# Linguistic and visual cues in the formation of hierarchically structured representations of space during driving with a navigation assistance

Wiebke Schick, Jakub Krukar, Angela Schwering

Institute for Geoinformatics, University of Muenster

schickw@uni-muenster.de

*Abstract*

*Using navigation assistance is associated with poorer incidental learning of the environment. We study the impact of route instructions on the incidental learning while driving with navigation assistance. The study was conducted with a driving simulator in a virtual city that consisted of four different regions which had no clear-cut boundaries, but each a different look as well as stereotypical landmarks (e.g. historic city center – cobblestone, church). Memory and learning were tested with a landmark recognition task and the quality of a sketch-map drawn after driving. We tested three types of instructions: 1) Classical turn-by-turn instructions 2) Reference to regions and landmarks 3) Reference to regions, landmarks and stereotypical views.*

*We show that reference to regions and landmarks increases both recall and recognition of landmarks, and also increased survey knowledge. This work contributes to work concerning the optimization of provided wayfinding information as well as work concerning orientation information: how can the detection and memorization of orientation information be enhanced visually and verbally?*

**Keywords: route instructions, regionalization, orientation information, survey knowledge, sketch maps**

## 1. Introduction

The use of navigation assistances alters the focus on the environment during driving. It is no longer necessary to consider the different route options with the help of a street map, decide for one, identify those points where actions like turns or changes of the route type are required, and then search in the environment for cues like signs that mark these decision points. The load on both memory and attention is different as compared to following route instructions provided by an assistance device. Still, some landmarks –buildings with a high salience, a lake, a bridge – may be recognized and memorized incidentally.

Anacta et al. (2017) proposed a classification scheme for information both for verbal and visual wayfinding assistance – for route instructions and for maps. They found that both local and global landmarks are often used in route instructions to keep the follower oriented (see also Steck & Mallot, 2000).

The improved recall of landmarks has also been reported for route instructions:

Tom and Denis (2004) found that subjects better remembered instructions that referred to landmarks than if the same word was used as street name ("turn left at the church" vs. "turn left into church street"). Also, their sketch maps were more precise.

More evidence for the better recall of landmarks comes from a longterm-study from Bahrick (1983), who asked people about landmarks and street names of their college cities, and reported a significantly better recall of landmarks.

Another feature that can provide orientation, facilitate recall – and also bias perception - is a regional subdivision of the environment (Schwering 2017).

Places can be memorized as belonging to one region. There are various grouping rules according to which a region can be defined. Spatial proximity is auxiliary, but not necessarily the key factor. Regions can be learnt from abstract representations like maps, the region formation rule is assignment. This knowledge can influence distance as well as position estimations: Knowledge about the position of the regions can lead to distortions regarding the positions of places in them, and this also holds for regions that have only been perceived on a map (Stevens & Coupe, 1978). This is not a problem, though: regions influence perception and cognition even if they are no longer existent (Carbon & Leder, 2005).

Regions can also be defined through enclosure, like a fenced park or city quarter. Similarity is another one, which can occur in different forms, e.g. similar looks, a homogeneous appearance, but also similarity in the case of a common or shared functions: the locations of an open-air-bath, like the racing pool, the shower area and the sunbathing lawn are all attributed to a larger compound, can be associated with a shared function, and then be perceived as region. We see that more than one rule may apply. Sometimes there are clear-cut boundaries, but often, region boundaries are fuzzy.

The importance of knowledge about the hierarchical structuring of an environment is also represented in human communication about space:

Uttal, Friedmann, et al (2010) studied navigation planning on the campus of Northwestern University in Evanston. It consists of three different regions, but there are no clear region boundaries. Students who had lived on the campus for about two years also referred to these regions in communication.

The incidental learning while driving can be enhanced through the navigation instruction, as Gramann et al (2017) showed. They modified classical turn-by-turn instructions either by adding irrelevant information about the landmarks, or by adding information with a personal relevance for the driver (e.g. a restaurant that serves his favorite kind of cuisine).

Subjects in both modified instructions showed significant differences as compared to the turn-by-turn-condition in all measured variables, which consisted of driving the route a second time without assistance, recognition of landmarks, and drawing of a sketch map. Further evidence for the possibility of incidental region learning comes from a study from Noack et al (2017), who found improved recall of regionalization as well as of the routes after sleep consolidation.

Language can also enhance region perception:

Landmarks positioned at intersections that belong to different semantic categories suffice to induce region perception and influence route choice (Wiener & Mallot, 2003).

The same behavioral preference has been induced through place names that belong to compounds that share a function, a context, e.g. four typical places of a university. The rules of verbal region formation, though, appear to be more complex than for landmarks, where semantic categories sufficed. (Schick et al. 2019, accepted for publication in Spatial Cognition and Computation, 16.01.2019).

Here we examine whether the mentioning of regions and landmarks in the route instruction enhances their recall as well as the acquired survey knowledge of the environment. We also test whether verbal emphasis of region characteristics and important landmarks has a beneficial effect as compared to mere mentioning of the respective names.

## 2. Material & Methods

**Participants**

60 subjects participated in the study. They signed the ethical consent form and received monetary compensation (10 €). The subjects were divided into three groups. Each group consisted of 20 subjects. They were mostly students and employees of the university. 56 of 60 had a driver's license (table 1).

| | Turn-by-Turn | Regions + Landmarks | Regions, landmarks + | Total |
|---|---|---|---|---|
| **f/m** | 9/11 | 8/12 | 8/13 | 24/36 |
| **age** | 25.55 | 25.75 | 26.75 | 26.02 |
| **driver's license** | 18 | 19 | 19 | 56/60 |

**Table 1:** Subjects' parameters

**Experimental conditions**

The experiment tested three different conditions with a between-subject-design. In the first condition, classical turn-by-turn instructions were used. In the second condition, regions as well as selected typical landmarks were mentioned. In the third condition, the general character of the region was also described, mainly with adjectives, but also through mentioning of typical associations, e.g. old city center- cobblestone.

**Experimental Design**

*Driving Simulator and virtual environment*

The driving simulator was positioned in front of a screen. It mimicked an automatic car, indication of turns was not necessary. It was steered with OpenDS (4.0), open source software.

The virtual environment was created with City Engine (ESRI City Engine 2018.1).

The environment was divided into four different regions with a homogeneous appearance and stereotypical landmarks:

1. A shabby apartment building area with 3 cheap-looking supermarkets and a mobile phone shop.
2. The historic city center with cobblestone and a big church.
3. The financial district with huge skyscrapers and a shopping mall.
4. A residential neighborhood with single-family-houses and the landmarks playground and high school.

**Fig. 1.** Experimental setup

*Verbal instructions*

There were no clear boundaries between the regions, the transitions were smooth.

The voice instructions were provided with a speaker. They were created with the IVONA text-to-speech converter and were spoken with voice of Kimberly, American English[1].

The subjects were seated in the driving simulator and performed a training route of 1 km. After that, the test route started. It was 9.5 km long and crossed region boundaries 5 times. When a driver took a wrong turn, he was transported back to the latest position on the correct route he had occupied before. There were neither other road users nor pedestrians.

After the driving task, subjects had to solve a landmark recognition task. They were shown pictures of landmarks of the environment as well as similarly looking distractor landmarks and had to select all those which they recalled. Then, they were asked to complete a questionnaire and had to draw a sketch map of the environment. The questionnaire inquired about the driving

[1] https://www.ivona.com/us/about-us/voice-portfolio/

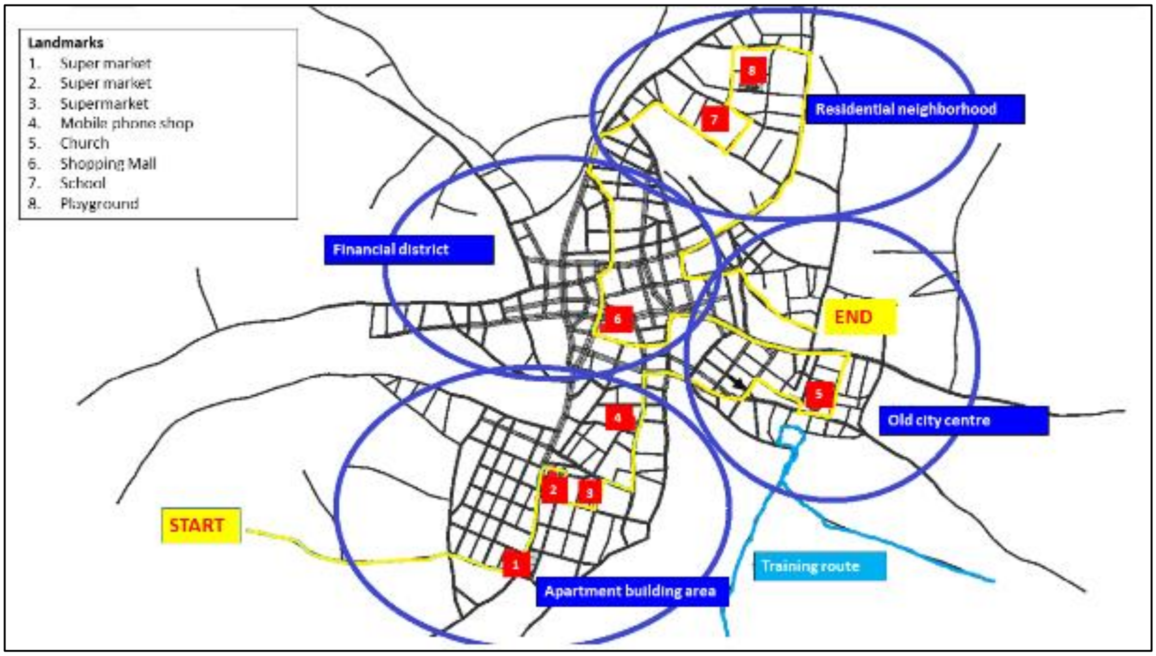


**Fig. 2:** Map of the virtual environment, showing the training and the test route, as well as the regions and the landmarks

and computer game experience, the subjective difficulty rating of the tasks, and whether certain strategies had been used for the recognition and for the sketch map drawing.

The instruction was: "Please draw a sketch map of the environment. Be as precise as possible, and if there were features you remember well or that helped you during the task, please mark them.

**Dependent measures**

Participants performed a landmark recognition task and drew a sketch map. These resulted in dependent variables:

(1) number of correctly recognized landmarks

2) route score and sketch score of the sketch map (according to the feature-based classification scheme proposed by Krukar et al. (2018)).

3) analysis of the region representation in the sketch maps: the crossings of regional boundaries of the route, and how the regions were positioned in relation to each other.

## 3. Results

### 3.1. Driving

An error was counted when the subject took a wrong turn or left the route altogether. They were then teleported to the last correct position of the route.

The mean error in Condition I was 0.4, in Condition 2 it was 0.3, and in Condition 3, 0.45, an ANOVA showed no effect of the condition (p = 0.7748, F(2,57 = 0.26)).

### 3.2. Landmark recognition

After the driving task, the participants saw 22 index cards displaying the 8 correct landmarks and 14 distractors (3 supermarkets, 3 churches, 2 mobile phone shops, 2 malls, 2 high schools, 2 playgrounds). They were asked to select those which they recognized (Fig. 4).

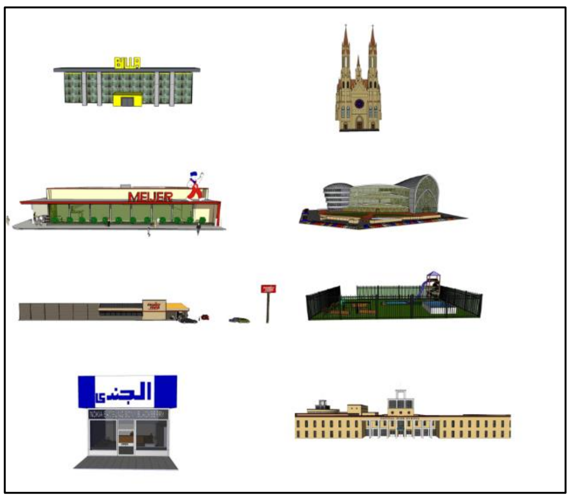

**Fig. 3** The landmarks of the virtual environment.

The number of correctly recognized landmarks equaled 3.40 in Condition 1, 5.90 in Cond. 2, and 5.45 in Cond. 3. The improvement of Condition 2 and 3 was statistically significant, compared to the baseline Condition 1 (Table 2).

| | number of correctly recognized landmarks | | |
|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* |
| (Intercept) | 3.40 | 2.69 – 4.11 | **<0.001** |
| cond 2 | 2.50 | 1.50 – 3.50 | **<0.001** |
| cond 3 | 2.05 | 1.05 – 3.05 | **<0.001** |
| Observations | 60 | | |
| $R^2$ | 0.334 | | |

**Table 2:** Table for the Poisson Regression of the landmark recognition task

### 3.3. Sketch map analysis

We analyzed the sketch maps in two ways:

First, with the classification scheme proposed by Krukar et al. (2018) that does not attempt to integrate all the features of the sketch into one model but separates them into two dimensions, route- likeness and survey-likeness. Here, we are interested in the incidental learning of vague regions, and how well the region transitions as well as the visual region characteristics were recalled. On top of distinguishing the route-and survey-likeness, we conducted an analysis of the region characteristics the adjacency to other regions and characteristic landmarks.

*Route -likeness*

The route-likeness is determined by 6 features that enable the reader of the map to follow the route, identify the correct decision points and take the right turns. 6 points can be obtained if all criteria are satisfied: r1: continuous, not fragmented route; r2: turns are included; r3: side streets at decision points; r4: side streets outside decision points; r5: local landmarks at decision points; r6: local landmarks outside decision points.

We would expect a difference between Condition 1 and Conditions 2 and 3 if the processing of the larger amount of information leaves fewer resources for memory and attention. The average route-likeness score for sketch maps drawn in Condition 1 was 0.95, in Condition 2 it was 1.65, and in Condition 3 it was 1.90. We used a simple linear model to model the improvement in route-likeness in Conditions 2 and 3, compared to Condition 1 (table 4). The difference was statistically significant for Condition 3.The modified route instructions with reference to landmarks led to a higher route score. In all three conditions, the scores are low. But we chose a long and complicated route, and did not explicitly tell the subjects to memorized the exact course of the route.

*Survey-likeness*

A coarser level of granularity is reflected with the survey-likeness: the relations between structuring features like global landmarks and regions are being considered here.

The survey score also consists of 6 criteria: s1: global, point-like landmark; s2: global, line-like landmark (e.g. a river); s3: region; s4: street network; s5: containment hierarchy (e.g. an object in a region); s6: spatial relation between distant objects.

We analyzed survey-likeness using the same method. The average survey-likeness score for sketch maps drawn in Condition 1 was 1.90, in Condition 2 it was 2.60, and in Condition 3 it was 2.85. The difference was statistically significant for Condition 3, as compared to Condition 1 (Table 3).

| **route-likeness** | | | | **survey-likeness** | | |
|---|---|---|---|---|---|---|
| *Predictors* | *Estimates* | *CI* | *p* | *Estimates* | *CI* | *p* |
| (Intercept) | 0.95 | 0.35-1.55 | **0.003** | 1.90 | 1.37-2.43 | **<0.001** |
| condition 2 | 0.70 | -0.15-1.55 | 0.106 | 0.70 | -0.05-1.45 | 0.065 |
| condition 3 | 0.95 | 0.10-1.80 | **0.030** | 0.95 | 0.20-1.70 | **0.014** |
| Observations | 60 | | | 60 | | |
| $R^2$ | 0.086 | | | 0.109 | | |

**Table 3:** Factorial regression of the route-likeness and survey-likeness scores

*Analysis of the sketches focusing on crossings of region boundaries and contact between regions*

The survey score is a sophisticated way to measure the learning and the recall of global structuring features of an environment. Possible benefits of linguistic enhancement of regionalization was our main interest. So we further analyzed with respect to the additional information included in the navigation description.

In the instructions of Condition 2 and 3 it was mentioned when there was a transition into another region: the name of the region through which the participant was currently driving was also mentioned. Through the highlighting of the transitions, we want to see if these boundary crossings are recalled, included in the sketch map, and whether this also conveys information about the layout of the regions.

The instructions of Condition 3 further included adjectives referring to characteristic landmarks as well as the general look of the respective quarter. If this enhancement of the regions facilitates recognition of the regions, we expect more exact positioning of the regions as compared to Condition 1 and 2.

*Correct crossings of region boundaries*

This requires route knowledge as well as survey knowledge. There were 5 transitions. If the sketch map contained the names of the respective regions and the route passing through them, one point was counted. Thus, a maximum of 5 points was possible.

*Correct region contacts*

Then, we looked at the layout of the regions in the sketches by counting the contacts between the regions. There were 5.

The number of correctly included contacts between regions ranged from 0 to 1 in Cond. 1, and from 0 to 5 in Cond. 2 and Cond. 3

Since this is count data, we used Poisson regression to model it. Results demonstrate that participants in Cond. 2, and Cond. 3 included more correct touching points between regions on their sketch maps, and the differences compared to Cond. 1 were statistically significant.

Because we are interested in the improvement caused by two versions of our intervention (Conditions 2 and 3) as compared to Condition 1, we present the analyses in the form of summarized model output that directly provides the estimates for Conditions 2 and 3, compared to the baseline Condition 1.

| correct crossings | | | | correct contacts | | |
|---|---|---|---|---|---|---|
| *Predictors* | *Incidence Rate Ratios* | *CI* | *p* | *Incidence Rate Ratios* | *CI* | *p* |
| (Intercept) | 0.15 | 0.04 – 0.39 | 0.001 | 0.45 | 0.22-0.81 | 0.017 |
| condition 2 | 4.33 | 1.40 - 18.90 | **0.022** | 4.56 | 2.32 – 10.00 | **< 0.001** |
| condition3 | 3.00 | 0.90 – 13.52 | 0.099 | 5.33 | 2.75 – 11.63 | **< 0.001** |
| Observations | 60 | | | 60 | | |
| Nagelkerke $R^2$ | 0.147 | | | 0.491 | | |

**Table 4:** Poisson regression analysis of correct crossings and correct contacts.

The number of correct crossings of the route included in sketch maps per participant ranged from 0 to 1 in Cond. 1, from 0 to 4 in Cond. 2, and from 0 to 3 in Cond. 3. Since this is count data, we used Poisson regression in order to model it. Results demonstrate that participants in Condition 2, on average, included significantly more correct crossings than participants in Condition 1. The improvement caused by Cond. 3 was not statistically significant (Table 4, Fig. 5).

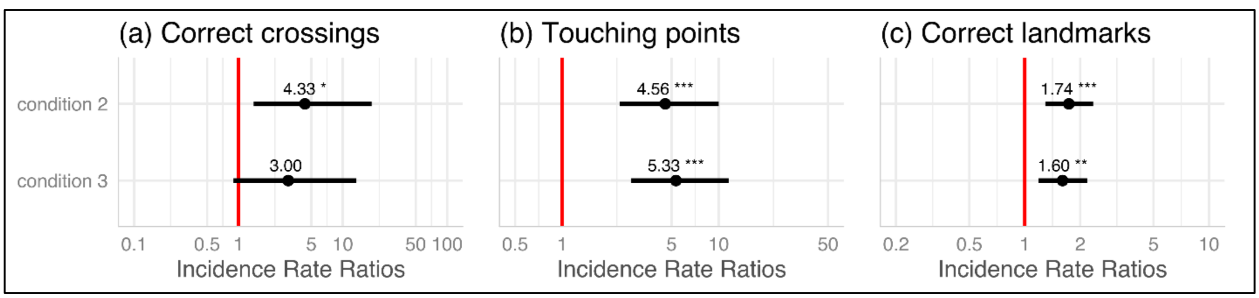


**Fig. 4** The red line indicates the base-line condition 1¸the horizontal bold lines are the 95 % -confidence intervals.

## 4. Discussion

In this study, we tested whether the detection and recall of regions could be enhanced with modified route instructions.

Our hypothesis of enhanced recall of regions and landmarks through modified route instructions proved right. We did not find, though, a difference between the mere mentioning of regions and landmark names and the condition in which we also added more descriptive information. One possible explanation could be that the cues have to be more evident, both visually as well as through more frequent repetitions in the route instructions.

Both the reported difficulty rating as well as the low route scores for all conditions show how little is being remembered of a route that has been driven only once, with reliance on assisting systems.

The sketches show that mentioning of the regions enhances their recall. We see from the results of Condition 2 and 3 that modified route instructions leads to better recall. Gramann et al. (2018) performed a similar study including EEG-data collection and reported increased amount of event-related potential in the EEG's of those subjects who drove with modified route instructions, which provided either a short description of the landmark or related the landmark to personal interests of the subject. They did not find, though, differences between the enhanced instructions. It seems that the extra attention an environmental feature receives through such an emphasis improves recall, but that more details do not lead to further improvement. This could be due to the focus that is necessary during driving; the drivers have to wait for the next instruction and keep track of the route.

We also found that the verbal highlighting enhances recall of two types of spatial features, of landmarks as well as regions. Additional descriptions as with the adjectives in Condition 3 seem not to enhance the recall. The Poisson regression showed significantly better recall and sketch map results for the Conditions 2 and 3. The reason for this could be that we used stereotypical landmark cues and visual appearance of the respective regions. Maybe for these regions and expected landmarks, the association between them was so strong that additional description did not facilitate recall.

The landmark cues in our experiment were picked to meet expectations. A next step would be to test whether ambiguous or unexpected landmarks – like a cathedral in a working class district – have an influence on the recall of the landmark, the region, or both.

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