landmarks data) to test the local landmark recall rate. The model for the verbal mode data explained 20% of the variance, with significant differences between *orientation instructions* and *spatial chunking* instructions (Table 4). Odds ratios of reusing a landmark in the *spatial chunking* condition were higher (over 11:1), compared to the *orientation instruction* condition. This difference is statistically significant.

To test the global landmark recall rate, we conducted a one-sample, one-tailed *t*-test, comparing the number of global landmarks recalled by participants in the *orientation instructions* condition ($M = 1.9$, $SD = 0.3$) to number 0. This test was significant $t(27) = 31.80$, $p < .001$.

Table 4
A logit mixed model describing the impact of instruction type and the Mental Rotation Test score on the odds of including a landmark in the sketch map, in the verbal mode.

Predictors	landmark included		
	Odds Ratios	*CI*	*p*
(Intercept)	3.12	0.83–11.67	0.091
spatial chunking	11.62	1.55–87.30	**0.017**
mental rotation	1.23	1.02–1.47	**0.029**
Random Effects			
σ^2	3.29		
$\tau_{00\ \mathrm{participant}}$	0.70		
$\tau_{00\ \mathrm{instr.type:landmark}}$	1.94		
ICC	0.45		
$N_{\mathrm{participant}}$	56		
$N_{\mathrm{instr.type}}$	2		
N_{landmark}	16		
Observations	448		
Marginal R^2/Conditional R^2	0.197/0.554		

Table 5
Number of sketch maps that received each of the possible scores (0–3) from the independent raters, in each condition, in the visual mode. The condition and mode from which each sketch map originated was unknown to the raters.

condition	0:nonsense	1:bad	2:medium	3:good
orientation instructions	0	0	7	21
spatial chunking	0	1	11	16
turn-by-turn	2	9	11	6

Furthermore, the Mental Rotation Test score was the only individual difference, including which significantly improved the model's fit compared to the null model ($\chi2(1) = 4.58$, $p = .032$). Scoring 1 point higher on the Mental Rotation Test was associated with a 23% increase in the chance to include a landmark in the sketch map.

Conclusion. This result is partially contrary to hypothesis H1. Participants in the *spatial chunking* condition included more local landmarks than participants in the *orientation instructions* condition. However, participants in the *orientation instructions* condition nevertheless recalled a significant proportion of global landmarks.

6.2. Quality of sketch maps

6.2.1. Visual

Descriptives. Raw counts of rating scores given to sketch maps are presented in Table 5. It demonstrates that orientation instructions resulted in higher ratings on average.

Inferential statistics. In order to test the hypothesis H2, we fitted a proportional odds model for ordinal data (Table 6). The model explained 39% of the variance. Results demonstrate that there was a significant influence of instruction type: sketch maps in the *orientation instructions* and *spatial chunking* conditions were significantly better than sketch maps in the *turn-by-turn* condition. The probability of producing a sketch map that was scored better increases by 20 times (odds ratio 0.05) when being in the *orientation instructions* condition, compared to the *turn-by-turn* condition. The *orientation instruction* received higher raw scores (Table 5), but were not statistically significantly better than *spatial chunking* sketch maps. Since the measurement scale was limited to 3, there is a likely ceiling effect that prevents the difference between *orientation instructions* and *spatial chunking* instructions to reach a statistical significance: almost all sketch maps in these 2 conditions were scored as “medium” or “good”.

Including global self-confidence scale improved the model's fit best, compared to the null model ($LR(1) = 9.28$, $p = .002$). Scoring 1 point higher on the global self-confidence scale was associated with a 94% chance increase in having a better map score.

Conclusion. The results are in line with hypothesis H2: *orientation instructions* yielded better sketch maps.

Table 6
A proportional odds models for ordinal data demonstrating the influence of condition on the sketch map's quality score, in the visual mode.

Predictors	map score		
	Odds Ratios	*CI*	*p*
(Intercept: 0|1)	0.04	0.00–0.42	**0.007**
(Intercept: 1|2)	0.43	0.06–3.10	0.400
(Intercept: 2|3)	5.38	0.71–40.77	0.104
spatial chunking	0.44	0.14–1.41	0.166
turn-by-turn	0.05	0.01–0.18	**< 0.001**
global self-confidence	1.94	1.25–3.01	**0.003**
Observations	84		
Nagelkerke's R^2	0.391		

Table 7
Number of sketch maps that received each of the possible scores (0–3) from the independent raters, in each condition, in the verbal mode. The condition and mode from which each sketch map originated was unknown to the raters.

condition	0:nonsense	1:bad	2:medium	3:good
orientation instructions	0	0	8	20
spatial chunking	0	0	10	18
turn-by-turn	1	16	7	4

Table 8
A proportional odds models for ordinal data demonstrating the influence of condition on the sketch map's quality score, in the verbal mode.

Predictors	map score		
	Odds Ratios	*CI*	*p*
(Intercept: 0|1)	0.00	0.00–0.02	**< 0.001**
(Intercept: 1|2)	0.11	0.03–0.45	**0.002**
(Intercept: 2|3)	1.55	0.49–4.86	0.456
spatial chunking	0.82	0.26–2.62	0.738
turn-by-turn	0.02	0.00–0.08	**< 0.001**
mental rotation	1.37	1.13–1.65	**0.001**
Observations	84		
Nagelkerke's R^2	0.547		

6.2.2. Verbal

Descriptives. Raw counts of scores given to sketch maps are presented in Table 7. It demonstrates that orientation instructions resulted in higher ratings on average.

Inferential statistics. Similarly to the visual mode analysis, we fitted a proportional odds models for ordinal data (Table 8). The model explained 55% of the variance.

Including the results of the Mental Rotation Test improved the model's fit, compared to the null model ($LR(1) = 12.39$, $p < .001$). Scoring 1 point higher on the mental rotation test was associated with a 37% chance increase in having a better map score.

Conclusion. The results are in line with the visual mode and partially confirm hypothesis H2: the *orientation instructions* condition was associated with the highest probability of producing a better sketch map (here: 50 times higher, odds ratio 0.02, compared to *turn-by-turn*). Similarly to the visual mode, the difference between *orientation instructions* sketch maps and *spatial chunking* sketch maps was not significant.

6.3. Type of sketch maps: survey-likeness and route-likeness

Fig. 6 provides a visual comparison of route-likeness and survey-likeness scores for the visual and the verbal mode across all conditions. It can be noticed, that sketch maps drawn in the *orientation instructions* condition tended to have high route-likeness as well as high survey-likeness. This indicates that the *orientation instruction* condition increased the survey-likeness of sketches without sacrificing their route-likeness score. This result fully confirms our hypothesis H3.

6.3.1. Visual

Descriptives. Table 9 presents the raw data in the visual mode. *Orientation instructions* generated route-likeness scores similarly high to *spatial chunking*, but resulted in much higher survey-likeness.

Inferential statistics. We fitted one proportional odds model for each dependent variable (route-likeness and survey-likeness), i.e., two models in total (Table 10). The models explained 43% of the variance in the route-likeness data and 74% of the variance in the survey-likeness data. It can be seen that the baseline *orientation instructions* condition was associated with higher odds of scoring better on the route-likeness scale, compared to the *turn-by-turn* condition and with higher odds of

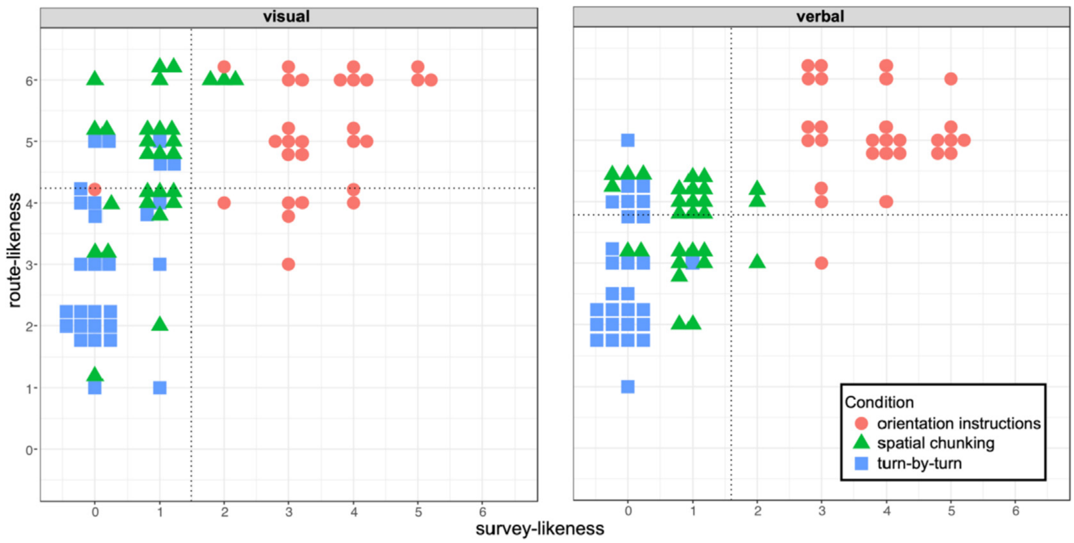

Fig. 6. Survey-likeness and route-likeness scores of sketches from all experimental conditions. Each symbol represents a single sketch map. The scales were ordinal - all symbols that are adjacent to each other represent the same number on both scales.

Table 9
Number of sketch maps that received each raw score of the route-likeness and of the survey-likeness scale, in the visual mode.

score:	0	1	2	3	4	5	6
route-likeness							
orientation instructions	0	0	0	1	7	9	11
spatial chunking	0	1	1	2	7	10	7
turn-by-turn	0	2	11	4	6	5	0
survey-likeness							
orientation instructions	1	0	2	13	9	3	0
spatial chunking	7	18	3	0	0	0	0
turn-by-turn	21	7	0	0	0	0	0

the sketch scoring better on the survey-likeness scale compared to the *spatial chunking* and *turn-by-turn* conditions (the estimated odds are lower than 0.01, meaning the chance over 100 times higher in the *orientation instructions* condition).

We present the models with the single measure of individual differences which best improved the model's fit. For the route-likeness variable, this was the Mental Rotation Test score (LR(1) = 11.50, p < .001 compared to the corresponding null model); for the survey-likeness variable, this was the global self-confidence scale of the Questionnaire on Spatial Strategies (LR(1) = 5.47, p = .019 compared to the corresponding null model).

Conclusion. These results confirm our hypothesis H3: participants in the *orientation instructions* condition did not produce sketch maps of significantly higher route-likeness (compared to the *spatial chunking* condition), but did produce sketch map of significantly higher survey-likeness.

6.3.2. Verbal

Descriptives. Raw data is provided in Table 11. It can be seen that *orientation instructions* resulted in higher route-likeness and survey-likeness scores. Noticeably, almost all participants in the *turn-by-turn* conditions generated sketch maps that scored 0 points on the survey-likeness scale.

Inferential statistics. Analogously to the visual mode, we fitted a proportional odds model for ordinal data for the route-likeness dependent variable (Table 12). This model explained 67% of the variance and showed significantly higher odds of scoring better on the route-likeness scale in the *orientation instructions* condition.

Including the results of the Mental Rotation Test significantly improved the model's fit, compared to the null model (LR(1) = 4.66, p = .030). Scoring 1 point higher on the Mental Rotation Test was associated with a 19% chance increase in having a higher route-likeness score.

The model could not be fitted for the survey-likeness dependent variable as this data was not informative enough: The range of survey-

Table 10
Two proportional odds models for ordinal data demonstrating the influence of condition on the sketch map's route-likeness (left) and survey-likeness (right), in the visual mode.

Predictors	route-likeness			survey-likeness		
	Odds Ratios	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept: 0|1)				0.01	0.00–0.13	**0.001**
(Intercept: 1|2)	0.01	0.00–0.05	< **0.001**	0.16	0.01–2.63	0.199
(Intercept: 2|3)	0.10	0.03–0.32	< **0.001**	1.07	0.12–9.48	0.951
(Intercept: 3|4)	0.22	0.07–0.67	**0.007**	13.83	1.60–119.92	**0.017**
(Intercept: 4|5)	1.10	0.39–3.07	0.863	91.75	8.27–1017.6	< **0.001**
(Intercept: 5|6)	6.01	2.05–17.6	**0.001**			
spatial chunking	0.54	0.20–1.43	0.214	0.00	0.00–0.02	< **0.001**
turn-by-turn	0.04	0.01–0.12	< **0.001**	0.00	0.00–0.00	< **0.001**
mental rotation	1.29	1.11–1.51	**0.001**			
global self-confidence				1.67	1.07–2.60	**0.023**
Observations	84			84		
Nagelkerke'sR^2	0.431			0.747		

Table 11
Number of sketch maps that received each raw score of the route-likeness and of the survey-likeness scale, in the verbal mode.

	0	1	2	3	4	5	6
route-likeness							
orientation instructions	0	0	0	1	3	17	7
spatial chunking	0	0	2	9	17	0	0
turn-by-turn	0	1	14	5	7	1	0
survey-likeness							
orientation instructions	0	0	0	11	10	7	0
spatial chunking	6	19	3	0	0	0	0
turn-by-turn	27	1	0	0	0	0	0

Table 12
A proportional odds model for ordinal data demonstrating the influence of condition on the sketch map's route-likeness, in the verbal mode.

	route-likeness		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept: 1|2)	0.00	0.00–0.00	**< 0.001**
(Intercept: 2|3)	0.00	0.00–0.03	**< 0.001**
(Intercept: 3|4)	0.01	0.00–0.10	**< 0.001**
(Intercept: 4|5)	0.40	0.11–1.50	0.174
(Intercept: 5|6)	7.78	2.25–26.96	**0.001**
spatial chunking	0.01	0.00–0.06	**< 0.001**
turn-by-turn	0.00	0.00–0.01	**< 0.001**
mental rotation	1.19	1.01–1.40	**0.033**
Observations	84		
Nagelkerke's R^2	0.665		

likeness scores was 3–5 in the *orientation instructions* condition, 0–2 in the *spatial chunking* condition, and 0–1 in the *turn-by-turn* condition (with only 1 person scoring a single point). We therefore report the result of the Dunn's test for the survey-likeness variable instead: Comparisons between all three groups were statistically significant (*Dunn's* $z = 5.03$ for the *orientation instructions* vs *spatial chunking* comparison; $z = 8.40$ for the *orientation instructions* vs *turn-by-turn* comparison; $z = 3.37$ for the *spatial chunking* vs *turn-by-turn* comparison; all p-values < 0.001).

Conclusion. These results confirm hypothesis H3. In contrast to the visual mode, here, the difference between *orientation instructions* and all other conditions was statistically significant even for the route-likeness measure. Thus, in the verbal mode, the result of sketch map type analysis exceeded our predictions.

7. Discussion

This study investigated the recall of route-like and survey-like information after an exposure to different wayfinding instructions. The results presented above showed that our overall hypothesis was confirmed: Equally high recall of route-like and survey-like information in wayfinding instructions was possible and could be triggered by the type of wayfinding instructions such as *orientation instructions*.

Since the pattern of results differed depending on the visual/verbal mode of presenting instructions, we discuss these modes separately.

7.1. Visual mode

We predicted that sketch maps would not differ in the quantity of recalled route-related information, but that *orientation instructions* would result in a better recall of survey-related information (H1). In order to test hypothesis H1, we counted the number of re-used elements: local landmarks as a measure of route-based information and global landmarks as a measure of survey-related information. Our hypothesis was confirmed: Participants exposed to *orientation instructions* reused significantly more local landmarks while they also reused a large proportion of the presented global landmarks. Thus, the visual mode of *orientation instructions* was very successful in communicating route- and survey-related information in a way that is memorizable. We believe that highlighting larger structures in the map (such as a route crossing the city center and the city center containing certain landmarks) provides users with meaningful cues that help in memorizing the route and the environment.

We predicted that *orientation instructions* would result in better quality of sketch maps (H2). In order to test hypothesis H2, we asked independent raters to judge all sketch maps. This subjective judgement was an important extension of the other analyses because, additionally to landmarks, it accounted for the completeness of the street network, the route, and the quality of the map in general. The results showed that sketch maps drawn after an exposure to *orientation instructions* were judged as having higher quality than those in the *spatial chunking* or the *turn-by-turn* condition. This confirmed our hypothesis H2. The statistical test between the *orientation instructions* and *spatial chunking* conditions was not significant, although we associate this fact with the likely ceiling effect mentioned earlier. Complex spatial relations in *orientation instructions* could be represented in a visualization and seeing this visualization resulted in subsequently producing higher quality sketch maps for other potential navigators.

We further predicted that *orientation instructions* would result in sketch maps of a more "survey-like" type (H3). In order to test hypothesis H3, we analyzed the type of produced sketch maps by rating their route-likeness and survey-likeness. The analysis showed that different types of wayfinding instructions resulted in sketch maps with different characteristics. Sketch maps drawn after exposure to *orientation instructions* had the highest survey-likeness scores and had (not significantly) higher scores on the route-likeness scale in comparison to the *spatial chunking* instructions. *Spatial chunking* instructions produced sketch maps with a higher route-likeness characteristic than *turn-by-turn* instructions, however they both scored poorly on the survey-likeness dimension. Even though participants in the *turn-by-turn* condition and in the *spatial chunking* condition could see the surroundings of the route on the map, highlighting survey-related information in the *orientation instructions* had a much stronger effect on the survey-likeness of sketch maps. This pattern of results confirmed our hypothesis H3: sketch maps produced after an exposure to *orientation instructions* might not have been higher on the route-likeness dimension, but were significantly more survey-like. Participants in this condition tended to recreate more complex spatial relation in their sketches.

Individual differences played a significant role in explaining participants' performance. This indicates that there are important interpersonal differences in the process of learning from wayfinding instructions and some people are more likely to benefit from the design of these instructions, than others. In the visual mode, the global self-confidence scale of the Questionnaire on Spatial Strategies (Münzer & Hölscher, 2011) consistently was the best predictor of performance; it improved the statistical models of landmark recall quantity, of sketch map quality, and of sketch map's survey-likeness. This was contrary to our expectations, considering the fact that another scale of that questionnaire (preference for an allocentric reference frame scale) had been suggested to be the most strongly tied to the frequency and competence of map use (Münzer et al., 2016). We explain this disparity by the nature of the task given to our participants in the sketch map drawing phase: they were asked to produce a sketch map for another person unfamiliar with the area. This task requires shifting perspectives to the egocentric reference frame, as one imagines what information is necessary for another person to navigate the route (Taylor & Tversky, 1996). It seems that in this context, a preference for an allocentric reference frame was of a lesser importance.

7.2. Verbal mode

In the verbal mode, hypothesis H1 was not confirmed. Although a comparison of the absolute values of reused landmarks was in favor of *orientation instructions*, the proportion of recalled landmarks relative to the total number of presented landmarks favored *spatial chunking*. This might have been caused by the fact that *spatial chunking* instructions referred, in total, to less than half of the number of landmarks, compared to *orientation instructions* (because only some landmarks can be integrated into a chunk in the *spatial chunking* condition). It was easier to recall a large proportion of five *spatial chunking landmarks* than of the eleven *orientation instructions* landmarks. Furthermore, it is difficult to encode complex (two-dimensional) spatial structures and relationships contained in *orientation instructions* in the verbal mode, given the linear (one-dimensional) structure of language. *Spatial chunking*, on the contrary, focuses on spatial structures and relations along a one-dimensional route, and can thus be represented very well in the verbal mode.

Similarly to the visual mode, hypothesis H2 was confirmed in the verbal mode: *orientation instructions* resulted in better quality sketch maps than *turn-by-turn* instructions. However, the difference between the *spatial chunking* condition was not statistically significant. Here, the influence of the ceiling effect is less likely. We acknowledge that the one-dimensional nature of language is not fully compatible with complex two-dimensional spatial information communicated by *orientation instructions* and that the improvement they bring, compared to *spatial chunking* instructions, is unclear in the verbal mode. It is an open research question, whether verbal instructions can be structured differently (from the predominant turn-by-turn paradigm), in order to better communicate hierarchical, complex spatial relations of *orientation instructions*.

Hypothesis H3 was confirmed in a manner similar to the visual mode: *orientation instructions* resulted in more route-like and more survey-like sketches. This might seem unsurprising, since participants in the *turn-by-turn* and the *spatial chunking* conditions did not receive any survey-related information. However, the result in the *orientation instructions* condition is still interesting within the verbal mode, as it confirms our hypothesis that it is possible to reuse survey-related information without harming the recall of route-related information.

Considering individual differences, it was the result of the Mental Rotation Test that consistently was a significant predictor of performance across multiple tasks in the verbal mode. It significantly improved statistical models of the landmark recall quantity, of sketch map quality, and of sketch map's route-likeness. As explained earlier, mental rotation abilities might be related to the problem of aligning map orientation with the imagined direction of locomotion; however, this could not have been the deciding factor in the verbal mode, where no visual map (and therefore, no predefined map orientation) was provided to participants. Instead, we associate this result to two possibilities. First, in the verbal mode, instructions were communicated from the egocentric viewpoint (e.g., “turn left”), and therefore keeping track of them required performing multiple subsequent mental turns. This process might be aided by better working memory which is correlated with Mental Rotation Test results (Kaufman, 2007). Second, performance in the Mental Rotation Test had been linked to a flexible use of alternative mental strategies when handling a spatial problem (Hegarty, 2018). It is possible that some of these implicit strategies are useful, and used, in the problem of understanding and memorizing verbal navigational instructions. As our study was not designed to test these assumptions, more work on the cognitive strategies involved in understanding different types of verbal instructions is needed.

7.3. Limitations of the study

The methodology applied in this study revealed several limitations. First, we did not control for the time participants spent on reading the instructions. The maps in the *spatial chunking* and in the *orientation instruction* conditions were schematized (not to scale) and the length of the route in the schematized map was shorter than in the non-schematized topographic map of the *turn-by-turn* condition. Participants could further influence the time by delaying the moment of pressing the continue button. In the verbal condition we also allowed participants to repeat the whole set of instructions. Since we did not measure the time spent on reading the instructions, we do not know whether training time influenced the results. This remains to be an open question for future research.

Second, our data in the verbal and visual mode are of limited comparability and we therefore could not formally test for the interaction of the instructions' mode and type. While in the visual mode we could keep the local landmarks constant, the amount of local landmarks differed across the conditions in the verbal mode. Exploring the interaction of instructions’ mode and type was not part of our research objectives, but it is a relevant research problem that should inform how wayfinding systems are designed in practice. We therefore encourage others to pursue this question, but want to point out that the current turn-by-turn paradigm of verbal instructions does not lend itself easily to describing survey information at multiple levels of hierarchy.

Third, our quantitative analysis focused only on landmarks. Although this is in line with most of other research, our understanding of orientation information goes beyond global landmarks, but includes global spatial structures in street networks (Anacta, Schwering, et al., 2017). The inclusion of street network structures was considered in 2 out of 3 performed analyses: sketch maps' quality and sketch maps' type.

Lastly, it bears noting that reliability of the route-likeness measure was only moderate 0.60 (Section 4.3). This means that 6 criteria loading the route-likeness dimension did not always co-vary consistently, i.e., that there was only a limited correlation between elements chosen by each participant to communicate route-related information. We associate this low reliability with a great disparity in the ways through which the same route was displayed across our experimental conditions: it is possible that the likelihoods of scoring different combinations of criteria were very unbalanced across the conditions. Although this does not invalidate the measure, it might be indicative of a larger measurement error associated with the route-likeness dimension in our sample. Thus, the exact statistical estimates related to the route-likeness measure (Tables 10 and 12) should be treated with caution. Nevertheless, the key premise of our hypothesis H3 was concerned with the survey-likeness dimension of sketch maps - and the reliability of the survey-likeness scale in our dataset was satisfactory.

7.4. General discussion

There are several theoretical implications that can be drawn from our study: First, we show that it is important to distinguish the recall of route and survey information in the analysis, because the presentation and acquisition of survey information might influence the recall of route information and the interaction between both can only be seen if both types of information are analyzed separately. Second, we contribute to the ongoing discussion on the potential reasons for the GPS-based navigation's detrimental effect on spatial learning (Ruginski et al., 2019). We suggest that additionally to the users getting detached from environments (Fenech et al., 2010), dividing attention (Gardony, Brunyé, Mahoney, & Taylor, 2013; Hejtmánek, Oravcová, Motýl, Horáček, & Fajnerová, 2018; Willis et al., 2009), not involving their working memory (Münzer et al., 2006; Parush et al., 2007), and offloading the process of active navigation (von Stülpnagel & Steffens, 2012), another key reason to be considered is the mismatch between the type of information communicated by the system and the type of information used in communication by humans.

The problem of the type of spatial information used by humans has been tackled in the work of Taylor and Tversky (1992) who showed that people remember spatial environments in a hierarchical form and in another work by Taylor and Tversky (1996) which demonstrated that people use both the route and the survey perspective when describing routes; even switching between perspectives during the route description. As Fig. 6 clearly demonstrates, participants of our study were able to hierarchically combine survey and route information into one sketch map, i.e., these types were not mutually exclusive. Fig. 6 also demonstrates that 86% of all sketch maps produced after exposure to *orientation instructions* were above the mean performance on both scales. Thus, it can be concluded that *orientation instructions* are particularly well-suited to support such hierarchical mental representations.

The *orientation instructions* map was designed as an overview-like, schematic representation of a route by selecting information assumed to be important for understanding the structure of the environment. This goes along with findings of Casakin, Barkowsky, Klippel, and Freksa (2000), who showed that schematic maps support orientation precisely because they only visualize specific information about the environment. The selection of relevant elements and the presentation of underlying structures makes schematic maps an effective wayfinding aid (Freksa, 1999).

Although it can be claimed that the purpose of turn-by-turn wayfinding support systems is not to foster environmental learning, researchers argue as to the exact cause of poor memorability of information communicated by these systems: mentioning detachment from the environment (Fenech et al., 2010), divided attention (Gardony et al., 2013; Hejtmánek et al., 2018; Willis et al., 2009), poor involvement of working memory (Münzer et al., 2006; Parush et al., 2007), and cognitive offloading of active navigation (von Stülpnagel & Steffens, 2012). By directly contrasting *turn-by-turn instructions* with two alternative designs of wayfinding support, our study demonstrates that another reason is possible: the turn-by-turn paradigm of communicating wayfinding instructions and the type of information communicated through it. Structuring wayfinding instructions into a more holistic form, either by combining multiple similar turn-by-turn segments (like in the *spatial chunking* condition), or better, by relating the route to the broader environment (like in the *orientation instructions* condition) makes this information easier to reuse and results in better-quality sketch maps.

Our findings correspond with results of other studies about the effect navigation instructions and the presentation mode have on people's spatial knowledge (Dickmann, 2012; Field et al., 2011; Gartner & Radoczky, 2005; Ishikawa et al., 2008; Ishikawa & Takahashi, 2013; Münzer et al., 2012, 2006). For example, Münzer et al. (2012) tested wayfinding performance and spatial learning in a real navigation task with various presentation styles of wayfinding instructions. They found that the presentation style influences the amount of route-related information and the amount of configural information being learned. There was a trade-off: a route presentation style supported wayfinding performance better than configural knowledge acquisition, while a map presentation style supported learning configural knowledge better than good wayfinding performance. Instead of wayfinding performance, our study compared route knowledge acquisition to survey knowledge acquisition and found that there must not be a trade-off: people can learn both types of knowledge if the presentation style supports it.

8. Conclusion

This study showed the effect of different wayfinding instructions on the reuse of route-related and survey-related information: Instructions differed in the type of information, the amount of information and in the way of presentation. *Turn-by-turn* condition described routes as a sequence of turns. *Spatial chunking* first identified coherent units in a route, called chunks, which are then described as a single instruction. *Orientation instructions* intentionally include survey-information into route descriptions in order to induce orientation in the environment. In analogy to memory research, we were interested whether it is possible to construct wayfinding instructions that are easier to remember by being more meaningful and integrated.

This study demonstrated that providing people with seemingly more complex *orientation instructions* results in a better reuse of survey information without sacrificing the quality of route-specific elements. Even though participants with *orientation instructions* could have limited their descriptions to the same, minimalistic *turn-by-turn* information or route-focused *spatial chunking* instructions, they highlighted more complex survey information. We explain these results by the fact that *orientation instructions* fit better to the way in which people communicate their environment and the instructions are more meaningful when they are embedded in the environmental context. Although *orientation instructions* are more complex in the sense that they combine local and global information in relation to the person's position and the required action, they are more meaningful, more memorable, and more likely to be reused.

This paper has practical implications for the design of navigation systems which, to date, still do not provide a meaningful, intuitive, and memorable way of communicating route instructions. The current paper shows that *orientation instructions* lead to higher quality sketch maps and better spatial learning. Thus, the suggested way to construct *orientation instructions* should guide the future development of navigation systems. Employing *orientation instructions* has the potential to decrease user's dependence on navigational technology and empower them to make unsupported spatial decisions in complex environments.

CRediT authorship contribution statement

Jakub Krukar: Conceptualization, Methodology, Software, Formal analysis, Writing - original draft, Writing - review & editing. **Vanessa Joy Anacta:** Conceptualization, Methodology, Investigation, Writing - original draft, Data curation. **Angela Schwering:** Conceptualization, Methodology, Software, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare no conflicts of interest.

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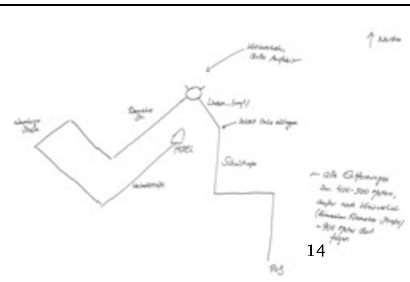
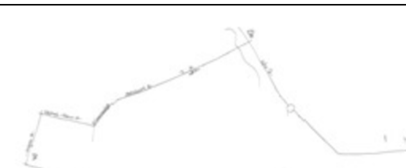
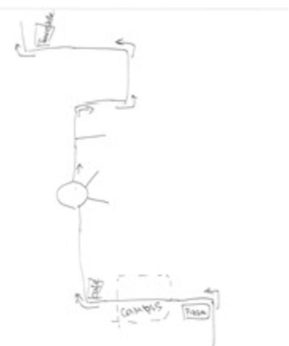
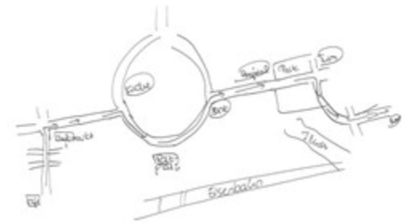
Appendix A. Examples of sketch maps with high survey-likeness and high route-likeness

	verbal	visual
turn-by-turn		

spatial chunking



orientation instructions



Appendix B. Route instructions of the same route (from Pub to Hotel) in the verbal mode, across three conditions

	Route Instructions
turn-by-turn	1. Drive north onto Alte Lauchstädter Strasse for 450 m.
	2. Turn left onto Schulstrasse and drive 550 m.
	3. Turn right onto Hatzfelder Strasse and drive 450 m.
	4. Slight left onto Lindenweg and drive 400 m.
	5. At the roundabout, take the third exit.
	6. Continue onto Riemeke Strasse and drive 900 m.
	7. Turn right onto Marienloher Strasse and drive 450 m.
	8. Turn left onto Naumburger Strasse and drive 500 m.
	9. Turn left onto Benhauser Strasse and drive 400 m.
	10. Turn right onto Heimatstrasse and drive 870 m.
	11. You have reached the destination.
spatial chunking	1. Start.
	2. Turn left at the pizzeria.
	3. Go through the campus.
	4. Turn right at the cafe.
	5. Drive straight until the roundabout. There, take the third exit.
	6. Turn right at the second intersection.
	7. Turn twice left.
	8. Turn right at the gas station.
	9. End.
orientation instruction	1. The pub is on the right. Drive straight until the pizzeria, located on the left before the intersection, and turn left.
	2. Continue straight ahead, past Burger King on your left.
	3. Go through the campus until the cafe, located on the left before the intersection, and turn right.
	4. Follow the road slightly turning left until the roundabout. There, take the third exit.
	5. Go towards the zoo and cross the railway track. Turn right at the second intersection before the tower, located inside the zoo.
	6. Go around the zoo, past a restaurant on your right. Turn right at the gas station, located on the left after the intersection.
	7. Continue straight ahead, past the bank on your left. The hotel is on the right.
	8. You have reached the destination.

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