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Landmark selection for route instructions: At which corner of an intersection is the preferred landmark located?

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Cognitive studies showed that good landmarks—salient objects in the environment—make it easier for recipients of route instructions to find their way to the destination. Adding landmarks to route instructions also improves mobile navigation systems for pedestrians. But, which landmarks do people consider most helpful when giving route instructions? Four experiments explored this question. In the first experiment, the environment, including the route and landmarks, was presented on a map. The landmarks were located at the four corners of a right-angled intersection. Participants had to select those landmark-based route instructions they considered most helpful. In all other experiments, the environment was presented from an egocentric perspective, either in a video or as a sequence of pictures of intersections. Participants had to select those landmarks they would use in a route instruction. All landmarks had the same visual and semantic salience. The positions of the participants at the intersection were varied. Results show that participants consistently selected landmarks at the side of the road into which they had to turn. Moreover, the participants' position at the intersection affected whether they selected landmarks before or behind the decision point. These results have consequences for human spatial cognition research and for the automatic selection of landmarks in mobile pedestrian navigation systems.

KEYWORDS

spatial cognition, human wayfinding, pedestrian navigation systems, landmark selection, route instructions

Introduction

Landmarks are one of the central concepts in spatial cognition research (Siegel and White, 1975; Montello, 2017; for a recent review see Yesiltepe et al., 2021). Most broadly, they are defined as easily recognizable objects that stand out from the environment and thus help wayfinders to determine their location or to describe the route to another person (Denis et al., 1999; Sorrows and Hirtle, 1999). People can select almost everything as a landmark from skyscrapers to small houses, all kinds of human-made objects such as sculptures in the public space. They can also use natural objects such as trees at an intersection, they can, of course, use signage, and they can even use the specific topography of the environment, for instance, when they say "go over the hill" (Tom and Denis, 2004; Tom and Tversky, 2012).

Landmarks are also important for mobile pedestrian navigation systems (Ross et al., 2004). It has also been demonstrated that both, pedestrians as well as car drivers profit from landmark inclusion in navigation instructions (e.g., Burnett, 2000; May and Ross, 2006; Wunderlich and Gramann, 2021). However, slight differences in the type of landmark information given might occur, for example, due to the speed with which car drivers and pedestrians move along their ways (i.e., the car driver has less time for her perceptions, route decisions, and actions, while pedestrians can focus on many more details in the environment, since they have much more time, and if necessary, can simply turn around, etc.). While car drivers primarily need access to the geometry of intersections and turn-by-turn instructions such as "In 300 meters, turn left into State Street," pedestrians also need information about landmarks, such as in "At the City hall, turn right" or "Behind the church, turn left." In the last decades, such landmark-based instructions became increasingly important for the development of pedestrian navigation systems (Millonig and Schechtner, 2005, 2007; Ohm et al., 2015). However, it is still challenging to develop techniques for the automatic extraction of suitable objects for pedestrian navigation instructions from the massive amount of available geospatial data from the internet and social media (Raubal and Winter, 2002; Elias, 2003; Winter et al., 2008; Selvi et al., 2012; Rousell et al., 2015). The present paper is not concerned with the conceptualizations and technical challenges in the development of pedestrian navigation systems (e.g., Hansen et al., 2006; Klippel et al., 2012). Our aim is rather to take a cognitive perspective on some of these challenges.

Developers of mobile navigation systems for pedestrians devised several methods for effective selection of landmarks for navigational instructions. We can distinguish two different lines of research: One is pure engineering and does not care much for cognitive considerations (e.g., Mohinder et al., 2001). The other branch of research aims to develop human-centered methods to help users to comfortably navigate through unknown environments. Such approaches often devise cognitively inspired methods for extracting landmarks from new sources, in particular social media (Quesnot and Roche, 2014; Zhu and Karimi, 2015) or OpenStreetMap (OSM) that are open, globally accessible, and provide enormous amounts of symbolic or pictorial information about potential landmarks. For example, Rousell et al. (2015) developed methods for extracting landmarks from OSM based on distance and estimated visibility. Rousell and Zipf (2017) devised algorithms for the extraction, weighing, and selection of landmarks based on their suitability for the generation of landmark-based navigation instructions for pedestrian routes. Raubal and Winter (2002) and Klippel and Winter (2005) proposed measures to formally specify the salience of landmarks for route instructions.

Cognitive scientists have identified several characteristics that contribute to the salience of potential landmark objects. Please note that not just objects can represent landmark information but also other sensory information (e.g., auditory or olfactory; e.g., Karimpur and Hamburger, 2016; Hamburger and Knauff, 2019) and regional-like features such as a park or lake as well as line features such as rivers or rail tracks can be considered as well (e.g., Anacta et al., 2017; Schwering et al., 2017; Löwen et al., 2019). In general, the salience of an object (or other type of information) is the quality by which it stands out from its surrounding. Psychologists see salience detection as a key attentional mechanism that enables people to deal with their limited perceptual and cognitive resources in order to act efficiently in their environment (Goldstein, 2015). For landmark selection, we can distinguish three types of salience: visual, semantic, and spatial salience (e.g., Caduff and Timpf, 2008; Nuhn and Timpf, 2017a,b). For a better and more comprehensive understanding, we want to briefly introduce all of them, even though the focus of the current work will be on the spatial/structural aspects of the environment. Visual salience is given, for instance, if a building with a unique shape or color stands out from its neighbors. It is related to findings from visual perception and attention research showing that objects that stand out from their surroundings quickly reach the focus of attention (e.g., Treisman and Gelade, 1980; Wang and Theeuwes, 2020). Researchers have extensively investigated how these factors affect landmark selection (e.g., Appleyard, 1969; Itti and Koch, 2001; Jin et al., 2004; Röser et al., 2013; Butz, 2014).

While the importance of visual features in landmark-based wayfinding has repeatedly been demonstrated (for review see Epstein and Vass, 2014), other research challenges this overarching importance of visual aspects in comparison to other sensory modalities, i.e., audition. For instance, Hamburger and Röser (2014) found that acoustic landmarks can be equally helpful for wayfinding. More generally, Knauff and Johnson-Laird (2002) could show that too much visual information can even hinder cognitive processes, such as spatial reasoning or problem-solving. They can hinder the construction of mental models, or, more generally, the generation of a mental representation from a given verbal (route) description (Knauff, 2013). Given that, we tried to keep the visual salience of landmark objects as constant as possible for the purpose of our study.

Semantic salience is obtained if the building has a particular meaning or function, like a police station in comparison to a regular building without any special relevance (Sorrows and Hirtle, 1999; Nothegger et al., 2004; Caduff and Timpf, 2008). While the visual salience of landmark objects is largely driven by bottom-up processes of perception and attention, semantic salience is based on top-down processes, in which prior knowledge is retrieved from long-term memory. Such retrieval processes can rely on semantic memory, i.e., on our world knowledge, ideas, concepts, beliefs, attitudes, and everything that we have accumulated throughout our lives that helps us to make sense of the world. For example, the knowledge that red buildings are often fire stations is stored in semantic memory (for an overview, see Anderson, 2000). Semantic salience can also rely on episodic memory, i.e., on our biographical knowledge about events, which are represented including the temporal and spatial context. For instance, an instruction-giver might say "Turn right at the bar where we were last Saturday." Such personal episodic knowledge is, of course, difficult to use in navigation systems. Yet, it might be usable at least in rudimentary form, e.g., when locations where the user has been before are re-used in a new route description. In order to control for semantic salience, we tried to keep it as low as possible and constant (please see our initial results for the chosen material in Table 1) in order to systematically investigate the third type of salience.

This third kind of salience, spatial salience, is the topic of this paper. Some researchers refer to these location-related aspects of landmarks as structural salience. They often emphasize how important this kind of salience is for human wayfinding (Lovelace et al., 1999; Sorrows and Hirtle, 1999; Steck and Mallot, 2000; Caduff and Timpf, 2008; Hamburger and Knauff, 2011; Röser et al., 2012). We agree with this position but think that the term "structural salience" is less clear than the term "spatial salience," which better expresses the fact that this kind of salience is related to the spatial location of landmarks in the environment. As described in the next section, the goal for the present work is to develop a better cognitive understanding of how the spatial salience of different landmark objects affects people's landmark selection. Are landmarks at a certain position of an intersection more salient than others? Do people prefer landmarks before or behind the decision point, at the same side of the street or on the opposite side?

Aims and methodology of the present experiments

Let us illustrate the research question with an easy example: Consider Figure 1 and imagine a tourist pedestrian asking you for directions to the train station. You know that she has to turn left at this intersection. How will you provide her with this information? Alternatively, you can also imagine a person who uses a navigation App on her smart phone. Which landmark should the system use in the verbal instructions?

Here are a few possibilities that could be helpful for the person to find her way to the train station:

Turn left at the intersection.
Turn left behind the hospital.
Turn left before you pass the police station.
Turn left directly before the gas station.
Turn left where the church is on the right.

Of course, many other possibilities are conceivable. But which alternative do people choose? Obviously, alternative 1 is the simplest description and actually sufficient to tell a pedestrian in which direction to turn at the intersection. However, you may consider other landmarks as more helpful when you generate your wayfinding instruction. For example, you might refer to certain landmarks just based on their position in the environment. The goal of the following four experiments therefore is to find out which landmarks at which position humans consider most helpful in route instructions. Note that this is not the same as the question which of the landmarks would actually be optimal or most helpful for the recipient of the wayfinding instruction. This is a different question, to which we return in the General Discussion.

In the following sections, we report four experiments in which human participants were asked to select those landmarks at an intersection that they considered most helpful for a route instruction in this situation and setup. To avoid effects of visual and semantic features, we used colored geometrical shapes as landmarks. We also varied the position of the participants at the crossroad. This is an important variation to previous experiments in this domain (for review see (Röser, 2015)) because in daily life we also often stand at different positions of an intersection, which can make some landmarks more or less salient and helpful than others. All experimental materials were generated from the SQUARELAND environment, which we have already used in several of our previous experiments (Röser et al., 2011; Hamburger and Röser, 2014; Röser, 2015; Karimpur and Hamburger, 2016; Hamburger and Knauff, 2019), and which is now also used in other labs (Albrecht and von Stuelpnagel, 2018). SQUARELAND basically consists of a 10 x 10 block raster with orthogonal intersections. The blocks can be flexibly adapted with respect to size, surface structure, and so on (Hamburger and Knauff, 2011). In the first experiment, which was largely explorative, the environment, including the route and landmarks, was presented on a map. The landmarks were located at the four corners of a right-angled intersection. Participants had to select those landmark-based route instructions they considered most helpful. In all other experiments, the environment was presented from an egocentric perspective, either in a video or as a sequence of pictures of intersections. Participants had to select those landmarks they would use in a route instruction. All experiments used simple colored geometrical figures as landmarks to avoid uncontrolled effects of visual and semantic salience. In Experiments 1 and 2, we combined four shapes (square, trapezoid, triangle, and circle) with four colors (blue, green, red, and yellow), resulting in 16 landmarks. In Experiments 3 and 4, we used four colored circles. These materials were already used and evaluated in a pilot study (Table 1) and are visualized in Figure 2. A statistical analysis for the present experiments showed that the visual object properties had no significant effect on participants' landmark preferences:

TABLE 1 Distribution of the visual object properties in all experiments.

	Selected visual objects [in %]			
	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Red	25.72	26.88	25.63	26.25
Green	25.96	24.06	26.88	25.00
Blue	23.08	25.00	22.19	24.25
Yellow	25.24	24.06	25.31	24.50
Statistics	$\chi^2(3) = 0.207, p = 0.976$	$\chi^2(3) = 0.212, p = 0.976$	$\chi^2(3) = 0.477, p = 0.924$	$\chi^2(3) = 0.095, p = 0.992$
Triangle	24.04	25.63		
Square	26.92	26.88		
Circle	24.04	22.19		
Hexagon	25.00	25.31		
Statistics	$\chi^2(3) = 0.221, p = 0.974$	$\chi^2(3) = 0.477, p = 0.924$		

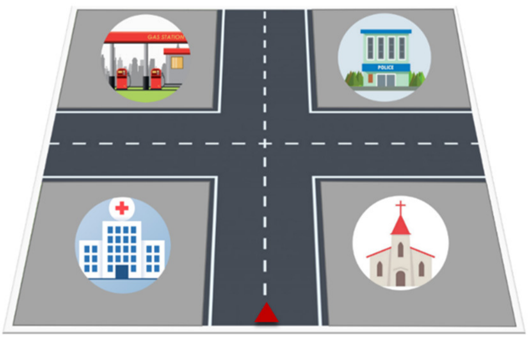

FIGURE 1
Example of an intersection with four landmarks. Which of these landmarks would you use in a route description if the person has to turn left to reach her destination?

squares, trapezoids, triangles, circles, as well as blue, green, red, and yellow objects were selected equally often (Table 1). Since these objects also did not vary in semantic salience, we can attribute participants' landmark selections in the following experiments just to their locations at the intersection.

For the statistical analysis of all experiments, we used Kendall's *W* to assess participants' agreement in choosing landmarks. Kendall's *W* is a non-parametric test that should be used when the assumptions of parametric tests are violated (Siegel and Castellan, 1988; Hollander et al., 2013). It allows to determine whether there is statistically significant agreement across participants on which of the four landmark objects they choose at the intersection. Kendall's *W* ranges from 0 (no agreement) to 1 (complete agreement). Typically, the following interpretation guidelines are used: 0.1 – < 0.3 small effect, 0.3 – < 0.5 moderate effect, and > 0.5 large effect (Hollander et al., 2013). When multiple tests were computed, the *p* values were corrected with the Bonferroni method to avoid α-error accumulation. Using just Kendall's *W* might be a relatively weak statistical method and could be accompanied by other statistics, e.g., mixed-models statistics to analyze both fixed and random effects. Unfortunately, this is not possible due to a technical problem leading to a data format that did not allow for more sophisticated statistical analyses. Of course, on the one hand, this weakens our general findings and therefore our results must be interpreted with caution. On the other hand, most differences are clearly visible in the descriptive data and we did not perform any *p*-hacking to make minor differences statistically significant.

Experiment 1: Map presentation

Our first experiment was exploratory. It tested whether people select route instructions with landmark objects at certain positions of the intersection more often than ones with landmarks at other positions. At each intersection, four landmarks were presented and therefore each of them would have a 25 percent chance of being selected if participants did not prefer a particular landmark location. Yet, we predicted that some landmarks should be selected more often than others. This experiment was an online experiment and the environment was presented from a bird's-eye perspective on the map.

Participants

Twenty-six students (18 females, 8 males) participated in the experiment. The mean age was 22.9 years, with a range of 19–38 years. They were recruited *via* the circular email system of the university (since in the online experiment there was no personal contact and data were collected anonymously, it was possible to participate in one

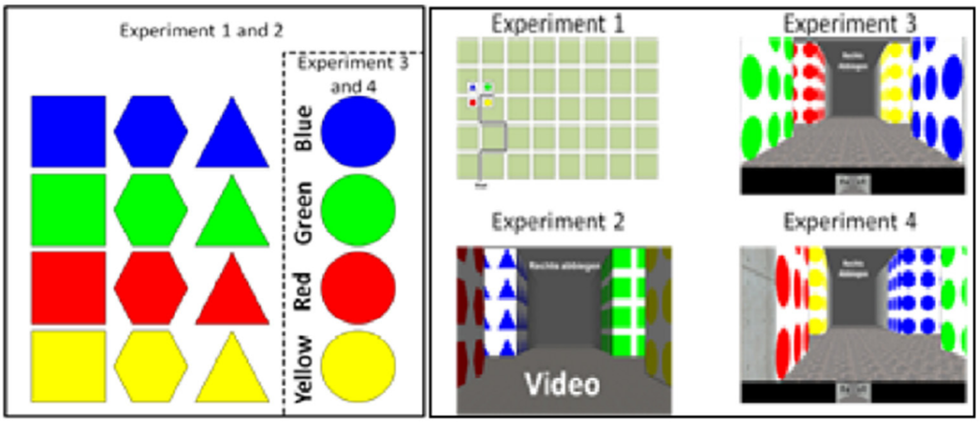

FIGURE 2
Materials and setups used in the experiments.

of the other experiments; but only in one of them in order to avoid any effects based on previous experience in the egocentric perspective). They all provided informed written consent and participated voluntarily. If required, they could receive course credits for participation. All experiments were reviewed and approved by the German Psychological Society (DGPs; MK3010200DGPS).

Materials and design

Each participant had to learn one route through the grid-like SQUARELAND environment with 7 × 4 orthogonal streets, making a total of 28 intersections. The route consisted of 8 left and 8 right turns at 16 intersections. The sequence of left and right turns was pseudo-random, with the limitation that walking in circles was impossible (i.e., three successive turns to either left or right) and the route remained within the maze grid. For each participant an individual sequence of intersections was provided in order to control for sequence or position effects. At each intersection, four landmarks were shown and the participants had to select one of four route instructions, each referring to one of these landmarks. The landmarks were the 16 colored geometrical figures presented in Figure 2 (left). The dependent variable was the relative frequency with which the participants selected the different landmark-based instructions at the intersections.

Procedure

The online experiment was implemented and administered with the software package Limesurvey 1.85. Participants were first informed that the experiment was concerned with route directions in human wayfinding. Then they saw the survey map of the environment including the complete route and all landmarks. They received the following instruction: "Imagine you must give verbal instructions to a person who is unfamiliar with this route, but needs to find his or her way to the target location. You will see different instructions for each intersection. Your task is to select the one that you think is the best." An example for a map is given in Figure 3 (start at lower left with intersection 1 and compare with the following text).

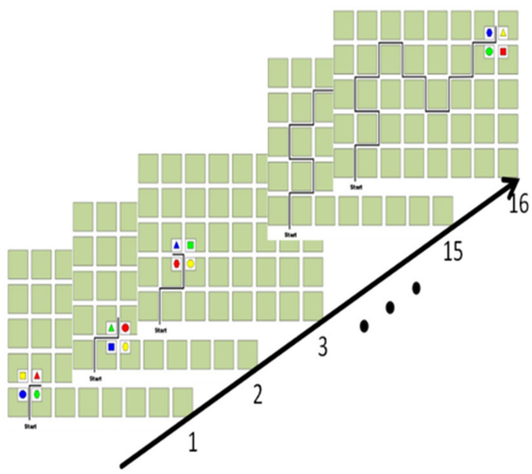

FIGURE 3
Example of the street maps and the procedure of Experiment 1. For each decision point, participants had to select one of four route instructions each referring to one of the four landmarks at the intersection.

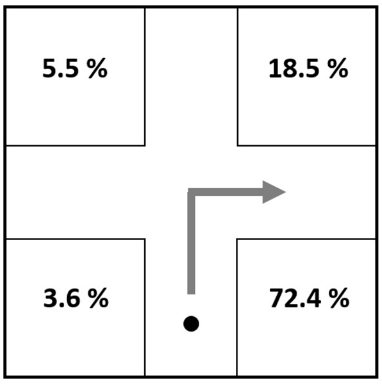

FIGURE 4
Results of Experiment 1 given as the relative frequency [%] of chosen route instructions; the landmark positions are: "side of the turn, before the intersection" **(bottom right)**; "side of the turn, behind the intersection" **(top right)**; "opposite side of the turn, behind the intersection" **(top left)**; "opposite side of the turn, before the intersection" **(bottom left)**.

Participants then saw the map with the first intersection, the direction of the turn, and the four landmarks. Below the map, four instructions were presented, e.g., for the first intersection:

Turn right before the red triangle.
Turn right behind the blue circle.
Turn right behind the green hexagon.
Turn right before the yellow square.

The order of the four alternatives was randomized. Participants had to answer the following question: "Which of these instructions appears to be the best to you?" They made their choice by clicking with the mouse on one of the instructions. Then they saw the second intersection (and the previous one) with the landmarks and the direction of the turn and again had to select one of four instructions by mouse click. This procedure was repeated 16 times, one for each decision point (intersection). After finishing the 16 trials, the participants' demographic data were collected.

Results and discussion

Figure 4 shows how often participants selected each of the different landmark-based route instructions. Interestingly, in almost three quarters of the trials, participants selected instructions with landmarks located on the side of the turn and before the intersection (independent from color and shape). The second most frequent choice was again on the side of the turn, but behind the intersection. Route instructions with the landmarks on the opposite side of the turn were almost never selected. The statistical analysis using Kendall's W showed a significant agreement among participants in the rank order of instructions $[W(3) = 0.571, p < 0.001]$.

The results of Experiment 1 agree with our hypothesis that participants' landmark selection is not random. To the contrary, over the entire sample we found strong preferences for instructions with landmarks before the intersection in the direction of the turn. This finding agrees with some previous studies that demonstrate the particular importance of landmarks that are on the side of the turn (Waller and Lippa, 2007; Hölscher et al., 2011; Karimpur et al., 2016). We will return to this in the General discussion. A possible limitation of this exploratory study, however, was that people saw the environment from an allocentric bird's-eye perspective on a map. This, of course, is very different from the egocentric perspective we typically use when giving instructions to another person on a street. The two different perspectives are essential in almost all areas of spatial cognition research (e.g., Klatzky, 1998; Ekstrom and Isham, 2017). In the next experiment, we therefore presented the intersections and landmarks from an egocentric perspective.

Experiment 2: Egocentric presentation

In this experiment, the intersections were presented from an egocentric, i.e., observer-based perspective. To realize this, the same materials as in Experiment 1 were now presented in a video sequence which was generated from the SQUARELAND environment. Note that in an egocentric perspective the landmarks at the four corners of the intersection vary in their visibility as well as in their distance and orientation relative to the observer. Based on previous findings (e.g., Röser, 2017), our hypothesis was that participants should select the same landmarks as in Experiment 1 but that their preference for particular landmarks might be less pronounced than in the allocentric bird's-eye perspective of Experiment 1.

Participants

Twenty students (11 females, 9 males) from the same population as in Experiment 1 with a mean age of 22.9 years (range 19–29) participated in this experiment. Now, they were tested in a quiet lab room and received course credit for their participation. Informed written consent was given. Since Experiment 1 and 2 were more than 6 months apart from each other and since we did not measure any type of performance but rather preferences, we assume that learning or carry-over effects are negligible.

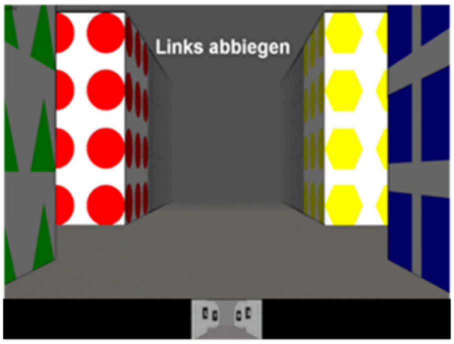

FIGURE 5
Example of an intersection in the virtual environment of Experiment 2 with four landmarks at the four corners of the intersection and the direction instruction ("Links abbiegen" = turn left).

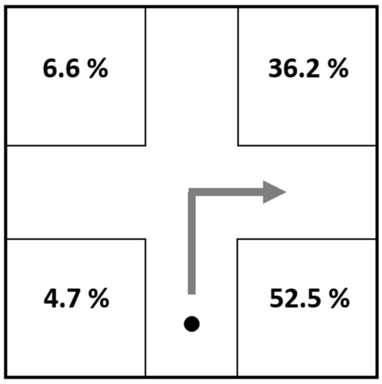

FIGURE 6
Results of Experiment 2 given as the relative frequency [%] of chosen route instructions; the landmark positions are: "side of the turn, before the intersection" **(bottom right)**; "side of the turn, behind the intersection" **(top right)**; "opposite side of the turn, behind the intersection" **(top left)**; "opposite side of the turn, before the intersection" **(bottom left)**.

Materials and design

The tasks were similar to those in Experiment 1. The main difference was that the route was now presented in a video (Figure 5) and participants had to select one of the four landmarks by pressing associated keys on a response box. Participants virtually walked from one decision point to the next and made their decisions at each of the 16 intersections. Again, the relative frequency of the selected instruction served as dependent variable.

Procedure

Participants were sitting in front of a screen; the full image subtended a 67-degree height by 85-degree width of the observer's visual field. The video of the route through SQUARELAND was presented *via* a Panasonic PT-F100NT projector. Landmarks were presented as illustrated in Figure 5. The participant's position was located in the middle of the street. The video stopped at each intersection and a written explanation (turn left, turn right) indicated the direction of the current turn. Participants received the following instruction: "Imagine you must give verbal directions to someone who is unfamiliar with this route, but needs to find his or her way to the goal location. Which of the four landmarks would you select in your instruction?" In a small display below the intersections, the landmarks were presented with the numbers 1–4. Participants had to select one of them by pressing associated keys on a response box (RB-530 response box; Cedrus©), which was located on the table in front of them. Participants received detailed instructions before the experiment started. Superlab 4.0 was used for executing the experiment and data recording.

Results and discussion

Figure 6 shows how often participants selected the different landmarks. As in Experiment 1, participants most often selected landmarks located on the side of the turn and before the intersection. The second most frequent choice was again landmarks on the side of the turn and behind the intersection. The preference for landmarks before the intersection is less pronounced than in Experiment 1 but still clearly visible. Again, the two landmarks on the side opposite of the turn were almost never selected. The statistical analysis using Kendall's W showed a significant agreement among participants in the rank order of landmarks [$W(3) = 0.364, p < 0.001$].

The difference between Experiments 1 and 2 can be explained by the fact that the spatial location of an object can be represented with reference to two basic classes of spatial coordinate frames: allocentric, as in Experiment 1, and egocentric, as in Experiment 2. In the allocentric perspective, objects are represented with reference to other objects, their relationships, and the spatial configuration in the environment. Maps are typical examples of allocentric representations of spatial environments (e.g., Yeap, 2014), as they represent the relations between the objects in the environment from an observer-independent bird's-eye perspective. In the egocentric perspective, in contrast, the position of objects is encoded with reference to the observer, more specifically, to her or his own position and orientation in the environment. Hence, the spatial relations take the observer as the reference object, rather than other objects. Countless experiments with human participants have emphasized the importance of these two different perspectives and that they also lead to two fundamentally different kinds of spatial representation in

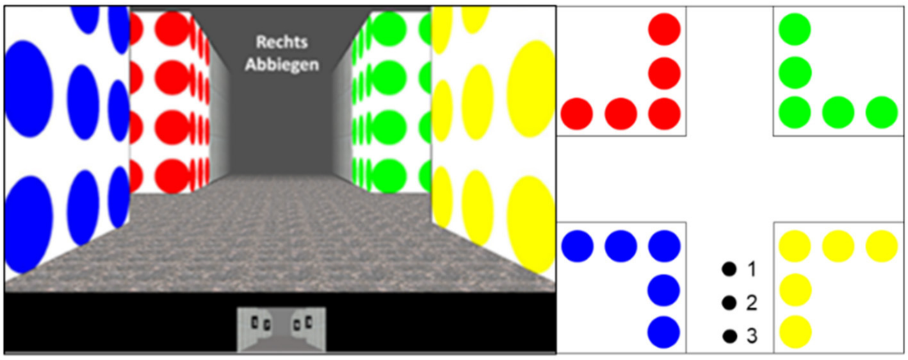

FIGURE 7
(Left) An example of an intersection in the virtual environment of Experiment 3. **(Right)** Illustration of the three distances "near" (1), "medium far" (2), and "far" (3). The participants were (virtually) standing at one of the three positions. The simulated distances from the intersection were about 1.5 meters for "near" (1), 2.5 meters for 'medium far' (2) and 3.5 meters for "far" (3).

the human mind (e.g., Klatzky, 1998). For instance, when we use an allocentric map perspective, we have access to several landmarks at once, which can be helpful but may sometimes hinder efficient cognitive processing and wayfinding. In contrast, in an egocentric perspective we can only see one or a few landmarks at a time. In an allocentric perspective, it is easier to make up mental hierarchies, while in an egocentric perspective, rather sequence learning is fostered as long as working memory capacities allow for such a type of wayfinding strategy (Keele et al., 2003; Deroost and Soetens, 2006). In comparing Experiments 1 and 2, we saw that there was a slight shift in the preferences (from landmarks before the intersection to landmarks behind the intersection), which can be attributed to the difference in perspectives. We return to this in the General Discussion.

Experiment 3: Distance from the intersection

In the third experiment, we varied the distance of the participants to the center of the intersection. They could be either close to the intersection, at a medium distance, or still farther away from the intersection. We expected that the differences in distance should affect landmark salience and thus influence instruction choices.

Participants

Twenty students (15 females, 5 males) from the same population as before with a mean age of 24.15 years (range 19–43) participated in this experiment. They received course credits for their participation. Five participants were excluded from the analysis due to software problems or because they appeared to prefer only landmarks in their favorite color, even though they were instructed not just to choose their favorite color, since this would not necessarily be helpful for others.

Materials and design

The tasks were similar to those in Experiments 1 and 2. The main difference was that we now varied the participants' distance to the center of the intersection, resulting in the three distance conditions illustrated in Figure 7. Participants were either positioned (1) near, (2) medium far, or (3) far away from the intersection (the simulated distances from the intersection were about 1.5 meters for "near," 2.5 meters for "medium far," and 3.5 meters for "far"). Instead of a video, we now used screenshots of the intersections, which were similar to the intersections in the video of Experiment 2. The only difference was that we now just used colored circles. The screenshots were used because otherwise it would have been difficult to exactly locate participants on particular positions at the intersections. The experiment followed a within-subjects design in which each participant saw each of the 24 intersections from all three distances, making a total of 72 trials. The dependent variable was again the relative frequency of selected landmarks.

Procedure

The procedure was similar to Experiment 2, but now static screenshots of the intersections were used instead of video sequences. The screenshots were presented on a 19-inch standard TFT computer screen, and Superlab 4.0 was used for executing the experiment and data recording. Participants used the numeric keypad to provide the numbers 1–4, which were again associated with the four landmarks at the corners of the given intersection. Although just screenshots were used, participants were informed that they were seeing images of intersections representing a path through a rectangular virtual environment. Again, participants were instructed to select those landmarks that they would use in a route instruction for others.

Results and discussion

The selected landmarks as a function of the participants' distance from the intersection are presented in Figure 8. The most obvious result is that participants again most often selected landmarks on the side of the turn. This preference is clearly visible in all three distance conditions. Again, the two landmarks on the opposite side of the turn were almost never selected. A closer inspection of the two choices with the landmarks on the side of the turn shows that participants' preference for landmarks before the intersection was more pronounced when they were far away from the intersection. In contrast, participants selected landmarks on the side of the turn behind the intersection more often when they were near or in medium distance to the intersection. However, the separate statistical tests using Kendall's W showed a significant agreement among participants in the rank order of selected landmarks in the three distance conditions [Near: $W(3) = 0.491$, $p < 0.001$, Medium: $W(3) = 0.546$, $p < 0.001$; Far: $W(3) = 0.676$, $p < 0.001$]. These results nicely agree with the previous experiments. They again emphasize the importance of landmarks located in turn direction. This preference seems quite robust and indicates that direction givers indeed prefer to describe a route by using landmarks that are located in the direction of the turn.

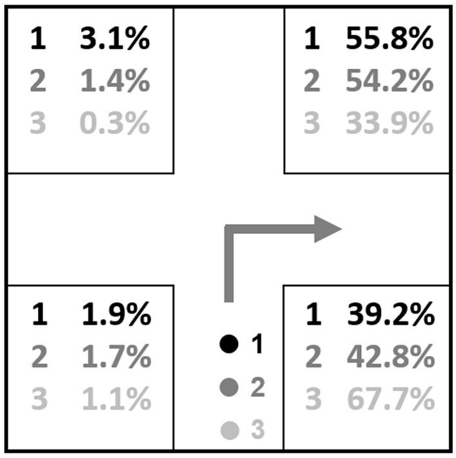

FIGURE 8
Results of Experiment 3 given as the relative frequency [%] of chosen route instructions; the observer positions from the intersection are "near" (1), "medium far" (2), and "far" (3); the landmark positions are: "side of the turn, before the intersection" [**(bottom right)**; $M \sim 48.9\%$]; "side of the turn, behind the intersection" [**(top right)**; $M \sim 48.0\%$]; "opposite side of the turn, behind the intersection" [**(top left)**; $M \sim 1.6\%$]; "opposite side of the turn, before the intersection" [**(bottom left)**; $M \sim 1.5\%$].

Experiment 4: Position between the left and right side of the route

In the last experiment, we varied the participants' position between the left and right side of the street. Since this leads to differences in landmark visibility, we predicted that participants should more often select landmarks that are more toward the center of their visual field.

Participants

Twenty-one students (17 females, 4 males) from the same population as before with a mean age of 23.0 years (range 19–29) participated in this experiment. They received course credits for their participation and provided informed consent. One of the participants was excluded from the analysis because of a software malfunction during her test run.

Materials and design

While in the previous experiment the distance to the intersection was varied, we now varied the participants' positions between the left and right side of the street, but kept the distances constant.

The five possible direction-giver positions are illustrated in Figure 9. Participants were either positioned far-left (1), half-left (2), in the middle (3), half-right (4), and far-right (5) on the street (the simulated distances from the walls was 1.38 m for the middle position, and for the more extreme positions about 0.92 and 0.46 m to the left and right, respectively). The experiment followed a within-subjects design in which each participant saw each of the eight intersections from all five positions, making a total of 40 trials. Again, colored circles were used as landmarks and counterbalanced over all positions and conditions. The presentation was randomized. The procedure was identical to Experiment 3.

Results and discussion

Figure 10 presents the relative frequency of selected instructions as a function of the participants' position between the two sides of the street. The first finding is that participants again had a strong preference for landmarks on the side of the turn. We already found this in the previous experiments and seems to be a robust effect that is largely independent from other

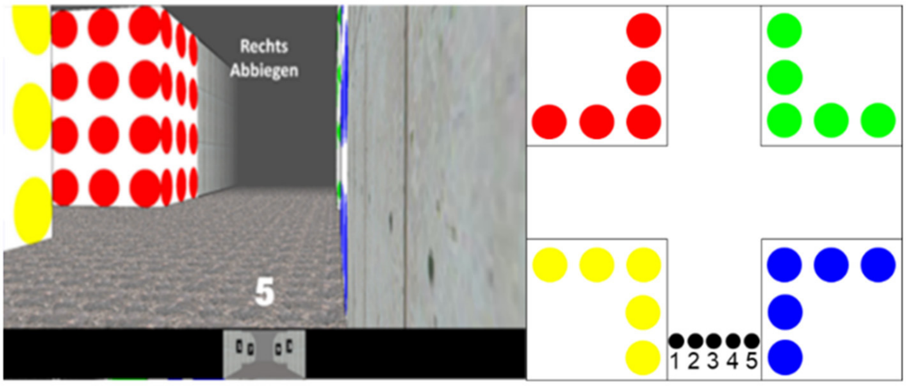

FIGURE 9
(Left) An example of an intersection in the virtual environment of Experiment 4. **(Right)** Illustration of the five positions "far-left" (1), "half-left" (2), "middle" (3), "half-right" (4), and "far-right" (5). The participants were standing at one of the five positions. Direction instructions were again presented centered in the scene. In the present example, participants had to turn right ("rechts abbiegen") and hence were positioned either "far in the direction of the turn" (5), "halfway in the direction of the turn" (4), "in the middle of the street" (3), "halfway in the opposite direction of the turn" (2), or "far in the opposite direction of the turn" (1). The simulated distances from the walls was 1.38 m for the middle position, and for the more extreme positions about 0.92 and 0.46 m to the left and right, respectively.

factors. The second finding of the present experiment, however, is that now we did not find an overall preference for landmarks before the turn. In fact, when participants selected landmarks on the side of the turn, they almost equally often selected landmarks before and behind the turning point. An interesting observation in the descriptive data is that when participants were extremely far on the side of the road they had to turn into, some of them (13%) selected a landmark on the other side of the road. However, this difference is only visible in the descriptive data and needs further experimental investigations. Nevertheless, the separate statistical tests using Kendall's W showed a significant agreement among participants in the rank order of landmarks when standing at the five positions on the street [far on the same side: $W(3) = 0.293$, $p < 0.001$; halfway on the same side: $W(3) = 0.395$, $p < 0.001$; middle: $W(3) = 0.561$, $p < 0.001$; halfway on the opposite side: $W(3) = 0.547$, $p < 0.001$; far on the opposite side: $W(3) = 0.524$, $p < 0.001$].

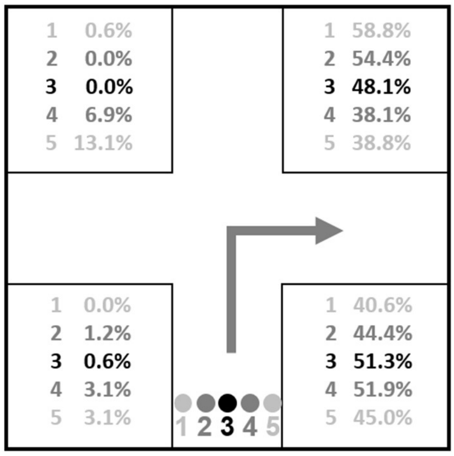

FIGURE 10
Results of Experiment 4 given as the relative frequency [%] of chosen route instructions; the observer positions from the intersection are "far on the opposite side of the turn" (1), "halfway on the opposite side of the turn" (2), "middle of the street" (3), "halfway on the side of the turn" (4), and "far on the side of the turn" (5); the landmark positions are: "side of the turn, before the intersection" [**(bottom right)**; $M \sim 46.6\%$]; "side of the turn, behind the intersection" [**(top right)**; $M \sim 47.6\%$]; "opposite side of the turn, behind the intersection" [**(top left)**; $M \sim 4.1\%$]; "opposite side of the turn, before the intersection" [**(bottom left)**; $M \sim 1.6\%$].

General discussion

We had two motivations for this work: First, we wanted to develop a better cognitive understanding of the features that might influence people's landmark selection. While most previous studies focused on the visual salience of a landmark, we want to understand how the location of objects influences their selection as landmarks when people give route instructions. Second, we wanted to contribute to some open issues in the development of mobile pedestrian navigation systems. Such systems use the Global Positioning System (GPS) or other positioning technologies to provide users with route instructions in real time (Corona and Winter, 2001). Compared to car navigation systems, the development of navigation systems for pedestrians is more complex, since pedestrians move with more degrees of freedom and the resolution of space is usually better than with car navigation (Corona and Winter, 2001). The development of specialized human-centered methods for the selection of landmarks becomes more and more important in such systems (i.e., cognitive capacities of the user).

The main finding of our study is that participants' landmark selection was not random. The spatial position of the landmark objects had a clear effect on whether they were chosen as landmarks. There were some differences between the four experiments, but overall direction-givers had a strong preference for instructions with landmarks that were located on the side of the road into which the recipient of the direction had to turn. This result agrees nicely with the fact that landmarks that are in the direction of the turn are easier to memorize and remember (Waller and Lippa, 2007). It also agrees with a study using a mobile eye-tracking device, in which participants more often focused on landmarks at spatially (structurally) salient locations when learning a route in a real-world environment (Wenczel et al., 2017). Waller and Lippa (2007) argued that landmarks at such positions might function as beacons and lead to less cognitive load because just remembering the landmark is enough to recognize the turn direction.

Another important result of our experiments was that the position of the participants at the intersection seems to determine whether they selected instructions with landmarks before or behind the decision point. In general, our experiments show that people prefer landmarks before the decision point. Yet, this overall preference is probably modulated by participants' position between the two sides of the street. When they were standing more toward the left side of the street they more often selected landmarks on the right side of the street, and vice versa (Experiment 4). This finding can be explained by the special characteristics of our environment and could also play an important role in more natural environments. Imagine you are standing in a city with many buildings along the street. In this case it is possible that these buildings occlude potential landmarks on the same side of the street, especially if you are standing extremely far on that side of the street. Therefore, in such cases, it is better to choose a landmark on the opposite side of the street (see also the concept of advance visibility addressed below; Winter, 2003).

Our results also emphasize that people do not only use visual features of objects when deciding what can serve as a good landmark. This finding nicely agrees with our previous research showing that the role of vision is often overestimated in spatial cognition research (e.g., Knauff, 2013). Of course, we do not doubt that our visual system gives us the most prominent access to the environment. However, our group has shown many times that information other than visual can also be of importance when we learn, represent, and utilize information about spatial environments (e.g., Hamburger and Knauff, 2019). Here it is essential to understand that spatial information should not be confused with visual information. We can create a spatial mental representation by vision, but also by means of acoustic information (e.g., Loomis et al., 1998, 2002; Marston et al., 2007; Karimpur and Hamburger, 2016), by touch or by proprioception (e.g., Klatzky, 1999; Marston et al., 2007; Tappeiner et al., 2009). Visual information is maintained and processed in another subsystem of working memory than spatial information (Logie, 1995; Zimmer, 2008), visual tasks interfere with other visual tasks but not with spatial tasks (Knauff et al., 2004), and visual object features are processed in different brain areas than information about the location of objects (Ungerleider and Mishkin, 1982). Congenitally blind and late-blind people can create spatial representations of their surroundings and often have excellent spatial orientation abilities (Vecchi, 1998; Knauff and May, 2006). In a recent study, we could even show that people can use odors as landmarks in wayfinding. In this study, participants could use olfactory cues to remember whether they have to turn left or right at an intersection (Hamburger and Knauff, 2019). In another study, we could show that navigation in the old town of a German city does rely on abstract spatial representations but not on visual images of buildings, intersections, and other urban objects (Meilinger et al., 2008).

However, our results also show how important it is from which perspective a direction-giver sees an intersection. Therefore, we can hardly argue that vision is irrelevant for the selection of landmarks in route instructions. Note, however, that the perspective is not the visual salience of the landmark object itself, but rather its visibility in the environment. In Experiment 3, the landmarks before the intersection were selected more frequently the farther away the participant was from the intersection. Obviously, the participants selected those landmarks that they could see well because they were closer to them. In Experiment 4, the effect of visibility was even stronger. Here participants switched to a landmark on the opposite side of the street if those on the same side became less visible or occluded. As far as we know, the present experiments are the first that so clearly identified how these factors impact the spatial salience of landmarks and how they could interact with each other when people have to decide which landmark they choose to give others helpful route directions. We plan further experiments to study these cognitive factors of spatial salience in more detail and with more sophisticated analyses.

Our results also provide valuable information for the development of mobile pedestrian navigation systems. In Geographical Information Science (GIS), Raubal and Winter (2002) and Klippel and Winter (2005) developed a mathematical model for automatic landmark selections that is a linear combination of visual salience (s_v), semantic salience (s_s), and spatial (structural) salience (s_u). Each of these parameters can be weighted by a corresponding weighting factor w_v, w_s, w_u, which leads to the equation $s_o = w_v s_v + w_s s_s + w_u s_u$ for the overall salience (s_o) of a landmark in the surrounding. We think that this model is helpful for many cases where the three parameters can be determined empirically. The authors also argue that the overall salience also depends on the (advance) visibility of the landmark object (Winter, 2003). Based on our results, we propose two further principles for the selection of landmarks based on their spatial salience:

- Select a landmark on the side of the turn whenever possible. In fact, we found that human instruction-givers almost never violate this principle. It seems to be very robust and thus should also be used in human-centered algorithms for pedestrian navigation systems.
- Select a landmark before the turn except of cases in which the instruction-recipient stands very close to the intersection. The exception was only found in Experiment 3, but nevertheless seems to be an important rule when humans give route instructions.

There might also be an exception to the first principle, which, however, is currently not reliable enough to be added to our suggestions. Intuitively, however, it makes sense to select a landmark on the opposite side of the street if there is some danger that the instruction-recipient cannot see a landmark on the same side from his or her particular point of view, because it might be covered by buildings or other objects along the street. In Experiment 4, some participants in such cases selected landmarks on the opposite side of the street, but further experiments are needed in this context. The important point, however, is that our empirical data can be used for the development of landmark selection algorithms that make pedestrian navigation systems more user-friendly and easier-to-use. Many people nowadays more and more rely on and trust in technical navigation aids (e.g., many do not even possess a physical map anymore). Even though we should once again cognitively engage more into the navigation process, it is sometimes inevitable to focus on other things instead of any street signs or buildings for orientation (i.e. traffic safety). Thus, artificial systems are needed to support us in the best possible way, including our individual cognitive abilities as well as limitations.

All this is of particular importance today, when a confusing number of pictures and symbolic information is available on the internet and geospatial databases that can be used as landmarks for pedestrian navigation.

Limitations and conclusions

Our studies, of course, also have some limitations. For instance, we cannot yet say how spatial salience interacts with the visual and semantic salience of landmarks. In the present paper, we tried to keep these other factors constant, as we wanted to explore spatial salience in detail. In further studies, however, we plan to explore the interactions of spatial salience with other sorts of landmark salience. For instance, in the current experiment, the visual (and semantic) salience was tried to be kept constant. This could also be addressed systematically, as well as the inclusion of other modalities (e.g., 3-D sounds) which could also provide some sort of salience (auditory and spatial). Also, the regional-like or line features could provide structural and visual aspects as well.

Another limitation is that our statistical methods are relatively week and further analyses were impossible due to a technical problem with data logging. Therefore, our results should be interpreted with caution. Although we believe that this drawback is at least partially compensated by the clearly visible descriptive patterns of results and the fact that we refrained from *p*-hacking, it certainly remains a limitation of our study that requires further examination that we will conduct in the future.

A related limitation is that our results do not really say which landmarks are optimal, most helpful, for the recipient of a wayfinding instruction. In other words, it is still not clear whether the landmarks selected by a participant preparing a route instruction are actually the most valuable for the recipient of such directions. On the one hand, Albrecht and von Stuelpnagel (2018), using our SQUARELAND environment, could show that people can remember a route better when the landmarks were located on the side of the turn. This might be interpreted as indirect evidence that our results also say something about the actual usefulness of the landmarks selected by our participants. On the other hand, it remains a fact that our results do not say how helpful the selected landmarks would later on be for the wayfinder. In our future research, we will use the landmarks that were selected in the present study to explore how helpful they are later on for the recipients of route instructions.

A further limitation of our experiments might be that they are currently restricted to the production of route descriptions. More experiments are needed to find out whether our results apply only to direction-giving tasks or also to wayfinding, which has been frequently explored in studies from other groups (e.g., Janzen and van Turennout, 2004; Barkowsky et al., 2007; Caduff and Timpf, 2008; Kim and Bock, 2021). Yet, we do not think that such a comparison would result in substantial differences in landmark choices between wayfinding and direction giving.

A further limitation of the present research might be that we used mere colored geometrical figures as landmarks. One could argue that this limits the ecological validity of our results. We think that this is partially correct and partially wrong. It is right insofar as several studies have demonstrated the (limited) transferability from quite artificial to more natural environments. Richardson et al. (1999), for instance, studied cognitive maps of an environment acquired from maps, from actual walking, and from a virtual environment. The last kind of mental representation resulted in the worst wayfinding performance and were particularly susceptible to disorientation after rotation. Riecke and Hastings (2011) found particular distortions in real environments, but not in the corresponding virtual environment. Good overviews on differences and similarities between wayfinding in real and virtual environments are given in De Kort et al. (2003) and

Kuliga et al. (2015). On the other hand, however, it is often difficult to conduct experiments in real urban environments, in which many influencing factors are uncontrollable. Of course, we always pay a price for the highly standardized experimental conditions in laboratory research. Typically, however, this leads to more reliable experimental results than we can obtain from field experiments. Moreover, several experiments have shown that the transferability from the lab to reality is much better than some people might believe (e.g., Witmer et al., 1996; Ruddle et al., 1997; Wallet et al., 2011; Kuliga et al., 2015).

In sum, we think that our results are important from basic and applied psychology points of view. In particular, they can help developers of navigation systems to devise better algorithms for extraction, weighting, and landmark selection for pedestrian route instructions. We know that navigation systems can have dramatic consequences on peoples' spatial memory and their ability to find their way if they cannot rely on an electronic device (e.g., Burnett and Lee, 2005; Brunyé et al., 2016; Schnitzler et al., 2016; Montello, 2017). It is very likely that this decline in the ability to orient in space might have further impact on independence, autonomy, and quality of life (Gramann et al., 2017). Indeed, it is weird that some people use a navigation app even when it would be much easier to find their way without it. They seem to trust their smartphone more than their own cognitive abilities. Of course, one can have mixed feelings about this development. However, this trend will continue (for a recent overview on these challenges see Ruginski et al., 2022) and it is therefore better to develop systems in such a way that the system adapts to the user and not the user to the system.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by German Psychological Society (DGPS); MK3010200DGPS. The patients/participants provided their written informed consent to participate in this study.

Author contributions

KH planned the experiments, analyzed the data, and wrote and revised the manuscript. FR planned and designed the experiments, collected and analyzed the data, and wrote the manuscript. MK planned the experiments and wrote and revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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