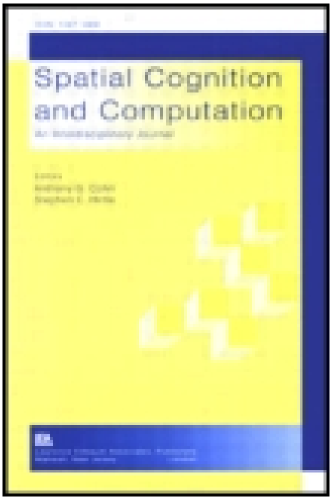

Spatial Cognition & Computation: An Interdisciplinary Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hscc20

Is Memory for Routes Enhanced by an Environment's Richness in Visual Landmarks?

Michel Denis[a], Célia Mores[a], Doriane Gras[b], Valérie Gyselinck[b] & Marie-Paule Daniel[a]

[a] LIMSI-CNRS, Université Paris-Sud, Orsay, France

[b] Laboratoire Mémoire et Cognition, Université Paris Descartes, Boulogne-Billancourt, France

To cite this article: Michel Denis, Célia Mores, Doriane Gras, Valérie Gyselinck & Marie-Paule Daniel (2014) Is Memory for Routes Enhanced by an Environment's Richness in Visual Landmarks?, Spatial Cognition & Computation: An Interdisciplinary Journal, 14:4, 284-305, DOI: 10.1080/13875868.2014.945586

To link to this article: http://dx.doi.org/10.1080/13875868.2014.945586

Spatial Cognition & Computation, 14:284–305, 2014
Copyright © Taylor & Francis Group, LLC
ISSN: 1387-5868 print/1542-7633 online
DOI: 10.1080/13875868.2014.945586

Is Memory for Routes Enhanced by an Environment's Richness in Visual Landmarks?

Michel Denis,[1] Célia Mores,[1] Doriane Gras,[2] Valérie Gyselinck,[2] and Marie-Paule Daniel[1]

[1]LIMSI-CNRS, Université Paris-Sud, Orsay, France
[2]Laboratoire Mémoire et Cognition, Université Paris Descartes, Boulogne-Billancourt, France

Abstract: We tested the hypothesis that a route's memorability is dependent on the frequency with which people are exposed to visual landmarks. Undergraduates learned either a route through an urban area lacking visually salient features, or a route in a neighborhood with many shops and urban objects. They were then asked to recall the learned route in the form of route directions and sketch maps. The results showed higher recall performance for the richer environment. When presented with photographs depicting scenes along the route, participants exposed to the richer environment had higher recognition scores and shorter response times than the others. The data confirm the functional role of landmarks in route memory and wayfinding.

Keywords: landmarks, navigation, route directions, sketch maps, spatial cognition, urban environment

1. INTRODUCTION

What makes an environment memorable? The answer is probably multifactorial, involving references both to intrinsic structural features of the environment to be memorized, and to each individual's episodic experience in this environment (cf. Golledge, 1999; Montello & Raubal, 2013). General characteristics expected to contribute to an environment's memorability are the nature and content of the experience generated during a person's navigation. To a large extent, this experience depends on the visual richness

---

Correspondence concerning this article should be addressed to Michel Denis, LIMSI-CNRS, Université Paris-Sud, BP 133, 91403 Orsay Cedex, France. E-mail: denis@limsi.fr

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/hscc.

of the scenes encountered. Consider extreme cases: Environments that are plain, devoid of any salient, visually attractive objects (e.g., deserts, ice fields, forests, etc.) contrast sharply with those rich in visually distinctive objects (e.g., amusement parks, city centers, malls, etc.). Clearly these two kinds of environment elicit qualitatively different cognitive experiences and may give rise to different patterns of navigational behavior. The difference between these environments is often described in terms of their relative richness in visual landmarks.

Reference to the etymology of "landmark" is significant here. When explorers of territories lacking notable natural objects have to keep track of their movements, they draw signs on the ground or create objects by which they leave a *mark* (e.g., a pile of stones, or cairn) somewhere on the *land*. In this sense, a *landmark* is an artifact fabricated intentionally to identify a place of interest and secure future navigation (including back to the point of departure during exploration of unfamiliar places). In built urban environments, there is no need to create such landmarks while navigating along a route. People simply make use of objects already available in the environment, thus intentionally conferring on them the *function* of landmarks (cf. Dudchenko, 2010).

Building on Lynch's (1960) definition of landmarks as distinct elements of an environment used as "points of reference," Presson and Montello (1988) noted that an element's "landmark" status is largely determined by the type of navigational task for which it might assist route decision. Golledge (1999) described landmarks as navigational tools that essentially help a moving person identify points where critical actions are to be executed, or that provide verification of route progress. At about the same time, Sorrows and Hirtle (1999) proposed a comprehensive framework in which landmarks are seen as identifying features in an environment that provide people with a way to locate themselves and establish goals.

As reference points in an environment, landmarks help a moving agent organize an internal representation of the surrounding space. Although the concept of landmark is usually associated with three-dimensional objects in an environment, other spatial entities may sometimes act as landmarks. These latter are known as "structural landmarks," an example being particular geometrical patterns formed by connecting paths (cf. Stankiewicz & Kalia, 2007). Interestingly, Sorrows and Hirtle developed a taxonomy of critical landmark characteristics. Their framework was later extended to robot navigation (cf. Hirtle, 2008).

In most studies on spatial knowledge and communication intended to assist navigation, the notion of landmark has been recognized as central. In Allen's (1997) conceptual framework for route direction analysis, special consideration was given to the classification of the speech acts that define places and refer to landmarks. The most detailed part of Allen's model reviews the nominals used to refer to environmental features such as landmarks typically used as subgoals along a route.

Experiments to test the value of the conventions used for conveying wayfinding information have confirmed that navigational performance is enhanced when directions are specified in more detail at decision points through reference to landmarks (Allen, 2000). Similarly, we proposed route directions to be considered as an ordered set of prescriptions of actions to be executed along a route, each new action being triggered when specific landmarks come into view for the navigating person. Interestingly, about 80% of the statements in route directions refer to landmarks, by either simply mentioning them, or describing their appearance, or specifying the actions to be executed when reaching them (cf. Denis, 1997; Denis, Michon, & Tom, 2006; Denis, Pazzaglia, Cornoldi, & Bertolo, 1999).

This brings us to the hypothesis of the present article: An environment should be more memorable if the quality or richness of the associated visual experience is more likely to be encoded in the form of vivid, distinctive memories. This is what we expect of an environment easy to travel through, where it is possible to build an informationally rich spatial mental model. Furthermore, such an environment is probably easier to describe than one that is visually poor. Our hypothesis is based on evidence that landmarks are predominant in verbal descriptions of routes, and have high rates of recall (Denis, 1997; Denis & Fernandez, 2013). The most efficient way to aid people moving in an unfamiliar environment thus involves helping them create in advance a visual model that contains references to distinctive landmarks where critical actions have to be executed.

People are generally successful at identifying landmarks containing noteworthy features, these being good candidates for assisting in wayfinding. Prominence, distinctiveness, and salience (in terms of figure/ground contrast) are among the most frequently cited features of objects or buildings expected to serve the function of landmarks. These characteristics are critical in human navigation, and are also taken into account in research programs aimed at implementing spatial cognition in artificial systems. A good example is provided by approaches based on measurements of façade area, shape, color, and visibility of buildings (from the egocentric perspective of a moving person) (Raubal & Winter, 2002; Winter, 2003). These studies have led to the development of computational models of the selection of salient landmarks, providing further evidence that there is reasonable correlation of automatic extraction of landmarks with human choices (Klippel & Winter, 2005; Nothegger, Winter, & Raubal, 2004).

Whether navigation is assisted by human discourse or by an artificial system, the functional role of landmarks in route memory and wayfinding is well established (e.g., Daniel & Denis, 2004; Lovelace, Hegarty, & Montello, 1999; Tom & Denis, 2004). More recent studies have shown the main factor underlying visual landmark memorability to be the vividness of the representations constructed during the processing of descriptions (cf. Tom & Tversky, 2012; Tversky, 2012).

Differences in a landmark's informational value have also been documented. For instance, in urban environments, buildings situated at reorientation points are more frequently mentioned by route describers than buildings lining a street section (cf. Michon & Denis, 2001). There are also other demonstrations of the cognitive differentiation of landmark types. In particular, landmarks at decision points (intersections) allow better long-term recognition than those at non-decision points, and elicit specific cerebral (parahippocampal) activation (cf. Janzen & van Turennout, 2004; Janzen, Wagensveld, & van Turennout, 2007; Wegman & Janzen, 2011).

Early studies on spatial cognition have provided hints that the richness of a navigational environment in landmarks is likely to impact its mental representation. Byrne (1979) used a distance estimation task following navigational experience in an urban environment. He found that routes are judged longer if they lie within a town center (typically richer in distinctive visual events) than in outlying areas. Larger amounts of complexity are usually associated with downtown districts than with suburbs. Thorndyke (1981; Thorndyke & Hayes-Roth, 1982) found that after map learning, distance estimates increase linearly with number of intervening points along a route.

In recent years, research on spatial cognition and the role of landmarks in building spatial knowledge has benefited greatly from the development of virtual reality techniques (e.g., Gras, Gyselinck, Perrussel, Orriols, & Piolino, 2013; Meilinger, Knauff, & Bülthoff, 2008; Picinali, Afonso, Denis, & Katz, 2014; Wang, Mou, & Sun, 2014; Wegman & Janzen, 2011). Even so, the availability of such tools should not lead to exclusion of investigation of navigational performance in real spatial environments. Indeed, a primary aim of this present research was to examine the role of landmarks in an ecologically valid setting as a key approach.

Furthermore, given the variety of forms of expression of spatial knowledge, the experimental design we used was based on the view that one single test is not sufficient for assessing the impact of an environment's richness in landmarks on its mental representation (cf. Wiener, Büchner, & Hölscher, 2009). We therefore employed a set of tasks chosen to probe the various different aspects of the representations built from navigational experience. This package of tasks proved highly valuable in earlier research on mental spatial representations following route learning in a complex outdoor environment (cf. Daniel, Mores Dibo-Cohen, Carité, Boyer, & Denis, 2007). In line with the procedure used in that study, our participants first learned a route through an urban environment. Each participant was assigned to one of two routes of similar lengths, which essentially differed in number of noteworthy buildings and conspicuous urban objects encountered during navigation. The participants then completed the following set of four tasks.

The first task focused on the generation of route directions, as verbal reflections of the internal spatial representations built from navigational experience. A number of studies have demonstrated the sensitivity of spatial discourse in capturing (and then conveying) landmark-related information (cf. Daniel, Tom, Manghi, & Denis, 2003; Denis, 1997; Denis, Ricalens, Baudouin, & Nespoulous, 2006; Golding, Graesser, & Hauselt, 1996; Schneider & Taylor, 1999). In the present context, two contrasting hypotheses can be considered. The first posits that the more landmarks in an environment, the more references to landmarks in the subsequent description. Empirical confirmation of this would indicate that the describer is exploiting the features of an environment mindfully to convey navigational information, i.e., generating output whose content tends to be aligned to the content experienced during navigation. Under the alternative hypothesis, the absolute number of landmarks encountered during navigation should have no impact on the number of reported landmarks. This finding would be compatible with the notion of a fixed rate of landmarks in verbal route directions, regardless of the density of visual landmarks in the navigated environment.

The second task was based on another classic method designed to express a person's spatial knowledge, namely, the drawing of a sketch map. Maps contain pieces of information that can also be conveyed by verbal directions (cf. Daniel et al., 2007; Tversky & Lee, 1998, 1999). They are of special value here because they free participants from the cognitive difficulties of translating visuo-spatial representations into linguistic output regulated by a constraining verbal code. Nevertheless, the two outputs should be guided by the same communicational objective of conveying to another person specific information that will help that person build a real representation of the route and navigate securely in the environment. Central to our investigation here is to seek any factual indication that the two outputs have a common underlying representation. We are not only interested in determining whether richer environments are expressed in the form of sketch maps displaying more landmarks. We are also looking for any reliable similarities between the content of verbal outputs and that of sketch maps.

The third test was a visual recognition task, providing an opportunity to measure aspects of route memory without involving any retrieval cost. Participants were presented with photographs of scenes encountered along the learned route, mixed with distractors. A classic measure of recognition of visual scenes was therefore obtained. Participants were not expected to encounter any particular problems during the task, which addressed the question of whether recognition accuracy and recognition speed would be affected as a function of saturation of the environment in visual landmarks. In particular, it is reasonable to anticipate that a route's greater visual richness would raise the probability of correct recognition of landmarks. Richer environments are likely to result in richer and more available memories.

The fourth task, also a recognition task, was designed to test participants' ability to identify the sequence in which two scenes were encountered along the learned route, thus examining another aspect of visual memory. Remembering the relative position of landmarks along a route is a critical component of navigational memory. Holding time-related information of visual events and thus recognizing the temporal sequence of scenes are likely to be sensitive to the variable under study. Specifically, the ease of temporal distinction between items is thought to be higher when the items belong to a richer set. In this case, one would expect participants to be more proficient at remembering the sequence of two items extracted from a set where remarkable items are more numerous and more distinctive.

The participants completed this set of four tasks in a fixed sequence. They did so after the learning phase, which consisted of experiencing a navigational episode under the control of an experimenter.

2. METHODS

2.1. Participants

The participants were 64 undergraduate students from the Department of Psychology of Paris Descartes University, aged between 19 and 27.

2.2. Setting and Routes

The location of the routes lay within a district of the town of Boulogne-Billancourt, a suburb southwest of Paris.

Two routes in this environment were designed for the purposes of the experiment. They were of similar length (Route 1: 1,360 m; Route 2: 1,245 m). Each route comprised a succession of eight contiguous segments; walking along it thus involved a total of seven major direction changes. The start points of the two routes were close to each other, on opposite sides of a wide avenue. Figure 1 shows a map of the environment and indicates the two routes.

Route 1 started from the Boulogne-Billancourt post office and ended at the front door of an arts center (Espace Landowski). It went through a quiet area whose streets were mainly lined with apartment buildings and lacked any visually salient constructions, except for a church, plus a few shops and bars. The route then continued along a succession of unremarkable office building façades. The overall impression was that of a rather plain neighborhood lacking any conspicuous visual landmarks.

Route 2 started from the town hall of Boulogne-Billancourt and ended in front of a clinic. It went through a lively area, including a large square near a shopping mall. Along the route there were numerous shops with colorful decorated windows, as well as restaurants and a series of remarkable objects and places, such as a merry-go-round, a large sculpture, a movie theater, a newsstand, etc. Navigating along this route gave the sensation of experiencing a set of rich and varied visual impressions.

From the outset, the contrast between the two routes in terms of richness in landmarks relied on the judgment of the authors of this research. This

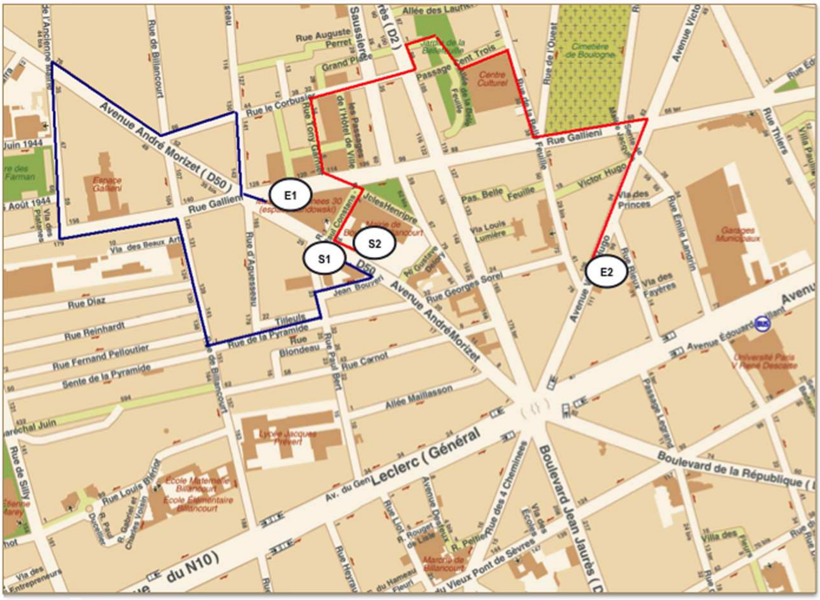

Figure 1. The setting of the experiment and the two routes (S1, E1, start and end points of Route 1; S2, E2, start and end points of Route 2).

judgment was corroborated by an objective measure. Using the set of verbal directions provided by the participants (analyzed in more detail below, Section 3.1), we established the list of all individual landmarks mentioned by at least one participant (buildings, shops, merry-go-round, newsstand, etc.). The total number of distinct cited landmarks amounted to 63 for Route 1 and 139 for Route 2, clear evidence that the two environments did differ in terms of richness in visual landmarks as perceived by participants.

2.3. Procedure

The participants were tested individually at each step of the experimental procedure.

2.3.1. Learning

Assignment of participants to Route 1 or 2 was random. The learning phase involved their walking along the route, accompanied by an experimenter (CM). They were instructed to pay attention to the route, and told they would be asked to provide information on the route later. Their description was to be as accurate as possible, in order that it could truly facilitate successful navigation of the route. The instructions did not include any explicit reference to the landmarks to be encountered along the route. Participants were told they would walk along the route twice. The time taken to walk was 17 to 20 minutes. When the first route walk was completed, the second began immediately. There was no measurement of navigational performance during the two walking episodes. After completing the learning phase, the participants were taken to an office in the nearby Centre Henri-Piéron (Department of Psychology), where they performed the four experimental tasks in succession.[1]

2.3.2. Task 1: Generating Route Directions

The participants were asked to give a verbal description of the route they had just followed. They were told to be as accurate as possible so that a person listening to their description would be able to walk along the route without error. The descriptions were tape-recorded.

2.3.3. Task 2: Drawing Sketch Maps

Participants were then given a sheet of A4 paper, and asked to draw a sketch map of the route. They had to imagine that someone arriving in the area for the first time would have to follow their itinerary. The sketch was to be as accurate as possible, so that the person would find the route without error with the aid of only the map. Participants were asked to include every landmark and street they thought would be helpful for this purpose. Participants were given additional sheets of paper as necessary.

2.3.4. Task 3: Recognizing Scenes Seen on the Route

Participants were shown a total of 32 color photographs depicting urban scenes from the district where the experiment took place. Of these photographs, 16 had been taken along the route followed by the participants (either Route 1 or 2), and from the viewpoint of a pedestrian walking along the route. Two photographs were taken for each segment, at points one-third and two-thirds of the way along the segment. A further 16 photographs were taken in the same district of the route, but these showed scenes not visually

---

[1] Although the Centre Henri-Piéron was in the vicinity of the navigated district (300 meters away from the closest route), the participants were not familiar with the environment traversed by the routes, which is separated from the Centre by a wide avenue. Most of the students attending courses in the Centre typically reach it from Paris via the subway network and spend their whole time on the campus, with no real opportunities of traversing the rest of the neighborhood. After the second navigation episode, the experimenter checked that the participants had no prior knowledge of the navigated environment.

accessible to a person walking along the route. The set of 32 photographs were displayed on a computer screen in succession in random sequence. Participants were informed that some photographs showed scenes encountered along the route, while others did not. The instructions specified that they should press a key on the right of the keyboard if they recognized the scene as belonging to the route taken, and a key on the left if they did not. Participants were instructed to respond as soon as they had made their decision. Response times were recorded by the computer.

2.3.5. Task 4: Recognizing the Order of Scenes

Participants were then presented with a set of 28 pairs of photographs. The two paired scenes were displayed side by side on the computer screen. They showed places that had been visible to the person walking along the route, and corresponded to the first photographs taken along each of the eight segments. The total number of pairs, 28, resulted from pairing the scene from Segment 1 to those from Segments 2 through 8, respectively; then, the scene from Segment 2 with those from Segments 3 through 8, respectively; and so on. Participants were told that in each pair one of the scenes had been encountered before the other along the route. If they thought they had seen the scene on the left first, they were to press the key on the left of the keyboard. Instead, if they thought they had seen the scene on the right first, they were to press the key on the right. They were asked to press a key as soon as they had made their decision. Response times were recorded.

3. RESULTS AND DISCUSSION

3.1. Task 1: Generating Route Directions

The first step of the analysis consisted of transcribing the individual protocols and coding them using the methodology developed by Denis (1997; Daniel & Denis, 2004; Daniel et al., 2007; Michon & Denis, 2001). The method involves re-expressing the statements in a protocol in terms of minimal information units combining a predicate and one or two arguments. Two authors (MPD and CM) coded the protocols. When a discrepancy appeared between them, a third coder (MD) gave advice.

The units of information were divided into five classes:

1. Prescription of an action without any reference to a landmark ("*Go straight on*");
2. Prescription of an action with reference to a landmark ("*Take the street beside the bakery shop*");
3. Reference to a landmark without any prescription of an action ("*There is a bar in front of you*");

4. Description of a landmark ("*The shop is painted blue and white*");
5. Comment ("*It's a nice walk*").

Table 1 shows the average number of information units per class for the descriptions of the two routes. Overall, there were significantly fewer units in the description of the route in a landmark-poor environment (Route 1) than in a richer environment (Route 2), 35.9 ($SD = 18.32$) vs. 59.3 ($SD = 37.33$), respectively, $F(1, 62) = 9.91$, $p < .01$. The greater richness of the protocols for Route 2 was confirmed for all item classes ($p < .05$ or less), with the exception of Class 5, where both routes elicited similar low levels of comments.

A further analysis focused on the frequency of statements that specifically referred to landmarks, i.e., statements pertaining to Classes 2, 3, and 4. The results showed the total number of such statements to be significantly lower for Route 1 than for Route 2, with average numbers of 25.7 ($SD = 15.86$) vs. 45.3 ($SD = 32.43$), respectively, $F(1, 62) = 9.10$, $p < .01$. Note that despite the difference between the two means, they represented similar percentages relative to the total number of statements, 72% and 76%, respectively.

Finally, we counted the number of distinct landmarks cited by each participant (whatever the unit class they were mentioned in). Average number of landmarks mentioned was 7.3 ($SD = 4.76$) for Route 1 and 12.5 ($SD = 5.98$) for Route 2, a statistically significant difference, $F(1, 62) = 14.91$, $p < .001$. In contrast, there was an opposite effect for number of street names mentioned, 3.0 ($SD = 2.89$) for Route 1 and 1.8 ($SD = 1.78$) for Route 2, $F(1, 62) = 4.17$, $p < .05$.

The whole set of verbal protocols was then reviewed by three judges (MD, MPD, plus an independent reviewer). The aim was to assess the value of the protocols in terms of navigational assistance. A protocol was classified as "good" if at least two judges thought it would provide adequate aid to a pedestrian trying to follow the route. Of the 32 protocols collected for Route 1, 16 (50%) were classified as "good," while 21 (66%) were judged

Table 1. Average number of information units per class for the two routes

	Route 1	Route 2
1. Prescription of an action without reference to a landmark	8.6 (24%)	12.2 (21%)
2. Prescription of an action with reference to a landmark	12.9 (36%)	20.7 (35%)
3. Reference to a landmark without prescription of an action	11.2 (31%)	20.5 (35%)
4. Description of a landmark	1.6 (4%)	4.1 (7%)
5. Comment	1.6 (4%)	1.8 (3%)
Total	35.9	59.3

"good" for Route 2, a difference in favor of the descriptions of the richer environment, while remaining below statistical significance according to the χ^2 test.

In summary, the results from the first task confirm that a richer environment elicits richer descriptions of a route through it. In other words, and not surprisingly, more is said when there is more to be said. Consequently, directions in an environment containing more noteworthy objects are richer overall, and this is true more specifically regarding references to landmarks and their descriptions. At the same time, a relatively poor environment elicits more references to street names. The increased focus on such references indicates the speaker's ability to switch to a replacement strategy, and reflects the greater attention paid to alternative reliable features to assist the person moving. Consistent with these data is the tendency for the richer environment to elicit directions that have greater value in terms of aid to navigation.

Overall, these results suggest that the task of a person expected to deliver verbal navigational aid is facilitated when the corresponding environment offers more possibilities of making reference to places of interest. In this sense, landmarks are noticed and selected in an environment to serve as anchors to the descriptive process, and to indicate places where critical directional choices have to be made. The cognitive prominence of landmarks is thus confirmed, although their relative frequency remains similar in the descriptions of both types of environment.

Reconsidering the hypothesis set out in the Introduction, it appears that the high number of landmark references in the description of an environment richer in visual landmarks relates to the speaker's ability to exploit the options offered by the environment to build up a message designed to assist another person. The number of landmark references in spatial directions is not constrained, and a richer navigational experience helps a speaker produce a discourse that is more likely to aid another person's navigation. In poorer environments, where there are limited opportunities to refer to visual landmarks, speakers nevertheless rely on them as far as possible, such that their frequency remains high relative to the other discourse components.

Although the preceding results informed about people's ability to generate spatial directions and presumably also their internal representation of the described routes, the question remained of whether these data were affected by the verbal nature of the task. This was addressed by testing whether a non-linguistic mode of communicating spatial information confirmed the results from the first step of this study. This was achieved through Task 2, in which participants had to externalize spatial information in the form of sketch maps.

3.2. Task 2: Drawing Sketch Maps

Figure 2 shows an example of a map drawn by a participant who learned Route 1 (2a), compared with a map by a participant who learned Route 2

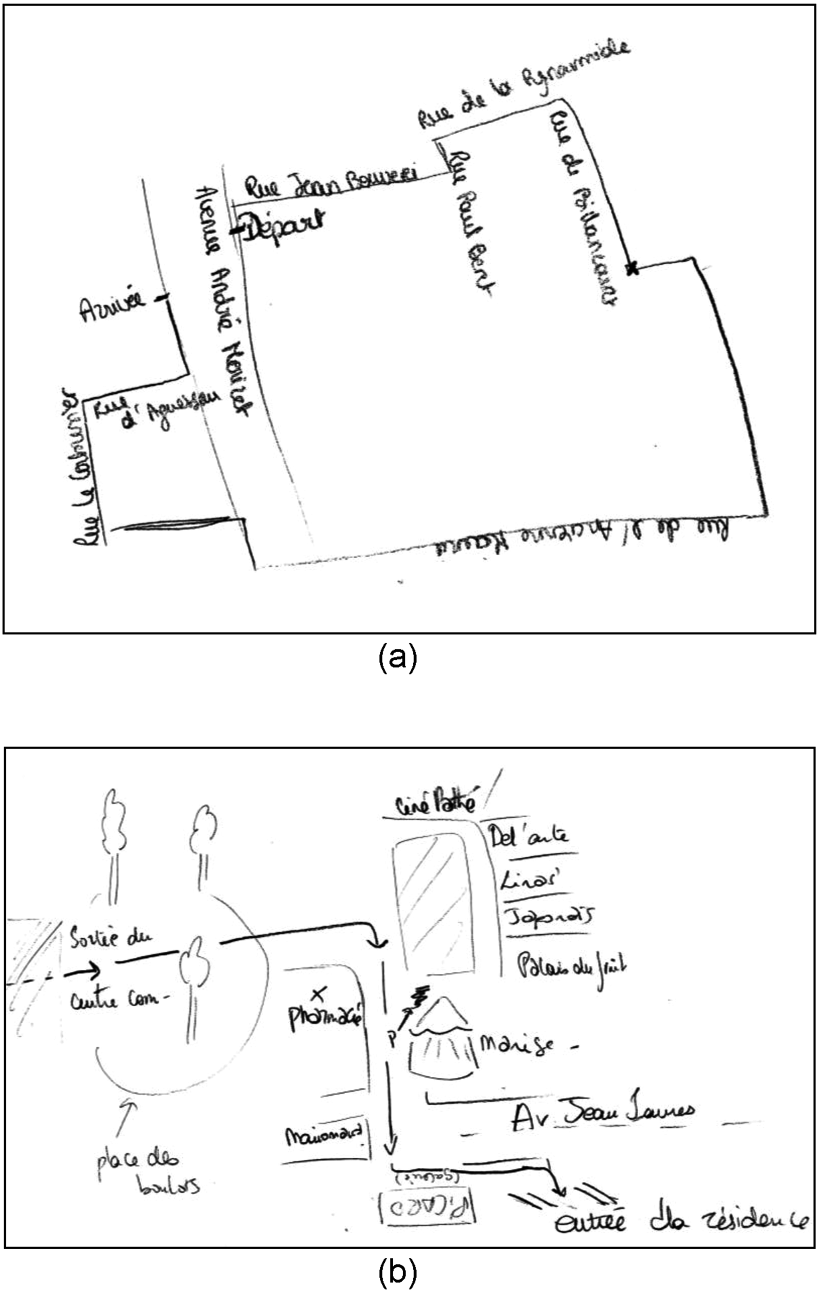

Figure 2. Examples of drawings by participants who were assigned to Routes 1 (a) and 2 (b). In the latter case, the drawing shows the middle section of the route.

(2b). Sketch maps were analyzed in terms of overall shape of the route drawn, richness in landmarks, and their judged value for aid in navigation.

Each route included a total of seven reorientations. The sketch maps for Route 1 included an average number of 4.7 (*SD* = 1.85) turns, and 6.4 (SD = 1.33) for Route 2. This difference was significant, $F(1, 61) = 17.10$, $p < .001$, and indicated that participants navigating a route in a richer environment constructed a more accurate representation of its structure. The overall shape of the configuration was better preserved than for the route in the poorer environment. Plausibly, a larger number of landmarks, primarily those situated at reorientation points, enhances the memory of the segments making up the route, and more generally the internal representation of its geometrical features.

We counted the number of landmarks included by the participants in their sketch maps (sometimes in very schematic form). In Route 1 maps, an average of 7.4 (*SD* = 5.14) landmarks were represented, while in Route 2 maps, there were 12.8 (*SD* = 6.58), a statistically significant difference, $F(1, 62) = 13.26$, $p < .001$. In contrast, the number of street names given in the maps was higher for Route 1 than for Route 2, 2.9 (*SD* = 3.32) vs. 1.4 (*SD* = 1.77), respectively, $F(1, 62) = 5.51$, $p < .05$.

As for the route directions in the previous task, the set of sketch maps were reviewed for their value in terms of aiding navigation. Classification of the maps was carried out by the same judges. A map was considered “good” if at least two of the three reviewers judged that it would help a person walk successfully along the full itinerary. Of the 32 sketch maps for Route 1, only 10 (31%) were assessed as “good,” while 17 (53%) were judged “good” for Route 2. Here, a marginally significant tendency appeared in favor of the Route 2 sketch maps, $\chi^2(1) = 3.14$, $p < .08$.

We calculated the Bravais-Pearson’s correlation between number of landmarks cited in route directions (Task 1) and those drawn on the maps (Task 2), for each route. The correlation coefficients were $r(30) = .76$, $p < .01$, for Route 1, and $r(30) = .74$, $p < .01$, for Route 2. These values indicate that for each environment, common factors determine people’s sensitivity to landmarks, whether they externalize their memories via language or graphic representation.

With the similar purpose of comparing verbal and graphic responses, we aimed to establish whether people who generated “good” verbal directions would also tend to produce “good” sketch maps. In the case of Route 1, this relation was clear, $\chi^2(1) = 5.24$, $p < .05$. Thus, proficiency in delivering navigational instructions appears to be somewhat independent of the medium used. For Route 2, no such relationship was found. This absence may be related to the greater interindividual variability of the number of landmarks mentioned or drawn from a route that contains a large number of landmarks.

Finally, we were interested in any overlap between the landmarks mentioned in descriptions and those drawn in sketch maps. Table 2 shows the average number of items common to both descriptions and maps, as well as

Table 2. Average number of landmarks mentioned in descriptions and maps

	Route 1	Route 2
Landmarks		
Mentioned in both descriptions and maps	4.8 (48%)	8.5 (51%)
Specific to descriptions	2.5 (25%)	4.0 (24%)
Specific to sketch maps	2.6 (26%)	4.3 (26%)
Total	9.9	16.8

those specific to either descriptions or maps. Of the whole set of reported landmarks, about one half appeared in both descriptions and maps. Of the remaining landmarks, about one half were specific to descriptions and the other half to maps. There was no difference between Routes 1 and 2.

In summary, the results of Task 2 reveal a set of features common to both descriptions and maps. First, there is a consistent trend that more landmarks are reported when people describe a route richer in landmarks, the absolute values being quite similar in both tasks. Furthermore, more streets are mentioned when people are exposed to an environment with fewer landmarks. These are robust characteristics, independent of the medium used to convey information. Another common feature concerns the individual characteristics of the participants. Those including more landmark information in their descriptions also put more information in their drawings.

Of interest is the finding that a large number of items (presumably of critical cognitive relevance in terms of navigational assistance) are mentioned in both descriptions and maps by the same people, while another set of items are mentioned in descriptions but not in maps, and vice versa. This does not contradict the hypothesis that a common set of underlying representations are used to generate verbal and graphic route directions (cf. Tversky & Lee, 1998, 1999).

3.3. Task 3: Recognizing Scenes Seen on the Route

Table 3 shows the average number of correct responses in the recognition task and corresponding response times. The number of correct responses (including both hits and correct rejections) was lower after learning Route 1 than learning Route 2, 24.3 ($SD = 2.43$) vs. 27.0 ($SD = 2.61$), $F(1, 62) = 19.89$, $p < .001$. Average times for correct responses were 3,590 ms ($SD =$ 2,019) and 3,240 ms ($SD = 859$), respectively, $F(1, 62) < 1$. Thus, for similar processing times, recognition performance was higher for those who had learned the richer environment.

Table 3. Average number of correct responses and corresponding response times

	Route 1	Route 2
Average number of correct responses		
Hits	11.4	12.7
Correct rejections	12.8	14.3
Response times (ms)		
Hits	2,995	2,632
Correct rejections	4,185	3,849

A closer analysis showed that there were significantly fewer correct recognitions than correct rejections, for both Route 1, $F(1, 62) = 9.25$, $p < .01$, and Route 2, $F(1, 62) = 10.62$, $p < .01$. Furthermore, response times were systematically shorter for correct recognitions than for correct rejections, for both Route 1, $F(1, 62) = 4.58$, $p < .05$, and Route 2, $F(1, 62) = 22.95$, $p < .001$.

Finally, we calculated d' values in order to assess participants' sensitivity in the recognition task. To do this, we used frequencies for hits and false alarms, then converted them into d' values. The analysis showed that d' values were 1.48 ($SD = .41$) for Route 1, and 3.15 ($SD = 1.46$) for Route 2. The difference was significant, $F(1, 62) = 28.94$, $p < .001$.

The difference in recognition rates is clearly in line with the notion that representations of routes stored in memory are more accessible when they have been elaborated from visually richer environments. This explanation is corroborated by the demonstration of higher capacity when people compare previously seen and new scenes. A richer environment elicits not only higher recognition scores, but also higher capacity for distinguishing between landmarks that have been encountered at some stage and new ones.

3.4. Task 4: Recognizing the Order of Scenes

Of the 28 pairs of photographs, the average number of those eliciting correct responses was 19.2 ($SD = 2.94$) for Route 1 vs. 25.1 ($SD = 2.22$) for Route 2. The difference was clearly in favor of Route 2, $F(1, 62) = 77.81$, $p < .001$. Average times for correct responses were 3,981 ms ($SD = 1{,}151$) and 3,601 ms ($SD = 843$), respectively, $F(1, 62) = 2.27$, $p = .14$. The data thus show that for similar processing times, participants who learned the route in the richer environment outperformed the others.

The structure of the data makes it possible to assess whether there was any systematic relationship between participants' response times and distance between the two scenes of a pair. Such a relationship is typically illustrated by the fact that making judgments about two items is easier (higher scores, shorter response times) when these items are more distant from each other in a given dimension. This pattern reflects the so-called "symbolic distance effect" (cf. Dean, Dewhurst, Morris, & Whittaker, 2005; Denis, 2008). Within the present data, we distinguished between three subsets of photograph pairs, as defined by the number of segments that separated the corresponding scenes along the route, that is, (a) pairs from two contiguous segments or segments separated by just one segment; (b) pairs from segments separated by two or three segments; (c) pairs from segments separated by four, five or six segments.

Table 4 shows average proportion of correct responses and corresponding response times for each pair subset, for each route. Because the three subsets do not include the same number of items, correct response proportions are given instead of absolute values for comparability.

Analysis of correct response proportions confirmed that response accuracy was lower for items from Route 1 than from Route 2. The novel finding is that this was true for all three item subsets: (a) $F(1, 62) = 48.96$, $p < .001$; (b) $F(1, 62) = 52.21$, $p < .001$; (c) $F(1, 62) = 32.39$, $p < .001$. Our data also revealed an overall symbolic distance effect, with correct response proportion increasing with increase in distance between the two scenes, $F(2, 93) = 7.30$, $p < .005$, for Route 1, and $F(2, 93) = 18.03$, $p < .001$, for Route 2. The effect was marked in the case of Route 2, with scores showing a clear ceiling effect. For Route 1, scores remained below maximal values, even for items involving the largest separations.

In line with the overall nonsignificant effect of routes on response times (as mentioned at the beginning of this section), no effect was found for the three subsets of items considered separately: (a) $F(1, 62) = 1.08$; (b) $F(1,$

Table 4. Average proportion of correct responses and corresponding response times for three subsets of photograph pairs

Route 1			
	(a)	(b)	(c)
Proportion of correct responses (%)	63	72	77
Response times (ms)	4,388	3,801	3,414
Route 2			
	(a)	(b)	(c)
Proportion of correct responses (%)	83	94	96
Response times (ms)	4,060	3,358	3,091

(a) Pairs from two contiguous segments or segments separated by just one segment; (b) pairs from segments separated by two or three segments; (c) pairs from segments separated by four, five, or six segments.

62) = 2.07; (c) $F(1, 62) = 1.49$; $p > .10$, in all cases. However, a clear symbolic distance effect was found, with response times decreasing as scene separation increased, $F(2, 93) = 4.56$, $p < .05$, for Route 1, and $F(2, 93) = 7.09$, $p < .005$, for Route 2.

Further analyses provided more detailed assessment of the situation. We considered the seven distinct values of distances between scenes. Average response times were calculated for each subset of items, and from them Bravais-Pearson coefficients. For Route 1, the coefficient indicated a moderate correlation between response times and distances, $r(5) = -.69$, $p = .09$. For Route 2, the correlation coefficient was significant, $r(5) = -.93$, $p < .01$. These findings show that the representation of a route containing a large number of landmarks preserves the metric qualities of the learned route. In contrast, the spatiotemporal information related to an environment with fewer landmarks seems to be less distinctly inscribed in the mental representation of a route.

The results of Task 4 add valuable information to those of Task 3, through demonstration that experiencing a rich environment not only increases the likelihood of better recognition of individual scenes, but also is beneficial to the encoding of their relative positions in a sequence of events.

4. CONCLUSIONS

The present study investigated the impact of environmental features, specifically visual landmarks, on memory for routes and communication about them. In view of the variety of forms of expression of spatial knowledge, it was considered important to investigate the role of landmarks not by studying a single form of space-related behavior, but by adopting a set of converging approaches involving a variety of behavioral measures. In addition, investigating empirically in real spatial environments demanding real navigation by participants was deemed to have particular ecological relevance.

The results showed that an environment's richness determines its memorability: There was better recall of richer environments than of those poor in salient visual features. This effect was independent of whether route recall was made verbally or as sketch maps. Furthermore, when an environment offers fewer opportunities to refer to visually remarkable buildings or urban objects/furniture, people tend to make more reference to the streets of the route. These findings extend previous studies assessing the commonality of the mechanisms underlying verbal and graphic recall of route directions (cf. Tversky & Lee, 1998, 1999).

Some specificities, however, remain. For example, the overall proportion of responses judged likely to assist navigation tends to be higher for verbal protocols than for sketch maps for both routes (Route 1, 50% vs. 31%; Route 2, 66% vs. 53%; overall, 58% vs. 42%). Lastly, when the constraints entailed by retrieval processes are removed, recognition scores confirm better memory of environments containing more landmarks. This effect is confirmed through recognition not only of individual items, but also of their sequential organization, an essential dimension of route memory (cf. Allen, 2000).

The data collected in this study confirm the role of landmarks in spatial memory, as objects likely to affect the construction of spatial representations, as well as communication about these representations (cf. Wegman & Janzen, 2011). What is actually relevant here is not so much the identities of the objects used as landmarks, but the fact that they signal *places* where specific *actions* have to be taken. They function as cues contributing to the segmentation of routes into distinctive portions and to the definition of what Allen (1997, 2000) called "delimiters," that is, statements that specify places or objects serving as points of origin or destinations.

Landmarks assist memory by freeing the navigating person from reasoning purely in terms of distances and reorientation angles. In addition to this key function in route directions, landmarks also provide confirmation of the details that are to appear along the route. They confer visibility to the critical points of space to be memorized in order that navigation be successful. In short, "landmarks help to organize space because they are reference points in the environment" (Sorrows & Hirtle, 1999, p. 40). Finally, and most importantly, landmarks may help to build an overall cognitive map of the environment navigated, thanks to the encoding of the relationships among paths making up a route and the surrounding objects (cf. Heth, Cornell, & Alberts, 1997). In this sense, landmarks are thought to contribute to the construction of *configural knowledge* of an environment.

The meaning of landmarks in various forms of space-related behavior has been indirectly confirmed by the impact of landmark agnosia on topographical orientation (Aguirre & D'Esposito, 1999; Takahashi & Kawamura, 2002). The investigation of the neural circuits involved in the encoding and retrieval of object locations also confirms that during navigation, memory for locations is mediated by memory for objects present in these locations (cf. Baumann, Chan, & Mattingley, 2010). Behavioral data and neurocognitive evidence aptly converge to support the claim of the functional role of landmarks in wayfinding, and the value of considering this process in the development of navigational systems inspired by our knowledge of human cognition.

ACKNOWLEDGMENTS

The authors are grateful to Susan Biggin for her invaluable help in the preparation of the manuscript, and to Dan Montello and three anonymous reviewers for providing valuable suggestions on an earlier version of this article.

FUNDING

This research was supported by a grant from the Agence Nationale de la Recherche to the SpaLife project (PI: Valérie Gyselinck).

REFERENCES

Aguirre, G. K., & D'Esposito, M. (1999). Topographical disorientation: A synthesis and taxonomy. *Brain*, *122*, 1613–1628.

Allen, G. L. (1997). From knowledge to words to wayfinding: Issues in the production and comprehension of route directions. In S. C. Hirtle & A. U. Frank (Eds.), *Spatial information theory: A theoretical basis for GIS (Proceedings of COSIT 1997)* (pp. 363–372). Berlin: Springer.

Allen, G. L. (2000). Principles and practices for communicating route knowledge. *Applied Cognitive Psychology*, *14*, 333–359.

Baumann, O., Chan, E., & Mattingley, J. B. (2010). Dissociable neural circuits for encoding and retrieval of object locations during active navigation in humans. *NeuroImage*, *49*, 2816–2825.

Byrne, R. W. (1979). Memory for urban geography. *Quarterly Journal of Experimental Psychology*, *31*, 147–154.

Daniel, M.-P., & Denis, M. (2004). The production of route directions: Investigating conditions that favour conciseness in spatial discourse. *Applied Cognitive Psychology*, *18*, 57–75.

Daniel, M.-P., Mores Dibo-Cohen, C., Carité, L., Boyer, P., & Denis, M. (2007). Dysfunctions of spatial cognition in schizophrenic patients. *Spatial Cognition and Computation*, *7*, 287–309.

Daniel, M.-P., Tom, A., Manghi, E., & Denis, M. (2003). Testing the value of route directions through navigational performance. *Spatial Cognition and Computation*, *3*, 269–289.

Dean, G. M., Dewhurst, S. A., Morris, P. E., & Whittaker, A. (2005). Selective interference with the use of visual images in the symbolic distance paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 1043–1068.

Denis, M. (1997). The description of routes: A cognitive approach to the production of spatial discourse. *Current Psychology of Cognition*, *16*, 409–458.

Denis, M. (2008). Assessing the symbolic distance effect in mental images constructed from verbal descriptions: A study of individual differences in the mental comparison of distances. *Acta Psychologica*, *127*, 197–210.

Denis, M., & Fernandez, G. (2013). The processing of landmarks in route directions. In T. Tenbrink, J. Wiener, & C. Claramunt (Eds.), *Representing space in cognition: Interrelations of behaviour, language, and formal models* (pp. 42–55). Oxford, UK: Oxford University Press.

Denis, M., Michon, P.-E., & Tom, A. (2006). Assisting pedestrian wayfinding in urban settings: Why references to landmarks are crucial in direction-giving. In G. L. Allen (Ed.), *Applied spatial cognition: From research to cognitive technology* (pp. 25–51). Mahwah, NJ: Erlbaum.

Denis, M., Pazzaglia, F., Cornoldi, C., & Bertolo, L. (1999). Spatial discourse and navigation: An analysis of route directions in the city of Venice. *Applied Cognitive Psychology*, *13*, 145–174.

Denis, M., Ricalens, K., Baudouin, V., & Nespoulous, J.-L. (2006). Deficits in the spatial discourse of Alzheimer patients. In M. Hickmann & S. Robert (Eds.), *Space in languages: Linguistic systems and cognitive categories* (pp. 335–349). Amsterdam: John Benjamins.

Dudchenko, P. A. (2010). *Why people get lost: The psychology and neuroscience of spatial cognition*. Oxford, UK: Oxford University Press.

Golding, J. M., Graesser, A. C., & Hauselt, J. (1996). The process of answering direction-giving questions when someone is lost on a university campus: The role of pragmatics. *Applied Cognitive Psychology*, *10*, 23–39.

Golledge, R. G. (1999). Human wayfinding and cognitive maps. In R. G. Golledge (Ed.), *Wayfinding behavior: Cognitive mapping and other spatial processes* (pp. 5–45). Baltimore, MD: Johns Hopkins University Press.

Gras, D., Gyselinck, V., Perrussel, M., Orriols, E., & Piolino, P. (2013). The role of working memory components and visuospatial abilities in route learning within a virtual environment. *Journal of Cognitive Psychology*, *25*, 38–50.

Heth, C. D., Cornell, E. H., & Alberts, D. M. (1997). Differential use of landmarks by 8- and 12-year-old children during route reversal navigation. *Journal of Environmental Psychology*, *17*, 199–213.

Hirtle, S. C. (2008). Landmarks for navigation in humans and robots. In M. E. Jefferies & W.-K. Yeap (Eds.), *Robotics and cognitive approaches to spatial mapping* (pp. 203–214). Berlin: Springer.

Janzen, G., & van Turennout, M. (2004). Selective neural representation of objects relevant for navigation. *Nature Neuroscience*, *7*, 673–677.

Janzen, G., Wagensveld, B., & van Turennout, M. (2007). Neural representation of navigational relevance is rapidly induced and long lasting. *Cerebral Cortex*, *17*, 975–981.

Klippel, A., & Winter, S. (2005). Structural salience of landmarks for route directions. In A. G. Cohn & D. M. Mark (Eds.), *Spatial information theory (Proceedings of COSIT 2005)* (pp. 347–362). Berlin: Springer.

Lovelace, K. L., Hegarty, M., & Montello, D. R. (1999). Elements of good route directions in familiar and unfamiliar environments. In C. Freksa & D. M. Mark (Eds.), *Spatial information theory: Cognitive and computational foundations of geographic information science (Proceedings of COSIT 1999)* (pp. 65–82). Berlin: Springer.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: The MIT Press.

Meilinger, T., Knauff, M., & Bülthoff, H. H. (2008). Working memory in wayfinding—A dual task experiment in a virtual city. *Cognitive Science*, *32*, 755–770.

Michon, P.-E., & Denis, M. (2001). When and why are visual landmarks used in giving directions? In D. R. Montello (Ed.), *Spatial information theory: Foundations of geographic information science (Proceedings of COSIT 2001)* (pp. 292–305). Berlin: Springer.

Montello, D. R., & Raubal, M. (2013). Functions and applications of spatial cognition. In D. Waller & L. Nadel (Eds.), *Handbook of spatial cognition* (pp. 249–264). Washington, DC: American Psychological Association.

Nothegger, C., Winter, S., & Raubal, M. (2004). Selection of salient features for route directions. *Spatial Cognition and Computation*, *4*, 113–136.

Picinali, L., Afonso, A., Denis, M., & Katz, B. F. G. (2014). Exploration of architectural spaces by blind people using auditory virtual reality for the construction of spatial knowledge. *International Journal of Human-Computer Studies*, *72*, 393–407.

Presson, C. C., & Montello, D. R. (1988). Points of reference in spatial cognition: Stalking the elusive landmark. *British Journal of Developmental Psychology*, *6*, 378–381.

Raubal, M., & Winter, S. (2002). Enriching wayfinding instructions with local landmarks. In M. J. Egenhofer & D. M. Mark (Eds.), *Geographic information science* (pp. 243–259). Berlin: Springer.

Schneider, L. F., & Taylor, H. A. (1999). How do you get there from here? Mental representations of route descriptions. *Applied Cognitive Psychology*, *13*, 415–441.

Sorrows, M. E., & Hirtle, S. C. (1999). The nature of landmarks for real and electronic spaces. In C. Freksa & D. M. Mark (Eds.), *Spatial information theory: Cognitive and computational foundations of geographic information science (Proceedings of COSIT 1999)* (pp. 37–50). Berlin: Springer.

Stankiewicz, B. J., & Kalia, A. A. (2007). Acquisition of structural versus object landmark knowledge. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 378–390.

Takahashi, N., & Kawamura, M. (2002). Pure topographical disorientation—The anatomical basis of landmark agnosia. *Cortex*, *38*, 717–725.

Thorndyke, P. W. (1981). Distance estimation from cognitive maps. *Cognitive Psychology*, *13*, 526–550.

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, *14*, 560–589.

Tom, A., & Denis, M. (2004). Language and spatial cognition: Comparing the roles of landmarks and street names in route instructions. *Applied Cognitive Psychology*, *18*, 1213–1230.

Tom, A. C., & Tversky, B. (2012). Remembering routes: Streets and landmarks. *Applied Cognitive Psychology*, *26*, 182–193.

Tversky, B. (2012). Telling tales, or journeys. In V. Gyselinck & F. Pazzaglia (Eds.), *From mental imagery to spatial cognition and language: Essays in honour of Michel Denis* (pp. 3–15). Hove, UK: Psychology Press.

Tversky, B., & Lee, P. U. (1998). How space structures language. In C. Freksa, C. Habel, & K. F. Wender (Eds.), *Spatial cognition: An interdisciplinary approach to representing and processing spatial knowledge* (pp. 157–175). Berlin: Springer.

Tversky, B., & Lee, P. U. (1999). Pictorial and verbal tools for conveying routes. In C. Freksa & D. M. Mark (Eds.), *Spatial information theory: Cognitive and computational foundations of geographic information science (Proceedings of COSIT 1999)* (pp. 51–64). Berlin: Springer.

Wang, L., Mou, W., & Sun, X. (2014). Development of landmark knowledge at decision points. *Spatial Cognition and Computation*, *14*, 1–17.

Wegman, J., & Janzen, G. (2011). Neural encoding of objects relevant for navigation and resting state correlations with navigational ability. *Journal of Cognitive Neuroscience*, *23*, 3841–3854.

Wiener, J. M., Büchner, S. J., & Hölscher, C. (2009). Taxonomy of human wayfinding tasks: A knowledge-based approach. *Spatial Cognition and Computation*, *9*, 152–165.

Winter, S. (2003). Route adaptive selection of salient features. In W. Kuhn, M. F. Worboys, & S. Timpf (Eds.), *Spatial information theory: Foundations of geographic information science (Proceedings of COSIT 2003)* (pp. 349–361). Berlin: Springer.