Max–Planck–Institut
für biologische Kybernetik
Spemannstraße 38 • 72076 Tübingen • Germany

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The Role of Global and Local Landmarks in Virtual Environment Navigation

Sibylle D. Steck[1] & Hanspeter A. Mallot[2]

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[1] AG Bülthoff, E–mail: Sibylle.Steck@tuebingen.mpg.de
[2] AG Bülthoff, E–mail: Hanspeter.Mallot@tuebingen.mpg.de

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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". Hexatown consists of a regular hexagonal grid of junctions joined together by streets. At each junction there are three buildings, or other objects. Additionally, we provide global direction or compass information by three distant "global landmarks" (a hilltop and a television tower at a mountain range, and a skyline of a distant city). Participants navigated in Hexatown by pressing the buttons of a computer mouse. According to their movement decisions, egomotion was simulated. Participants had to learn the route back and forth between two specific buildings. In the test-phase individual junctions were approached and the participants' movement decision was recorded. We performed two experiments with the same task but different paradigms. In the first experiment we used conflicting cues by transposing one landmark type after learning. In the second experiment we reduced either the local or the global landmark information after training. Results show that both local and global landmarks are used in the decisions for the way-finding task. Different participants rely on different strategies to make navigation decisions. In the first experiment (cue conflict), some of the participants used only local landmarks while others relied exclusively on global landmarks. Still other participants used local landmarks at one location and global landmarks at the other location. When removing one landmark type in the second experiment, the other type could be used by almost all participants.

1 Introduction

In visual navigation, landmarks can be used in a number of different ways. Distant landmarks visible from a large area ("global landmarks") define world–centered directions that do not change with small movements of the observer. A distant mountain, for instance, can be used to travel a straight line, e.g., following the instruction "keep the mountain to your right". Global landmarks therefore resemble a compass. In contrast, "local landmarks" are visible only from a small distance.

An alternative classification of landmarks follows their respective functions (see O'Keefe and Nadel, 1978; Trullier, Wiener, Berthoz, and Meyer, 1997). In *guidance*, movements of the observer keep landmark bearings constant or have them change in certain ways. Examples include the approach of a landmark (beacon) or the approach of a location in open space characterized by a configuration of landmarks. In *direction* or *recognition–triggered response*, a landmark is recognized and an associated movement direction is retrieved from memory. If responses are triggered by the recognition of places (Poucet, 1993), independent information about the observer's body orientation is required in order to specify the next movement direction. This is due to the fact that the recognition of places is, by definition, independent of the observer's orientation or viewing direction. Thus, the observer could remember instructions such as "walk north (or towards the distant mountain) when arriving at Central Square". If, however, movement is triggered by the recognition of views rather than places ("view–recognition–triggered response"), no additional compass information is required. Movements can be specified with respect to the current observer orientation, which is implied by the recognized view. In this case, the observer remembers something like "go left when facing city hall". In honey–bees, Collett and Baron (1995) have shown that movement decisions can be triggered by recognition of particular views. Associations of views and movements are also the basic element of the view–graph theory of spatial memory presented by Schölkopf and Mallot (1995). Gillner and Mallot (1998) presented evidence for recognition triggered responses in humans exploring a virtual environment.

One way to address the question of view–triggered vs. place–triggered responses is to look for the additional compass information that would be required in place–based schemes, but not in view–based schemes. Put differently, view–based schemes predict that global landmarks should be of minor relevance for maze navigation whereas in place–based schemes, one would expect global landmarks to play a crucial role as a compass. In this paper we present two experiments addressing the role of local and global landmarks in a way–finding task in a virtual maze–like environment.[1]

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 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 where 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 lighting conditions. E.g., 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.

Both experiments were carried out in a virtual environment (VE) using a 180° projection screen (Veen, Distler, Braun, and Bülthoff 1998). The main reason for using this technology is the high level of control of all experimental parameters. In particular the exchange or manipulation of landmarks and lighting conditions would hardly be possible in field studies. Furthermore, the movements of the observer are easily recorded in VE–experiments. In our experiments, sensory information was restricted to the visual modality; i.e., no vestibular or proprioceptive information about body movements were presented. This allows to study landmark navigation in isolation. For a review of advantages and drawbacks of virtual environments for investigating human spatial cognition, see Péruch and Gaunet (1998). Landmark navigation in composed environments has been studied e.g., by Tlauka and Wilson (1994), who showed that local landmarks can be used in a simulated indoor environment. Aginsky, Harris, Rensink, and Beusmans (1997) manipulated landmarks in a route learning task, in order to investigate the relation between route and map knowledge. The authors found examples of each knowledge type within different participants in the same experimental group. Elements of route and map knowledge have been shown to be present in individual participants by Gillner and Mallot (1998). Participants who used stereotyped recognition–triggered responses (i.e., a part of route memory) were at the same time able to draw survey maps of the explored environ-

[1] Way–finding tasks are sometimes referred to as "navigation in large scale environments" (e.g., Kuipers, 1978). However, the relevant distinction seems to be not between small and large scale, but between open and composed environments, i.e., environments where the goal is visible from the start and those where the goal is visible only from one compartment. We use the term way–finding to refer to navigation in composed environments (cf. Trullier et al. 1997).

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	–

Table 1: Hypotheses and expected results in the cue conflict experiment.

ment. Brain activity related to landmark information obtained from virtual environments has been demonstrated by Maguire, Frith, Burgess, Donnett, and O'Keefe (1998).

The transfer of knowledge obtained in a virtual environment to the real world has been studied by Witmer, Bailey, Knerr, and Parsons (1996). They found that training in VE is comparable to training in the actual environment, if a sufficient degree of realism is provided. This finding was confirmed and extended by Waller, Hunt, and Knapp (1998) who even noticed that training in VE can be superior to real world training. Ruddle, Payne, and Jones (1997), replicated a real–world study on the estimation of distance and directions in indoor environments first performed by Thorndyke and Hayes-Roth (1982). The results of the VE study were in good agreement with those performed in real buildings. Similarly, Distler, Veen, Braun, Heinz, Franz, and Bülthoff (1998) found no significant difference for the accuracy of orientation judgments in real and virtual environments.

In summary, virtual environments seem to be a valid tool for navigation experiments. In our experiments, the high degree of realism that seems to be important is provided by a large field of view (180° on a projection screen) and a high graphical resolution.

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. Cue conflict was used to study various strategies which could be used by the participants. We designed a navigation task in which the information offered by the local landmarks was in contradiction to the information provided by global landmarks. For example, a decision in agreement with the local landmarks would be a right turn, and a decision in agreement with the global landmarks would be a left turn.

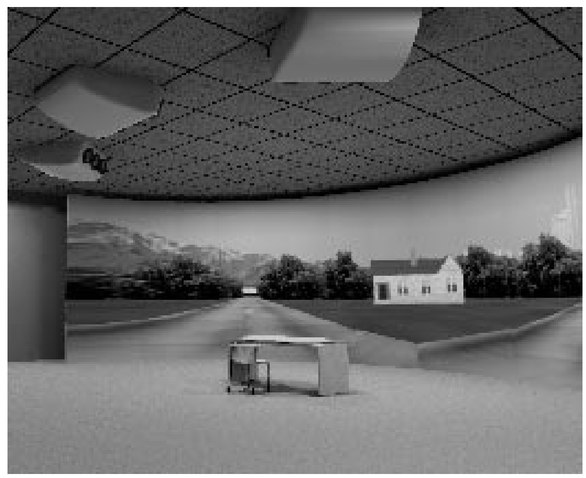
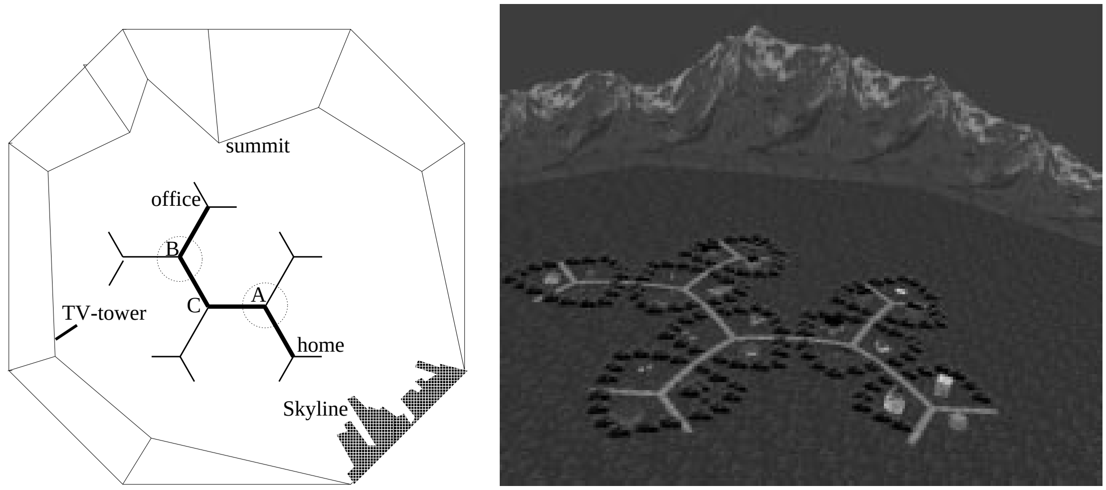


Figure 1: Virtual environments lab with 180° projection screen presenting our simulation. The participant is sitting in the center of the half cylinder formed by the projection screen. In front of him or her is a table with a computer mouse and a keyboard as input devices.

Hypotheses. We assume that humans use one of the navigation strategies summarized in Tab. 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 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 nec-



a. b.

Figure 2: **a.** Street map of Hexatown. "Home" and "office" are the two goals. The surrounding mountains and the skyline were projected in the direction of the center of the ground floor. **b.** Aerial view of Hexatown oriented as in a.

essarily 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.

2.2 Method

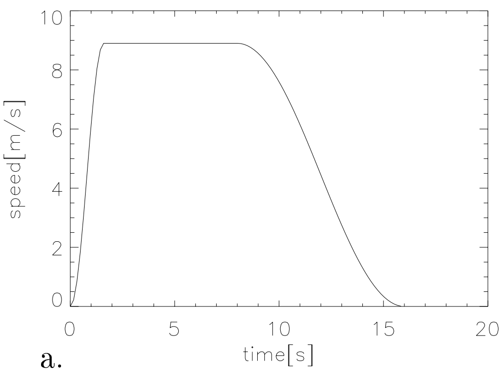
2.2.1 Participants

A total of 32 participants (18 male and 14 female, aged 15-31) took part in the experiment. All except two of participants were students. Participation in this experiment was voluntarily and a honorarium was payed for participation.

2.2.2 Virtual Environment

Visualization. The experiment was carried out using 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 non-stereoscopically, with an update rate of 36 Hz, on a half-cylindric (7m diameter and 3.15m height) projection screen (Fig. 1). The computer rendered three 1280×1024 pixel color-images, projected side by side with a small overlap and corrected to 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 1.25m), this display covers a field of view of 180° horizontally by 50° 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 (Geiger, Gillner, and Mallot 1997) we used virtual environments on a monitor with a 60° field of view to examine the role of global and local landmarks in route finding tasks. The performance of the participants in this setup was less than optimal (85.9% correct decisions in the control condition). With a bigger field of view it is also possible to use three conspicuous global landmarks one of which would be visible all the time. In the small field of view experiment, six landmarks had to be used which were sometimes confused by the participants.

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 hilltop, television tower and city skyline are "global landmarks". The buildings were constructed using Medit 3-D modeling software. A schematic



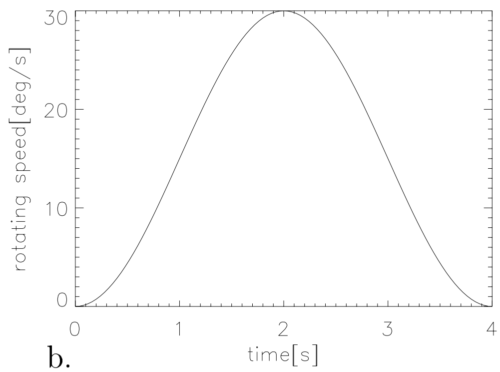


Figure 3: Velocity profiles of the simulated self motion, **a** translation and **b** rotation.

map of the town is shown in Fig. 2a. The aerial view (Fig. 2b) was not shown to the participants. The virtual environment (called "Hexatown", see Gillner and Mallot, 1998) consists of a hexagonal raster with a distance of 100 meters between adjacent junctions. A junction is built of three adjoining streets. The streets formed 120°–corners. In each corner an object (buildings, gas station, etc.) is placed. Streets at the ends of the raster were modeled as dead ends with barriers 50 meters from the junction. A circular hedge or row of trees was placed around each junction with an opening for each of the three streets (or dead ends) connected to that junction. This hedge looked the same for all junctions and prevented participants from seeing the objects at distant junctions. We used hills between places to block the views of buildings on adjacent places. The objects at the junctions are called "local landmarks", as they are only visible at a single junction. The hexagonal layout was chosen to make all junctions look alike, so that when approaching a junction, one cannot infer the approach direction from the geometrical layout. Another important advantage of these Y-junctions is that they represent binary decision points. This feature was used in the conflict condition of the experiment.

In the conflict condition we introduced a cue conflict by rotating the spatial position of each building at one junction either clockwise or counterclockwise by 120°. After transposition, the movement decisions in agreement with the local landmark contradict the decisions with the global landmarks, e.g., a left turn based on the local information and a right turn based on the global information.

In the experiment participants had to learn the route connecting two goals ("home" and "office"). From now on we will refer to the route between "home" and "office" as "main route" (shown as a bold line in Fig. 2a). The roads leading to the main route will be called "side streets". Note that in the actual simulation all roads have the same width (6.5 meters).

Interaction. Participants could navigate through Hexatown using the different buttons of the computer mouse. They were allowed to move along the streets and to make turns at the junctions. This simple motion model was used to help keep participants' attention on the navigation task. The translation movement was initiated by hitting the middle mouse button and was then carried out with a predefined velocity profile (Fig. 3a) without further possibilities for the participant to interact. The translation between two adjacent junctions took 16 seconds with a fast acceleration to the maximum speed of 9 meters per second and a slow deceleration. The translation movement ended at the next junction, in front of the object facing the incom-

Figure 4: Transposition condition in Expt. I. Each row shows the three pictures projected on the 180° screen. the discontinuity between the pictures was resolved by overlapping projection on the screen. **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.

ing street. At the junctions, 60° turns could be performed by pressing the left or right mouse button. The simulated turn movement was "ballistic", following a predefined velocity profile (Fig. 3 b). Turns took 4 seconds, with a maximum speed of 30° per second and symmetric acceleration and deceleration phases. The smooth profiles for translation and rotation were chosen to prevent participants from getting simulator sick.

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 fourth between the "home" and the "office" (Fig. 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 picture of the goal 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 had the possibility to expose a small picture of the current goal in the bottom left corner of the middle screen by pressing a special button.

Training phase I. At the start of the experiment, participants were released at the "home" building in the orientation towards that building. Participants explored Hexatown to find the "office". When they had reached their goal, a message was displayed, indicating whether they had used the shortest path or not. From the "office" they had to find the shortest way back to the "home" and so on. When they reached location C (Fig. 2a) the first time, after completing one way without mistakes, they had to do an orientation task once. The training was finished when they would go back and forth between "home" and "office" without mistakes.

Orientation Task. The orientation task was included to made sure that the partici-

task number	1	2	3	4	5	6	7	8
location	A	A	A	A	A	A	A	A
goal	home	home	home	home	office	office	office	office
approach	main	main	side	side	main	main	side	side
transposition	=	x	=	x	=	x	=	x
expected results								
local LM	R	R	L	L	L	L	R	R
global LM	R	L	L	R	L	R	R	L

task number	9	10	11	12	13	14	15	16
location	B	B	B	B	B	B	B	B
goal	home	home	home	home	office	office	office	office
approach	main	main	side	side	main	main	side	side
transposition	=	x	=	x	=	x	=	x
expected results								
local LM	L	L	R	R	R	R	L	L
global LM	L	R	R	L	R	L	L	R

Table 2: Different conditions for training II and the test phase. The transposition condition ("=": control; 'x': conflict) was varied only in the test phase. ("L" = left turn, "R": right turn).

pant did take notice of both types of landmark. At location C (Fig. 2a) participants were asked to orient themselves towards one of four landmarks by continuously turning the simulated environment. They had to do this task for two local landmarks, "home" and "office", and for two global landmarks, skyline (see Fig. 4 top row, right picture) and 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 (marked A, B in Fig. 2 a) and had to find the goal ("home" or "office") which had been presented previously as a picture. They had to perform this task 8 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 location along the main route (connection between "home" and "office"). In the "side street" condition, participants were transported from a side-way street to A or B. By choosing intermediate starting positions we ensured that participants could not use path integration or strategies like memorizing decision sequences (e.g., left-right-right). We varied starting location, goal, and approach direction, leading to a total of 8 tasks (Tab. 2). The transposition condition was not varied in the second training phase. The sequence of tasks was 5, 11, 7, 9, 15, 1, 13, 3 (non-conflict tasks). During the fourth task (task number 9) the orientation task was inserted (see above).

Test Phase. We used two types of conditions in the test phase: a control condition which was used for measuring participants performance, and a conflict condition used to find preferred strategies. This phase consisted of 16 trials as listed in Tab. 2. 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 two transposition conditions were a "control" condition which was the same as in the training phase, and a "conflict" condition. Conflict was produced by transposition of objects such that the global and local landmarks predicted different movement decisions (bottom row of Fig. 4). For example, if the decision in agreement with the local landmarks would be a right turn, the decision in agreement with the global landmarks would be a left turn.

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 9, 6, 12, 13, 10, 7, 1, 14, 3, 5, 4, 15, 11, 8, 2, 16 (Tab. 4).

For each participant the training and the test phases took a total of approximately 1 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

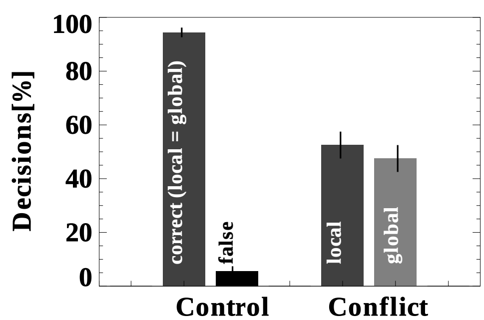


Figure 5: Results of Expt. I averaged over the participants not recognizing the conflict (N=20). **Left part:** control condition showing participants performance. **Right part:** conflict condition. The third column shows decisions in agreement with the local landmarks and the forth column those in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

Twelve out of 32 participants (37.5%) reported a conflict in the test phase. There was no significant difference in the performance between participants who reported conflict and those who did not. This was shown with a 5-way analysis of variance (ANOVA, 2 recognition states × 2 sequences × 2 goals × 2 locations × 2 approach directions) of the correct decisions in the control condition ($F(1, 28) = 2.06$, $p = 0.163$). 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 decision in a total of 8, $p < 0.04*$). We restricted our analysis to the data of the 20 participants who did not report the conflict. These participants are more likely to use global and local landmarks independently. From the test phase we got two types of behavioral answers. In the control condition the performance of the participants was measured (measurement = error rate) whereas in the conflict condition the preferred landmark type was assessed (Fig. 5). The error bars represent one standard error of the mean. If only local landmark information were used, the number of correct decisions in the control condition would have been the same as the number of decisions in agreement with the local landmarks in the conflict condition; this is clearly not the case ($\chi^2 = 528.5, df = 1, p < 0.0005 * **$). If only global landmark information were used, the number of correct decisions would have been the same as the number of decisions in agreement with the global landmarks; this is also not the case ($\chi^2 = 662.3, df = 1, p < 0.0005 * **$). We conclude that both types of landmarks were used in the task.

The results in the conflict condition (Fig. 5) are not due to random decisions. Fig. 6 shows the use of different landmark types for different goals and at different junctions. 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. At location A 66.3% ± 5.3% of the decisions were in agreement with global information and at location B 71.3% ± 5.1% with local information. This indicates that different strategies are used at different locations (Fig. 6b) or when pursuing different goals (Fig. 6a). We performed a 5-way analysis of variance (ANOVA, 2 gender × 2 sequences × 2 goals × 2 locations × 2 approaches) of the decisions in agreement with the global landmarks. The results (summa-

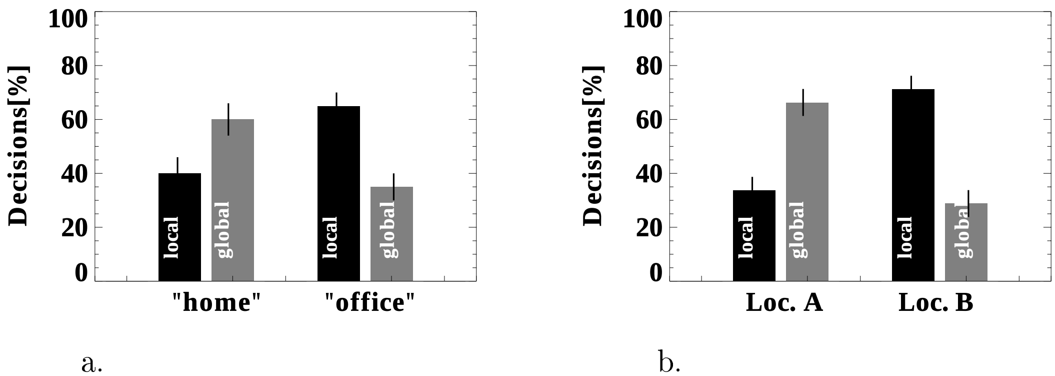


Figure 6: **a** Decisions in the conflict condition grouped by goal ("home", "office"). **b** Same data as in a grouped by location (Loc.).

main effects within subjects	location	goal	approach direction
	$F(1,16) = 19.6$ $p < 10^{-3} * **$	$F(1,16) = 21.1$ $p < 10^{-3} * **$	$F(1,16) = 3.56$ $p = 0.078$
main effects between subjects	sequence	gender	
	$F(1,16) = 8.048$ $p = 0.012*$	$F(1,16) = 0.762$ $p = 0.396$	

Table 3: Factors affecting the use of global vs. local landmarks in the conflict condition of Expt. I. Main effects of 5-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.

rized in Tab. 3) show significant main effects in the factors goal, location and sequence.

Some participants showed a clear strategy. Tab. 4 displays the performances of the individual participants who showed a strategy in the conflict condition which was significantly different from chance ($p < 0.04*$). The first group of participants in the table relies 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. No effect of gender on landmark preference was found (Table 3).

2.4 Discussion

Our main result is that both types of landmarks are used in the decision task and different participants used different strategies to make the 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.

In generalizing across participants these results were confirmed (Tab. 3). 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

subjects	Control		Conflict			
			decisions in agreement with			
	correct	false	local LM	global LM	local LM	global LM
			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

Table 4: Performance of individual participants showing clear strategies in the conflict condition. Upper part: preference for local landmarks, middle part: alternating strategies used at different locations, lower part: preference for global landmarks.

local landmarks at location A are three inconspicuous buildings, such as the one shown in Fig. 4. This could lead to a preference for decisions in agreement with the global landmarks.

We found that the goal affects the type of landmarks used to make the navigation decisions (as shown in Fig. 6). This could be explained by the constellation of landmarks. The participants associate the "home" target with the skyline of a far 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. Similar results were shown in scene recognition ("change blindness", see Simons and Levin (1997) for review).

The fact that conflict was mostly not reported, seems to indicate that the information associated with global and local landmark, is stored and recalled independently of each other. Changing the landmark configuration in the transposition experiment seems not to interfere with the information conveyed by each landmark.

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. The use of strategies seems to be not only effected by the goal and the location but also by participants history, e.g., the sequence of tasks.

We did not find any gender effects, contrary to the results of Waller et al. (1998). These authors found performance differences between men and women when navigating in virtual environments, but not in a real world condition. Waller et al. (1998) assume that the gender difference is due to different familiarity with simulated environments. In our experiment the interface was very simple, i.e., the computer mouse, which might explain the missing gender effect.

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

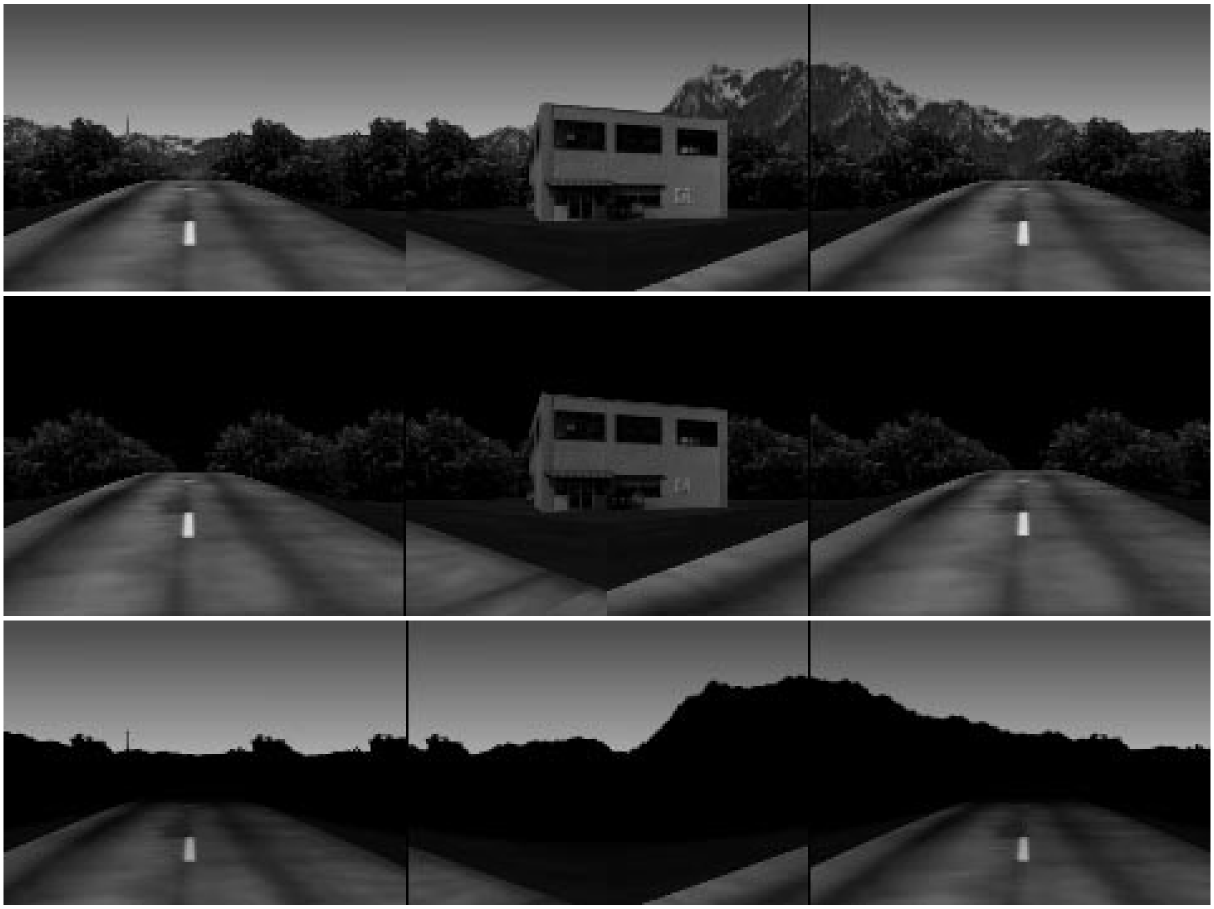


Figure 7: Experiment II: different lighting conditions. **Top** Daylight: global and local landmarks (control condition); **middle** Night: local landmarks only; **bottom** Dawn: global landmarks only (no textures).

3 Experiment II: Navigation Using Partial Information

3.1 Purpose

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

3.2 Method

3.2.1 Participants

A total of 36 participants (18 male and 18 female, aged 15-31) took part in the experiment. All but three of them were students. 20 of these participants were the participants who did not reported the conflict in the first experiment. The other 16 were naive participants who had no prior experience with Hexatown. The participation in this experiment was voluntarily and an honorarium was payed.

3.2.2 Virtual Environment

The experiment was performed using the same hardware, software and mouse interface as in experiment I. We used the same scenery as in the first experiment but with different lighting conditions (Fig. 7): A "control" lighting condition, which was identical to the training phase, included local and global information; a "night" lighting condition (which created the effect of driving with a spotlight by night), in which only local information was available; and a "dawn" lighting condition where only global information was seen, displayed as a silhouette, composed of the moun-

main effects within subjects			
location	goal	approaching	lighting
$F(1,28) = 7.99$	$F(1,28) = 10.5$	$F(1,28) = 2.51$	$F(1,28) = 8.81$
$p = 0.009 **$	$p = 0.003 **$	$p = 0.124$	$p < 10^{-3} ***$
main effects between subjects			
sequence	gender	familiarity	
$F(1,28) = 9.04$	$F(1,28) = 1.50$	$F(1,28) = 1.95$	
$p = 0.006 **$	$p = 0.231$	$p = 0.174$	

Table 5: Main effects of 7-way analysis of variance (ANOVA, 2 gender × 2 sequences × 2 familiarity × 2 goals × 2 locations × 2 approach directions × 3 conditions) of decisions.

tains, the city skyline and the TV-tower. 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. The experiment had three different phases, as in the first experiment: two training phases, and a test phase. The participants' task was to learn the route between "home" and "office" (Fig. 2 a). 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 condition (conflict or control) but three lighting conditions: "day", "night" and "dawn" (Fig. 7). The group of participants was divided in two subgroups for which the sequence of trials was reversed.

Participants who had previously participated in Expt. I completed the training and the test phase in approximately 40 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. The performance of the participants was again very good. Averaged over all participants and all lighting

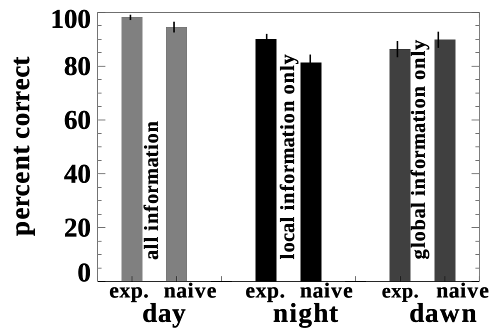


Figure 8: Results of Expt. II. Correct decisions over lighting conditions (left columns: experienced participants (N=20), right columns naive participants (N=16)).

conditions 90.2% correct decisions were found. There was no significant difference between the participants who run both experiments, and those who had no prior experience with Hexatown. This was shown by a 7-way analysis of variance (ANOVA, 2 gender × 2 sequences × 2 familiarity× 2 goals × 2 locations × 2 approach directions × 3 lighting), see Tab. 5.

The result shows significant main effects in location, goal, lighting condition and sequence. The difference between the lighting condition can be seen in Fig. 8. The correct decisions averaged over all participants was 96.5% ± 1.9% for the day condition (all information), 86.1% ± 2.0% for the night condition (only local information) and 87.9%±1.9% for the dawn (only global information). In the two conditions in which one type of local or global information is reduced, the performance is still very good.

3.4 Discussion

The primary objective of this experiment was to determine whether participants, who prefer one landmark type or the other 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.

We therefore conclude that both types of landmarks are stored in memory. For the conflict condition of Expt. I, were some participants used clear strategies, this result means that one landmark type was ignored.

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

4 General Discussion and Conclusion

From the data presented in this paper, two major conclusions can be drawn: Both local and global landmarks are used in the decisions for the way-finding task, and different participants rely on different strategies to make navigation decisions. Some of the participants used only local landmarks for decisions in the navigation task, others only global landmarks, and further participants used local landmarks at one location and global landmarks at the other location. Aginsky et al. (1997) also found the usage of different strategies in learning a route at the same competence level. Rather than a distinction between local and global strategies they found a difference between a more "visually" dominated and a more "spatially" dominated strategy.

In the second experiment landmark information was reduced by removing global or local landmarks in the test phase. Nevertheless both types of landmark information were stored in memory, which is shown by the good performance of participants in Expt. II. Even though some participants used just one type of landmark in the conflict experiment, they were able to perform both single landmark tasks in Expt. II.

These findings described for individual participants also hold when the data from all participants is considered together. Parts of the decisions in the test phase were in agreement with either landmark type. The salience of a landmark influenced the response type; for example the local strategy was preferred at the gas station. The movement decisions based on local landmarks and neglecting the compass information provided by the global landmarks can be interpreted as view–recognition–triggered responses.

Other participants referred to the information of global landmarks, independent from their viewing direction and the local landmarks. The global landmarks could be used in two different ways, as a compass for place–recognition–triggered response or as a beacon. Note that no compass is required in view–recognition–triggered response. A beacon is a landmark which is approached to reach a goal, e.g. "go towards the hilltop". However, this function of the global landmarks was not possible in all tasks. Decisions in agreement with the global landmarks, taken in the trials where "office" was the goal, can be taken as evidence for place–recognition–triggered response where global landmarks act as a compass.

In our experiments the participants showed more than just route knowledge (i.e., procedural knowledge), they showed also map–like knowledge. 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 connecting isolated bits of knowledge about landmarks into chains. Map like knowledge is more than just a sequence of actions 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 decide to go either towards "home" or towards "office". The participants were able to learn this side street approaches and we found no difference between the main route approach and the side street approach in the test phase of Expt. I. Both findings indicate that more than route knowledge, i.e., map like knowledge was present.

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