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The Role of Global and Local Landmarks in Virtual Environment Navigation

Abstract

In visual navigation, landmarks can be used in a number of different ways. In this paper, we investigate the role of global and local landmarks in virtual environment navigation. We performed an experiment in a virtual environment called "Hexatown," consisting of a regular hexagonal grid of streets and junctions. Each junction was identified by the presence of distinct local landmarks (buildings, phone box, and so on). Additionally, compass information or a global frame of reference was provided by global landmarks (hilltop, television tower, and city skyline). According to participants' movement decisions, egomotion was simulated, and displayed on a 180 deg. projection screen. Participants learned the route back and forth between two local landmarks. In the test phase, individual junctions were approached and the participant's movement decision was recorded. We performed two experiments involving landmark changes after learning. In the first, we used conflicting cues by transposing landmarks. In the second experiment, we reduced either local or global landmark information. Results show that both local and global landmarks are used in wayfinding decisions. However, different participants rely on different strategies. In the first experiment (cue conflict) for example, some of the participants used only local landmarks while others relied exclusively on global landmarks. Other participants used local landmarks at one location and global landmarks at the other. When removing one landmark type in the second experiment, the other type could be used by almost all participants, indicating that information about the neglected landmark type was present in memory.

1 Introduction

In visual navigation, landmarks can be used in a number of different ways. In this study we investigate two landmark functions called *local* and *global* in the sequel. Distant landmarks such as towers or mountain peaks are visible from a large area and can serve as global landmarks; they define world-centered directions or a global reference frame that does not change when the observer moves a small distance. Global landmarks therefore resemble a compass. This compass function may be considered a special case of a guidance in the sense of O'Keefe and Nadel (1978). In guidance, the observer moves in a way to keep landmark bearings constant or have them change in certain well-defined ways. Examples include the approach towards a landmark (beacon) or the approach of a location in open space characterized by a configuration of landmarks.

In contrast, local landmarks are visible only from a small distance. Navigation by local landmarks relies on a sequence of intermediate goals defined by these

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local landmarks. They are therefore linked to route navigation. In the sense of O'Keefe and Nadel (1978), local landmarks can be used either for guidance, that is, as reference points guiding the observer to the intermediate goal, or as pointers, directing the observer's way onwards from the intermediate goal. Direction (also called recognition-triggered response) is the crucial mechanism for the construction of higher-level memories of space, such as routes which may be modeled as chains of intermediate goals and directions, or cognitive maps which may be modeled as graphs of intermediate goals and directions (Kuipers, 1978; O'Keefe & Nadel, 1978; Schölkopf & Mallot, 1995; Trullier et al., 1997).

Landmark function (local or global) is not a unique property of a particular object but depends on how the navigator uses that object. In fact, one object serving as a global landmark in some phase of the navigation task may serve as a local landmark later. Generally, the issue of landmark function should not be confused with the question of how landmarks are found and defined in a scene. These two aspects—landmark definition and landmark function—are clearly represented in the definition given by Cohen & Schuepfer (1980), stating that "landmarks are unique visual configurations which are used as course-maintaining aids." In this paper, we focus on landmark function. By the design of the experimental environment, we sought to eliminate ambiguities in landmark definition.

From a number of previous studies, it is quite clear that route navigation based on local landmarks is a common strategy in human wayfinding (for example, Allen et al., 1979; Heft, 1979; Thorndyke & Hayes-Roth, 1982; Gale et al., 1990). However, many studies, especially those done in real environments, provide the participants with a wealth of additional navigation cues, including geographical slant, uncontrolled views to distant places, and, most notably, egomotion information that might be used to infer metric relations by way of path integration. Therefore, it is not always easy to decide which strategies have been used in any particular task. Aginsky et al., (1997), using virtual environments, separated local landmark usage from survey knowledge by exchanging individual landmarks in a route navigation task. They showed that some participants preferred a strategy based on local landmarks while others built a survey representation from the beginning, presumably by path integration. Also in virtual environments, Mallot and Gillner (in press) investigated a further distinction within local landmark usage. Intermediate goals may be defined by individual landmarks or by landmark configurations, that is, panoramic views. By exchanging landmarks both within and across places, Mallot and Gillner found that directions are associated to individual objects, not to places or panoramic views. In the present paper, we attempt to cross local and global landmark functions, excluding at the same time all other navigation aids.

We present two experiments addressing local and global landmark usage in a wayfinding task in a composed virtual environment.[1] Two classes of objects were designed in a way to ensure that each of them could be used as local or global landmark only. In the remainder of the paper, we call these classes local and global landmarks, according to the function they were designed for. Local landmarks were houses and other objects placed at street junctions; each of them was visible from one junction only. Global landmarks included a mountain peak, a distant city skyline, and a television tower on a distant mountain.

Two different paradigms were used in the experiments. In experiment I, a cue conflict was generated between local and global landmarks. In the training phase, a standard configuration of landmarks (both local and global) was learned. The relation of global and local landmarks could then be changed in the test phase of the experiment to generate a conflict. The tasks were designed such that the use of local and global landmarks in the conflict condition led to opposite predictions about the expected movement decisions. In experiment II, we used a conflict-free paradigm in which landmark information in the test phase was restricted to either the local or the global type. This was achieved without conspicuous changes in the environment by different simulated

1. Wayfinding tasks are sometimes referred to as "navigation in large scale environments" (for example, Kuipers 1978). However, the relevant distinction seems to be not between small and large scale, but between open and composed environments, that is, environments where the goal is visible from the start and those where the goal is visible from only one compartment. We use the term *wayfinding* to refer to navigation in composed environments (cf. Trullier et al., 1997).

lighting conditions. In a "night" condition, only the local landmarks were illuminated by a spotlight moving along with the observer. In a "dawn" condition, only the silhouette of a distant mountain range and skyline were visible by back illumination.

These controlled landmark manipulations and the controlled changes of lighting conditions would not be possible in real environments. Therefore, both experiments were carried out in a virtual environment (VE) using a 180 deg. projection screen (Veen et al., 1998). In fact, we think that creating inconsistent environments is among the key advantages of virtual environments technology for psychological research. In our experiments, sensory information was restricted to the visual modality; that is, no vestibular or proprioceptive information about body movements was present. This allows us to study visual landmark navigation in isolation. Furthermore, the movements of the observer are easily recorded in VE experiments.

In the remainder of this section, we give a brief overview of VE applications in psychological research. For a comprehensive review of the advantages and disadvantages of virtual environments for investigating human spatial cognition, see Péruch and Gaunet (1998).

Landmark navigation in composed environments has been studied—for example, by Tlauka and Wilson (1994), who showed that local landmarks can be used in a simulated indoor environment. Aginsky et al. (1997) manipulated landmarks in a route-learning task, in order to investigate the relation between route and map knowledge. The authors found evidence for each knowledge type in different individuals in the same group of participants. Elements of route and map knowledge have been shown to be present simultaneously in individual participants by Gillner and Mallot (1998). Participants who used stereotyped recognition-triggered responses (that is, a part of route memory) were at the same time able to draw survey maps of the explored environment. Brain activity related to landmark information obtained from virtual environments has been demonstrated by Maguire et al. (1998).

The transfer of knowledge obtained in a virtual environment to the real world has been studied, for example, by Witmer et al. (1996). These authors found that performance after training in a VE is comparable to the performance after training in the actual environment, if a sufficient degree of realism is provided. This finding was confirmed and extended by Waller et al. (1998) who even suggested that training in VEs can be superior to real-world training. Ruddle et al. (1997) replicated a real-world study on the estimation of distance and directions in indoor environments first carried out by Thorndyke and Hayes-Roth (1982). The results of the VE study were in good agreement with those obtained in real buildings. Similarly, Distler et al. (1998) found no significant difference for the accuracy of pointing to remembered targets in real and virtual environments.

In summary, virtual environments are a valuable tool for navigation experiments, both for consistent and inconsistent environments. In our experiments, the high degree of realism that seems to be important is provided by a high graphical resolution and, more essentially, by a large field of view (180 deg on a projection screen).

2 Experiment I: Landmark Transposition

2.1 Purpose

This study aims at examining the role of different types of landmarks in a route-finding task. Local landmarks can be used as intermediate goals, whereas global landmarks form a global system of reference and provide compass information.

Cue conflict was used to study various strategies that the participants could employ. For the test phase, we designed a navigation task in which the information offered by the local landmarks contradicted the information provided by global landmarks. For example, a decision in agreement with the local landmarks would be a right turn, whereas a decision in agreement with the global landmarks would be a left turn.

2.1.1 Hypotheses. We assume that humans use one of the navigation strategies summarized in Table 1. Participants might rely entirely on local landmarks (H_1) or entirely on global ones (H_2). Alternatively, they could use different strategies at different locations, tasks, or trials (H_3). Finally, they might use information from

Table 1. *Hypotheses and Expected Results in the Cue-Conflict Experiment*

Hypotheses	Expected results: Conflict recognized	Decisions
H_1 local strategy	no	according to local LM
H_2 global strategy	no	according to global LM
H_3 alternating strategies	no	some local and some global
H_4 combined strategy	yes	no unanimous decision possible

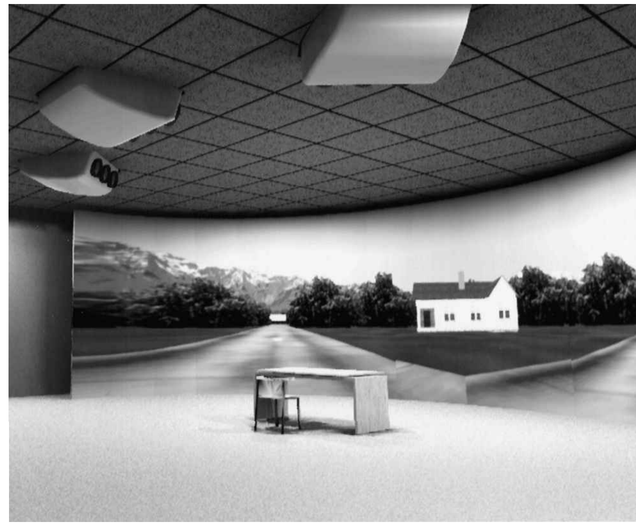

Figure 1. *Virtual environments lab with 180 deg. projection screen showing the Hexatown simulation. The participant is sitting in the center of the half cylinder. In front of the participant is a table with a mouse and a keyboard as input devices.*

both kinds of landmarks (H_4) in combination. In this case, we expect the conflict to be recognized. If no conflict is reported, this does not necessarily mean that no conflict was perceived nor that the conflict did not influence the decision. The data of participants who did report conflict were excluded from evaluation, because no unanimous decision can be expected if participants are aware of the conflicting landmark information.

2.2 Method

2.2.1 Participants. A total of 32 participants (18 male and 14 female, aged 15 to 31) took part in the experiment. Thirty of them were students. Participation in this experiment was voluntarily and a honorarium was payed for participation.

2.2.2 Virtual Environment

Visualization. The experiment was performed on a high-end graphics computer (Silicon Graphics, Inc., ONYX2 3-pipe Infinite Reality), running a C-Performer application that we designed and programmed. The simulation was displayed nonstereoscopically, with an update rate of 36 Hz, on a half-cylindric (7 m diameter and 3.15 m height) projection screen (Figure 1). The computer rendered three 1280 × 1024-pixel color images projected side by side with a small overlap. Images were corrected for the curved surface by the projectors to form a 3500 × 1000-pixel display. For an observer seated in the center of the cylinder (eye height 1.25 m), this display covered a field of view of 180 deg. horizontally by 50 deg. vertically. The field of view of the observer was identical to the field of view used for the image calculations. A detailed description of the setup can be found in Veen et al. (1998).

In pilot experiments using a desktop virtual environment (21 in. monitor, 60 deg. field of view (Geiger et al., 1997), we found that global landmarks are only rarely used. In order to provide a global reference frame for all viewing directions with a field of view of just 60 deg., six landmarks had to be used, and these landmarks were sometimes confused by the participants. With a larger field of view, it is sufficient to use only three conspicuous and clearly recognized global landmarks, one of which would always be visible.

Scenery. The model of the environment was generated using MultiGen 3-D modeling software. The environment consists of an octagonal ground plane surrounded by a flat background showing irregular mountain ranges and a city skyline. The mountain peak,

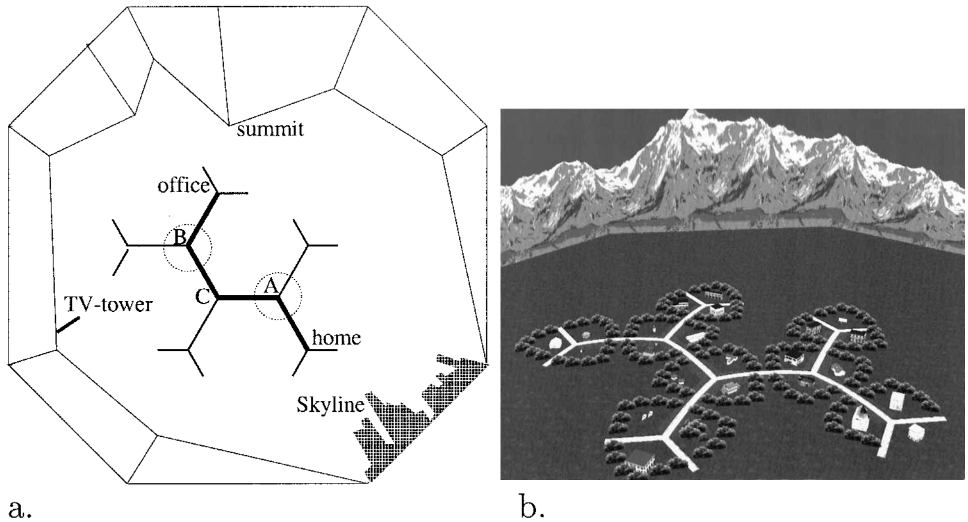

Figure 2. *a. Street map of Hexatown. "Home" and "office" are the two goals. The surrounding mountains and the skyline are shown by projecting them down into the ground floor. b. Aerial view of Hexatown with orientation as in 2a.*

television tower, and city skyline are global landmarks. The buildings were constructed using Medit 3-D modeling software. A schematic map of the town is shown in Figure 2a. (This aerial view was never shown to the participants.) The virtual environment (called "Hexatown," (Gillner & Mallot, 1998) consists of a hexagonal raster of streets with a distance of 100 m between adjacent junctions. A junction is built of three adjoining streets forming 120 deg. corners. In each corner, an object (building, gas station, and so on) is placed. See Figure 2b. At the periphery of Hexatown, streets end blindly, and these dead ends are marked by barriers 50 m from the junction. A circular hedge or row of trees is placed around each junction with an opening for each of the three streets (or dead ends) connected to that junction. This hedge looks the same for all junctions and prevents participants from seeing the objects at distant junctions. Each street connecting two junctions passes across a little hillock (4 m high), such that viewing neighboring places is prevented. Due to the hedges and hillocks, each object is visible only from its corresponding junction. Thus, by the design of the environment, the objects at the junctions are strictly local landmarks.

The usage of geometrical cues, as demonstrated by Hermer and Spelke (1994), is not possible in Hexatown. All junctions are identical and symmetrical, so that, when approaching a junction, one cannot infer the approach direction nor the approached place from the geometrical layout. Rectangular city rasters are also symmetrical but have the disadvantage that the straight-on direction is preferred. The type of symmetrical junctions we used are triangular Y-junctions with the streets forming 120 deg. angles. This leads to balanced, binary movement decisions much as in a two-alternative, forced-choice paradigm. This feature was essential in the conflict condition of the experiment.

In the conflict condition, we introduced a cue conflict by rigidly rotating the array of the three local landmarks around the center of their junction either clockwise or counterclockwise by 120 deg. The global landmarks were left unchanged. Because each test involved just one movement decision at one junction, it would be equivalent to rotate the global landmarks in the reverse direction, this time leaving the local landmarks unchanged. After transposition, the movement decisions in agreement with the local landmarks contradict those suggested by the global landmarks. For instance, local landmarks might suggest a turn to the left and global landmarks a turn to the right.

In the experiment, participants had to learn the route

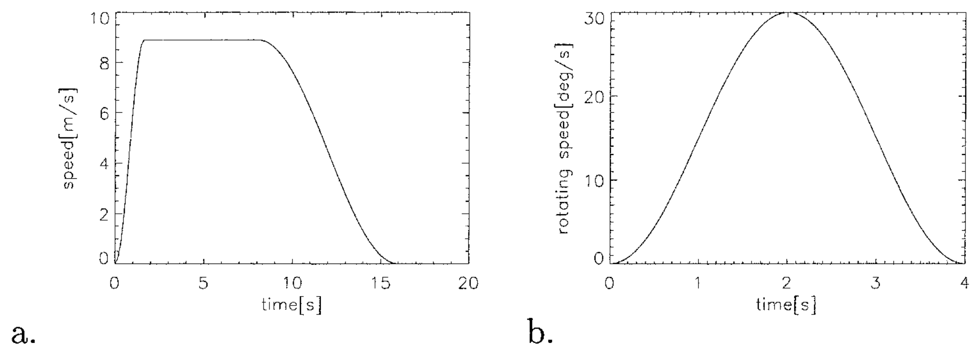

Figure 3. *Velocity profiles of the simulated self-motion: a. translation, and b. rotation.*

connecting two goals ("home" and "office"). From now on, we will refer to the route between home and office as the "main route" (shown as a bold line in Figure 2a). The roads leading to the main route will be called "side streets." Note that all roads in the actual Hexatown environment have the same width (6.5 m).

Interaction. Participants could navigate through Hexatown using three mouse buttons. They were allowed to move along the streets and to make turns at the junctions. The translation movement was initiated by clicking the middle mouse button and was then carried out with a predefined velocity profile (Figure 3a), without further possibilities for the participant to interact. The translation between two adjacent junctions took 16 sec. with a fast acceleration to the maximum speed of 9 m per second and a slow deceleration. The translation movement ended at the next junction, in front of the object facing the incoming street. At the junctions, 60 deg. turns could be performed by clicking the left or right mouse button. The simulated turn movement was ballistic, following a predefined velocity profile (Figure 3b).

Turns took 4 sec., with a maximum speed of 30 deg. per second and symmetric acceleration and deceleration phases. The smooth profiles for translation and rotation were chosen to prevent participants from getting simulator sick. Other, more realistic motion models might distract participants from the navigation task and were therefore not employed in our study.

2.2.3 Procedure. Participants were run through the experiment individually. The experiment had three different phases: two training phases and a test phase. In the first training phase, the participants' task was to learn the way back and forth between the home and the office (Figure 2a) until they completed this route without mistake. In the second training phase, they had to find a goal (home or office) from different starting points. In the test phase, participants were asked to indicate the first turn decision required to go from their current release point to the goal. Before each trial, a full 180 deg. panoramic view at the goal location was shown. By pressing the space bar of a computer keyboard, the goal presentation was terminated, and participants were positioned at the current starting position. During the entire experiment, the participants could display a small picture of the current goal object on a gray background in the bottom-left corner of the middle screen by pressing a special button.

Training phase I. Participants explored Hexatown to find the office. At the start of the experiment, participants found themselves in front of the home building, which appeared in their central field of view. When they reached their goal, a message was displayed, indicating whether they used the shortest path (with the least number of motion decisions). From the office, they had to find the shortest way back to the home, and so forth. When they reached location C (Figure 2a) for the first time after completing a one-way trip

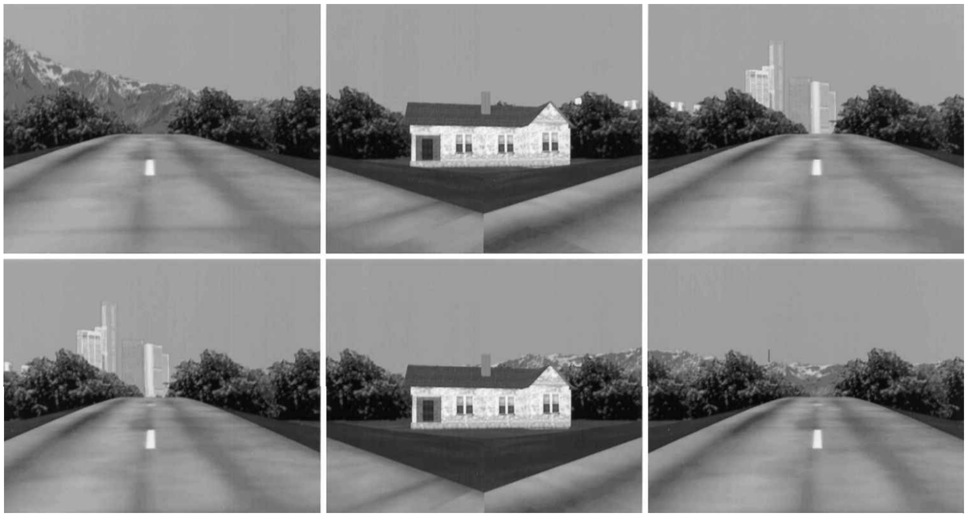

Figure 4. *Transposition condition in Experiment I. Each row shows the three pictures projected on the 180 deg. screen. The images are projected with a small overlap, resulting in the apparent discontinuities in this figure.* Top row: *Learning and control condition, no conflict: local (house) and global landmarks (skyline) are in standard combination.* Bottom row: *Conflict condition, local and global landmarks contradict.*

without mistakes, they had to perform an orientation task once. The training was finished when they could go back and forth between home and office without mistakes.

Orientation Task. The orientation task was included to make sure that the participant did take notice of both types of landmark. At location C (Figure 2a), participants were asked to orient themselves towards one of four landmarks by continuously turning the simulated environment. A fixed pointer superimposed on the turning image was used to mark the forward direction to which the goal had to be aligned. Participants had to do this task for two local landmarks (home and office) and for two global landmarks (skyline (see Figure 4) and the TV tower).

Training Phase II. The training phase II served as a preparation for the test task. Participants were transported to one of two locations (A and B in Figure 2a) and had to find the goal (home or office) that had been presented previously as a panoramic view. By choosing different starting positions, we ensured that participants could not use path integration or strategies like memorizing decision sequences (for example, left, right, right). Further, we started the transportation between two places, so that the participant could see only the place where the decision had to be made.

Participants had to perform this task eight times with different conditions. We used two approach directions from the main route and from a side street. In the main-route condition, participants approached the decision point along the main route (connection between home and office). In the side-street condition, participants were transported from a sideway street to A or B. We varied starting location, goal, and approach direction, leading to a total of eight tasks (Table 2, upper part). The sequence of tasks was 3, 6, 4, 5, 8, 1, 7, and 2. During the fourth task (task number 5), participants were asked to do the orientation task at junction C as described above.

Test Phase. We used two transposition conditions in the test phase. A control condition without transpositions was used for measuring participants performance. In the control condition, the landmark configuration was the same as in the training phase. A conflict condition was used to find preferred strategies. Conflict was produced by the transposition of objects such that the global and local landmarks predicted different movement decisions (bottom row of Figure 4).

Table II. *Different Conditions for the Test Phase (Upper and Lower Part) and Training II (upper part). The Transposition Condition (Control and Conflict) Was Varied Only in the Test Phase. ("L": Left Turn, "R": Right Turn)*

Task number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Location	A	A	A	A	B	B	B	B	A	A	A	A	B	B	B	B
Goal	home	home	office	office	home	home	office	office	home	home	office	office	home	home	office	office
Approach	main	side	main	side	main	side	main	side	main	side	main	side	main	side	main	side
Transposition	control	control	control	control	control	control	control	control	conflict	conflict	conflict	conflict	conflict	conflict	conflict	conflict
Expected results according to																
Local LM	R	L	L	R	L	R	R	L	R	L	L	R	L	R	R	L
Global LM	R	L	L	R	L	R	R	L	L	R	R	L	R	L	L	R

The test phase consisted of sixteen trials as listed in Table 2 (both parts). In each trial, the participants were transported to a junction where they had to make a turning decision. Their decision was recorded, and the trial was terminated to avoid feedback.

The group of participants was divided into two subgroups for which the sequence of tasks was reversed. The sequence of task numbers for the first subgroup was 5, 12, 13, 7, 14, 4, 1, 16, 2, 3, 9, 8, 6, 11, 10, and 15 (Table 2).

For each participant, the training and the test phases took a total of approximately one hour. After the behavioral task, participants had to fill out a questionnaire on the navigation strategies they used and anything they might have noticed during the experiment. The transposition was not explicitly mentioned in the questionnaire.

2.3 Results

2.3.1 Performance in control condition. The performance of the participants was very good. In the control condition, the performance of 30 out of 32 participants was significantly above chance level (7 or 8 correct decisions in a total of 8, $p < 0.04^*$).

2.3.2 Recognition of conflict. Twelve out of 32 participants (37.5%) reported a conflict in the test phase. Most of those participants who did not report conflict were quite astonished when being told about the conflict after the experiment. This indicates that they indeed did not notice any conflict. In the control condition, there was no significant difference in the performance between participants who reported conflict and those who did not. This was shown with a five-way analysis of variance (ANOVA, 2 conflict reported, Y/N $\times$ 2 sequences $\times$ 2 goals $\times$ 2 locations $\times$ 2 approach directions) of the correct decisions in the control condition ($F(1, 28) = 2.06$; $p = 0.163$).

Further analysis of the data was restricted to the twenty participants who did not report the conflict. The instruction becomes meaningless for those participants who recognized the conflict. These participants could not give a reasonable answer based on the perceived scene information.

2.3.3 Comparison of control and conflict conditions. From the test phase, we got two types of behavioral answers. In the control condition, the performance of the participants was measured (dependent variable = error rate), whereas, in the conflict condition, the preferred landmark type was assessed.

The results from both conditions (control and conflict) are summarized in Figure 5. In the conflict condition, about half of the decisions is in accordance with either landmark type. If participants would rely exclusively on local landmarks (hypothesis H1 in Table 1), the performance in the control condition (94% correct) would be due to this landmark type, and we would expect the same number of decisions following local landmarks in the conflict condition. This is clearly not the

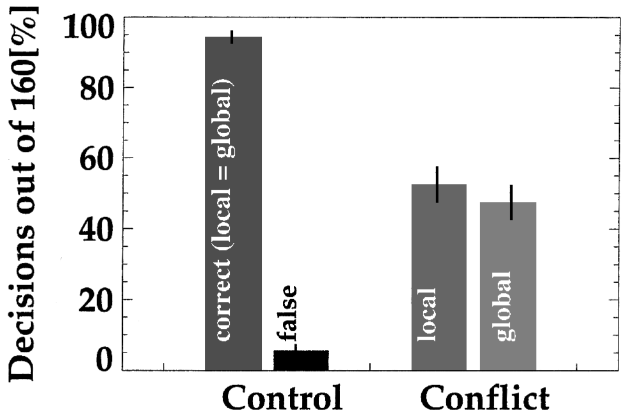

Figure 5. *Results of Experiment I, averaged over the participants not recognizing the conflict (N = 20).* Left part: *control condition showing participants' performance.* Right part: *conflict condition. The third column shows decisions in agreement with the local landmarks and the fourth column those in agreement with the global ones. Error bars represent one standard error of the mean.*

case ($\chi^2 = 528.5$, $df = 1$, $p < 0.0005^{***}$). Conversely, if the performance in the control condition would be due to global landmark usage (hypothesis H2 in Table 1), we expect to see this preference for this landmark type in the conflict as well. Again, this is not the case ($\chi^2 = 662.3$, $df = 1$, $p < 0.0005^{***}$). We can thus conclude that both landmark types have been used.

2.3.4 Strategies. The results in the conflict condition (Figure 5) are not due to random decisions, as can be seen when breaking down the data with respect to goal, location, or participant. Figure 6 shows the use of different landmark types for different goals and at different locations. For the "home" goal, 60.0 ± 5.5% of the movement decisions were in agreement with the global landmarks, and, for the "office" goal, 65.0 ± 5.4% of the decisions were based on local landmarks. Similarly, 66.3 ± 5.3% of the decisions at location A were in agreement with global landmarks; at location B, 71.3 ± 5.1% were in agreement with local landmarks. This indicates that different strategies are used at different locations (Figure 6b) or when pursuing different goals (Figure 6a). We performed a five-way analysis of variance (ANOVA, 2 gender × 2 sequences × 2 goals × 2 locations × 2 approach directions) of the decisions in agreement with the global landmarks. The results (summarized in Table 3) show highly significant main effects in the factors goal and location. No effect of gender on landmark preference was found.

Breaking down the data from the conflict condition with respect to individual participants, we find a bimodal distribution; that is, some participants prefer local landmarks, some prefer global landmarks, and only a few participants make alternating use of both types. The distribution is significantly different from chance (χ^2, $p < 0.01^{**}$).

These effects can also be illustrated by data from individual participants. Table 4 shows the performances of those participants who showed a strategy that was significantly different from chance ($p < 0.04^{*}$). The first group of participants in the table relied on the local landmarks throughout. Participants of the second group used the global landmarks at location A and the local landmarks at location B, and participants of the third group preferred global information.

2.4 Discussion

The main results of Experiment I is that both types of landmarks are used in the decision task and that different participants used different strategies for their navigation decisions. Some participants always preferred local landmarks, others used only the global landmarks, and some alternated between global landmarks at location A and local landmarks at location B.

The same results have been found when generalizing across participants. A significant difference between the landmarks used for decisions made at location A and location B was found. Participants seem to prefer decisions in agreement with local landmarks at location B and global ones at location A. The preference for local landmarks at location B could be explained by the fact that those landmarks are more salient. The landmarks at location B—a gas station and a tower—differ from "normal buildings" such as houses, and thus may be more readily memorized. Moreover, at location B, the city skyline is partly occluded by trees and hence more difficult to use. The local landmarks at location A are three inconspicuous buildings, such as the one shown in Figure 4. This could lead to a preference for decisions in agreement with the global landmarks.

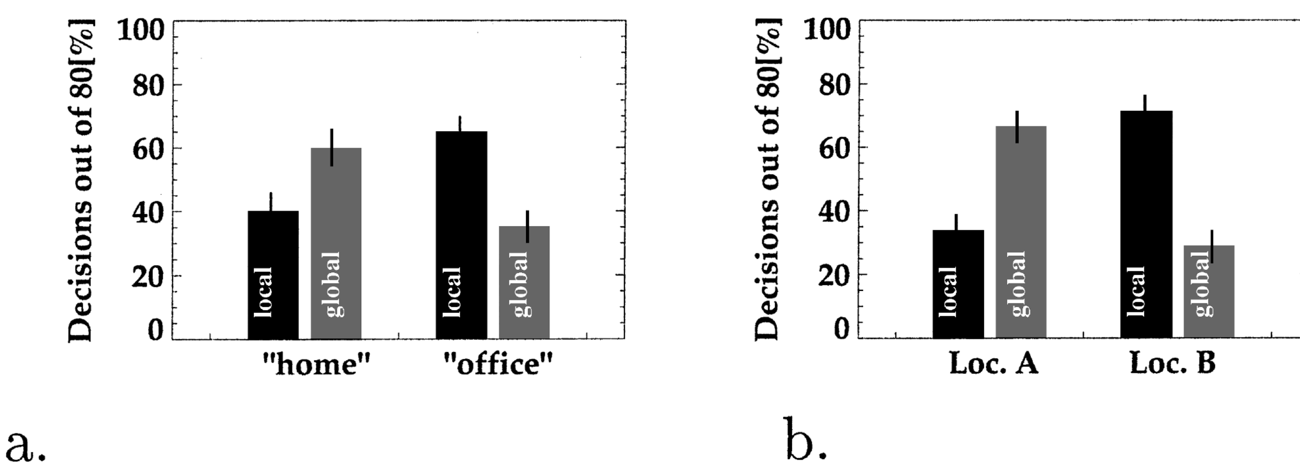

Figure 6. *a.) Decisions in the conflict condition broken down by goal. b.) Broken down by location (Loc.).*

Table III. *Factors Affecting the Use of Global Versus Local Landmarks in the Conflict Condition of Experiment I*

Main effects within subjects			Main effects between subjects	
Location	Goal	Approach direction	Sequence	Gender
$F(1, 16) = 19.6$ $p < 10^{-3}$ ***	$F(1, 16) = 21.1$ $p < 10^{-3}$ ***	$F(1, 16) = 3.56$ $p = 0.078$	$F(1, 16) = 8.048$ $p = 0.012$*	$F(1, 16) = 0.762$ $p = 0.396$

Main effects of five-way analysis of variance (ANOVA, 2 gender × 2 sequences × 2 goals × 2 locations × 2 approaches) of the decisions in agreement with the global landmarks in the conflict condition.

We found that the goal affects the type of landmarks used to make the navigation decisions (as shown in Figure 6). This could be explained by the constellation of landmarks. The participants associate the home target with the skyline of a distant city, whereas, for the office goal, there is no such salient global landmark. This could explain the preference for local landmarks when making decisions regarding the office navigation task, and the preference for global landmarks for the home goal.

Another interesting result is that more than half of the participants did not report any conflict. This implies that they did not consciously combine information about local landmarks with information about the global ones. This is reminiscent of the failure to recognize changes in scenes which has been called "change blindness." (For review, see Simons and Levin (1997).) However, in those experiments, the changes occurred in one scene in consecutive instants, whereas, in our experiments, the changes occurred between the current scene and a scene encountered several minutes ago. This scene is presumably represented in a long-term spatial memory, which makes our effect different from standard change blindness in which working memory is affected.

The sequence of tasks did not show any effect within the control trials ($F(28, 1) = 0.071, p = 0.793$). In contrast, a weakly significant effect of sequence was found in the conflict condition (Table 3). The use of strategies seems to be affected not only by the goal and the location but also by participants' experience, that is, the sequence of tasks.

We did not find any gender effects, contrary to the results of Waller et al. (1998). These authors found per-

Table IV. *Performance of Individual Participants Showing Clear Strategies in the Conflict Condition*

	Control		Conflict decisions in agreement with			
			Local LM	Global LM	Local LM	Global LM
Subjects	Correct	False	Place A		Place B	
mia	8	0	4	0	4	0
nah	8	0	4	0	4	0
wij	8	0	4	0	4	0
hia	8	0	3	1	4	0
mes	8	0	3	1	4	0
sts	7	1	0	4	4	0
wol	8	0	0	4	4	0
grf	8	0	0	4	1	3
scs	8	0	0	4	1	3

Upper part: preference for local landmarks. Middle part: alternating strategies used at different locations. Lower part: preference for global landmarks.

formance differences between men and women when navigating in virtual environments, but not in a real-world condition. Waller et al. themselves ascribe their gender effect to a confoundation with familiarity with computer-simulated environments. In our experiment, the interface was very simple—just the computer mouse—which might explain the missing gender effect. Also, the study areas of our student participants were about equally distributed among men and women.

The usage of different strategies for the navigation task leads to the question whether landmark information not used during the task is still stored in memory. We performed a second experiment to examine this issue as will be described in the following section.

3 Experiment II: Navigation Using Partial Information

3.1 Purpose

We wanted to study whether landmark information that was not used in the conflict condition of the first experiment was still stored in memory. We designed a second experiment in which only part of the landmark information was available in the test phase, that is, either the local or the global landmarks were removed.

3.2 Method

3.2.1 Participants. A total of 36 participants (18 male and 18 female, aged 15 to 31) took part in the experiment. All but three of them were students. Twenty of these participants were the participants who did not report the conflict in the first experiment. The other sixteen were naive participants who had no prior experience with Hexatown. The participation in this experiment was voluntary, and a honorarium was payed.

3.2.2 Virtual Environment. The experiment was performed using the same hardware, software, and mouse interface as in the first experiment. We also used the same scenery as in the first experiment but with different lighting conditions (Figure 7): A "control" lighting condition, which was identical to the training phase,

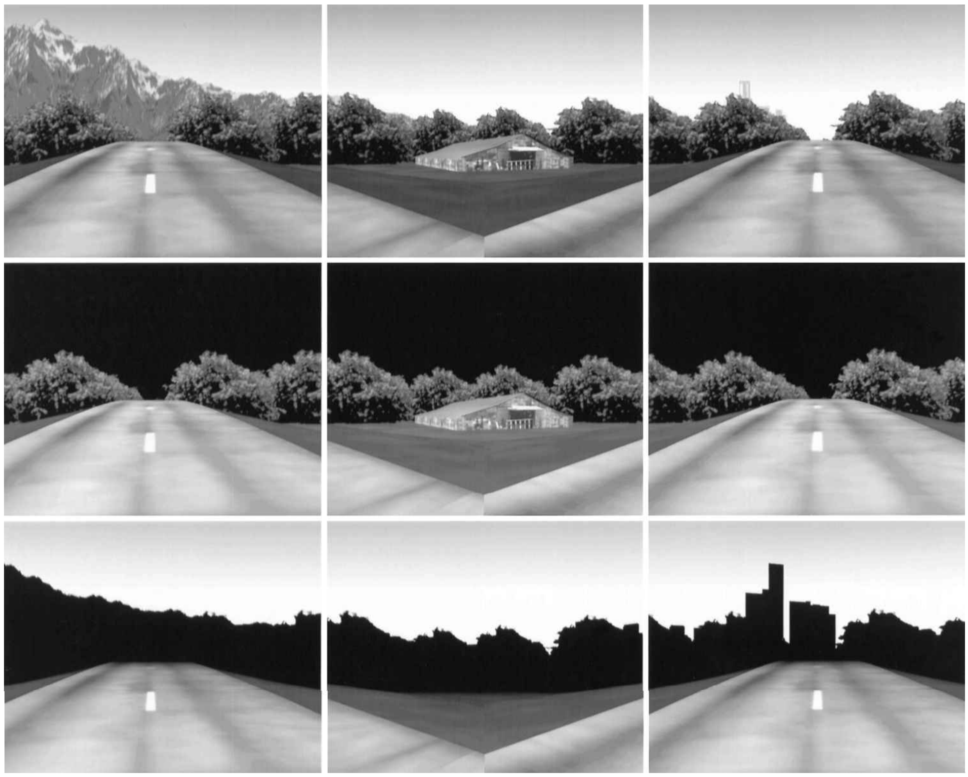

Figure 7. *Experiment II: lighting conditions.* Top: *daylight (control condition); global and local landmarks are visible.* Middle: *night; local landmarks only.* Bottom: *dawn; silhouettes of global landmarks only (no textures).*

included local and global information. A "night" lighting condition created the effect of driving with a spotlight by night; here only local information was available. Finally, in the "dawn" lighting condition, only global information was visible. Global landmarks (the mountain range, the city skyline, and the TV tower) appeared as silhouettes. In the dawn condition, we removed the local landmarks completely, which lead to minor changes of the silhouette.

3.2.3 Procedure. Participants were tested individually. Like the first experiment, experiment II had three different phases: two training phases, and a test phase. The participants' task was to learn the route between home and office (Figure 2a). The training phases were the same as in experiment I. The task in the test phase was also the same: the participants were transported to one of the decision points (A or B), where they had to make a turning decision. Their decision was recorded, and the trial was terminated. The difference between the two experiments lies in the stimulus conditions. In this experiment, we had no transposition conditions (conflict or control) but three lighting conditions: day, night and dawn (Figure 7). The group of participants was divided into two subgroups for which the sequence of trials was reversed.

Participants who had previously taken part in experiment I completed the training and test phases in approximately forty minutes, whereas it took the naive participants approximately one hour for the same task.

3.3 Results

We measured the participants' performance by the percentage of correct turning decisions in the test phase. Again, the performance of the participants was very good. Averaged over all participants and all lighting conditions, 90.2% correct decisions were found.

Table 5 shows a seven-way analysis of variance (ANOVA, 2 gender × 2 sequences × 2 familiarity × 2 goals × 2 locations × 2 approach directions × 3 light-

Table V. *Main Effects of Seven-Way Analysis of Variance (ANOVA, 2 Gender × 2 Sequences × 2 Familiarity × 2 Goals × 2 Locations × 2 Approach Directions × 3 Lighting) of Correct Decisions*

Main effects within subjects				Main effects between subjects		
Location	Goal	Approaching	Lighting	Sequence	Gender	Familiarity
$F(1, 28) = 7.99$ $p = 0.009$**	$F(1, 28) = 10.5$ $p = 0.003$**	$F(1, 28) = 2.51$ $p = 0.124$	$F(1, 28) = 8.81$ $p < 10^{-3}$ ***	$F(1, 28) = 9.04$ $p = 0.006$**	$F(1, 28) = 1.50$ $p = 0.231$	$F(1, 28) = 1.95$ $p = 0.174$

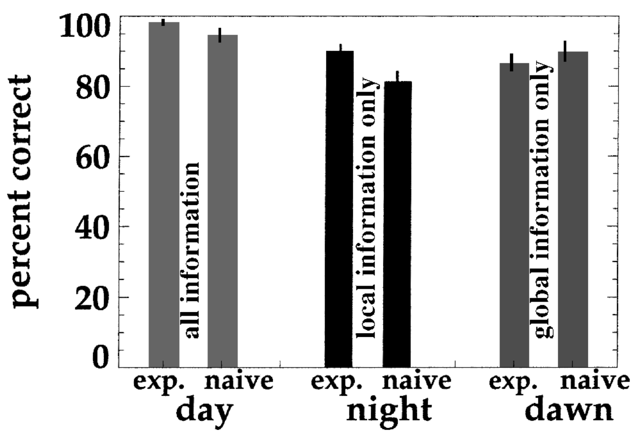

Figure 8. *Results of experiment II. Correct decisions over lighting conditions (left columns: experienced participants (N = 20), right columns naive participants (N = 16)).*

ing) of correct versus false decisions. We find significant main effects in the location, goal, lighting, and sequence conditions. (The difference between the lighting conditions can be seen quantitatively in Figure 8.) The rate of correct decisions averaged over all participants was $96.5 \pm 1.9\%$ for the day condition (all information), $86.1 \pm 2.0\%$ for the night condition (local information only), and $87.9 \pm 1.9\%$ for the dawn condition (global information only). This means that, in the conditions with reduced information, performance is slightly decreased. Although the ANOVA shows that this decrease is significant, the overall performance is still very good. This performance is not due to the increased familiarity of the participants who did both experiments, as can be seen from the missing main effect of familiarity in the ANOVA.

3.4 Discussion

The primary objective of this experiment was to determine whether participants, who prefer either one or the other type of landmark in the conflict experiment, also have knowledge about the other type of landmark, which was not preferred. Although there is a highly significant difference between the three lighting conditions, the overall performance even with reduced information was still very good. This could be a result of the repeated training in the experienced group, so we examined a second group of participants who had no prior knowledge about the city. There was no difference between these two groups.

The results of experiment II show that participants have access to both types of landmark information. This result holds also for individual participants who consistently decided in accordance with one landmark type in experiment I. The presence of conflicting information did not lead to the perception of a conflict by most of the participants.

The discussion of experiment I applies for the other main effects of location, goal, and sequence.

4 General Discussion and Conclusion

From the data presented in this paper, three major conclusions can be drawn:

1. **Strategies:** Both local and global landmarks are used in the decisions for the wayfinding task. However, instead of making equal use of both landmark types, different participants rely on different strate-

gies. Some of the participants used only local landmarks for decisions, others used only global landmarks, and still other participants used local landmarks at one location and global landmarks at the other location. Aginsky et al. (1997) also found different strategies in navigators who learned a route up to a given competence level. Rather than finding a distinction between local and global strategies, they found a difference between a more "visually" dominated and a more "spatially" dominated strategy.

2. **Memory content:** In the second experiment, landmark information was reduced by removing global or local landmarks in the test phase. Even though some participants used just one type of landmark in the conflict experiment, they were able to perform both single landmark tasks in experiment II. The good performance with either type of landmark alone shows that both types of landmark information have been stored in memory.
3. **Dissociation between conflict perception and landmark usage:** The knowledge of the neglected landmark type affects behavior in experiment II, but not in experiment I. Even though both types of landmark are stored in memory, the conflict was not consciously perceived by the participants who took part in both experiments. Note, however, that we did also find a significant number of participants who did report conflict.

How do participants select a landmark for a certain decision? One factor influencing this selection is landmark salience. For example, the local strategy was preferred at the gas station, which is easily distinguished from the other local landmarks used in our study. Vice versa, the global strategy is preferred at location A where the local information was provided by three residential buildings with no particular salience. Another factor influencing landmark selection seems to be a preference for one or the other landmark function. For example, five participants showed a clear local strategy, and two participants a clear global strategy.

In our experiments, the participants showed not only pure route knowledge (procedural knowledge), but also map-like knowledge. Pure route knowledge is information about the sequence of actions required to follow a particular route (to find a certain goal). Route knowledge is built by concatenating isolated bits of knowledge into chains. In contrast, map-like knowledge is more than just a sequence of actions required to follow a particular route. Rather, at a certain decision point, one needs to know which action will lead to one goal and which action to another goal. For a discussion of route and map knowledge, see O'Keefe and Nadel (1978). In the side-street approach, the participants had to make a movement decision that would lead them either towards home or towards office, depending on instruction. The participants were able to learn this side-street approach, and we found no difference between the main-route approach and the side-street approach in the test phase of the two experiments. Both findings indicate that more than route knowledge was present, i.e., map-like knowledge was present.

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