Landmark-Based Navigation Instructions Improve Incidental Spatial Learning in Real-Life Environments

Anna Wunderlich[1] and Klaus Gramann[1,2,3]

Berlin Institute of Technology

Anna Wunderlich,[1] (0000-0003-2378-1164) and Klaus Gramann[1,2,3] (0000-0003-2673-1832)

[1] Technische Universität Berlin, FG Biopsychologie und Neuroergonomie, Berlin 10623, Germany

[2] School of Computer Science, University of Technology Sydney, Sydney 2007, Australia

[3] Center for Advanced Neurological Engineering, University of California, San Diego 92093, CA, USA

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Correspondence should be addressed to Anna Wunderlich; anna.wunderlich@tu-berlin.de

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Abstract

Background. The repeated use of navigation assistance systems leads to decreased spatial orienting abilities. Previous studies demonstrated that augmentation of landmarks using auditory navigation instructions can improve incidental spatial learning when driving a single route through an unfamiliar environment.

Objective. Based on these results, two experiments were conducted to investigate the generalizability of both the impairment of spatial knowledge acquisition by standard navigation instructions and the positive impact on incidental spatial learning using landmark augmentation in auditory navigation instructions.

Method. In a first experiment, spatial knowledge was tested after watching a video of navigation of a real-world urban route. A second experiment investigated incidental spatial knowledge acquisition when participants actively navigated through the same real-world, urban environment.

Results. Both experiments demonstrated better cued-recall performance for participants navigating with landmark-based auditory navigation instructions as compared to standard instructions. Notably, standard instructions were associated with reduced learning of landmarks at navigation relevant intersections while the acquired knowledge about landmarks alongside straight segments as well as the recognition of novel landmarks was comparable across navigation conditions.

Conclusion. The results replicated an improved spatial knowledge acquisition for landmark-based navigation instructions emphasizing the positive impact of auditory landmark augmentation on incidental spatial learning and its generalizability to real-life settings.

Application. This research is paving the way for navigation assistants that, instead of impairing orienting abilities, incidentally foster spatial learning during every-day navigation.

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Keywords: automation, spatial knowledge acquisition, real-world, cued-recall

Précis: Two experiments replicated the suppression of incidental spatial learning by standard navigation instructions as well as its improvement by landmark augmentation in auditory navigation instructions. The experiments testing varying degrees of realism revealed that this effect can be generalized and applied to real-life settings.

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Introduction

Navigation aids have become common everyday tools (Axon, Speake, & Crawford, 2012; Kalin & Frith, 2016; Kitchin & Dodge, 2007). They provide visual as well as auditory guidance as a support during wayfinding through known and unknown environments (Allen, 1999). With the use of navigation aids, wayfinding evolved from analog 2D map-based tasks into digitally assisted instruction following tasks. Accordingly, a recent survey revealed a stronger trend towards route-based wayfinding strategies as compared to twenty years ago, along with an increasing inability to use wayfinding strategies among younger adults (Ulrich, Grill, & Flanagin, 2019). This trend towards route-based wayfinding strategies is likely fostered by the increased use of navigation assistance systems providing turn-by-turn instructions and biasing a route perspective (Gardony, Brunyé, Mahoney, & Taylor, 2013).

Several studies investigated the user's interaction with navigation aids in order to describe and understand the underlying cognitive processes. One finding was that the use of automated assistance systems was associated with divided attention between the movement related task and the assisted navigation (Fenech, Drews, & Bakdash, 2010; Gardony et al., 2013; Gardony, Brunyé, & Taylor, 2015). This resource allocation conflict increases the reliance on the navigation assistant in order to reduce attentional demands (Baus, Kray, & Krüger, 2001; Klippel, Hirtl, & Davies, 2010; Parush, Ahuvia, & Erev, 2007) leading to an automation bias (Lin, Kuehl, Schöning, & Hecht, 2017). The users tend to hand over the decision-making to the automated system (Bakdash, Linkenauger, & Proffitt, 2008; Fenech et al., 2010; Parush et al., 2007). They follow the system instructions without checking other available information (Mosier, Skitka, Burdick, & Heers, 1996; Parasuraman, 2000) and this overreliance leads to a decrease in processing the surrounding environment (Leshed, Velden, Rieger, Kot, & Sengers, 2008; Hirtle & Raubal, 2013; Münzer, Zimmer, Schwalm, Baus & Aslan, 2006). With repeated use of navigation assistance systems, the users' ability to

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autonomously solve the navigation task decreases, revealing a deskilling of orienting abilities (Bertel, Dressel, Kohlberg, & von Jan, 2017; Münzer, Zimmer, & Baus, 2012; Parush et al., 2007).

As a consequence, people are more likely to get lost because of their inability to orient using their own sense of direction when the navigation aid is no longer reliable (e.g., because of system errors or GPS signal loss). However, even when the system works properly, the risk of getting lost remains by an inadequate application of or overreliance on navigation assistance systems. Errors during navigation can have more or less severe consequences ranging from time loss and stress to potential disaster when orientation fails in extreme environments (Aporta et al., 2005). Lin and colleagues (2017) collected a corpus of 158 so called “Death by GPS” incidents published in the English news between 2010 and 2017. Only those reports were chosen that contained incidents caused by an improper use of navigation assistance systems. They found an unusual high number of single-car crashes (32%) and that most of the “Death by GPS” incidents happened in an unknown environment (78%). These data point to a relative increase of rare accidents involving no other road users demonstrating that the use of automated assistive technologies can negatively impact the primary driving task.

To maintain spatial abilities while using navigation assistance systems, a variety of methods can be used (Giannopoulos, Kiefer, & Raubal, 2015, Gramann, Hoepner, Karrer-Gauss, 2017). One promising approach to support navigation without endangering the users’ safety is the inclusion of environmental information about salient objects, so called landmarks (Evans, Smith, & Pezdek, 1982), in the navigation instructions (Li, Fuest, & Schwering, 2014; May, Ross, Bayer & Burnett, 2001; Raubal & Winter, 2002). Studying pedestrian navigation in the real world showed that visual augmentation of landmarks in the navigated environment enhances spatial knowledge acquisition (Brügger, Richter, &

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Fabrikant, 2019; Huang, Schmidt, & Gartner, 2012; Münzer et al. 2006). Furthermore, it was shown that spatial knowledge can be incidentally acquired during navigation to a similar level as intentional learning (van Asselen, Fritschy, & Postma, 2006). These previous studies used visual tools only to improve spatial knowledge acquisition. Such tools require the same visual resources for processing the navigation instructions that are also necessary for the primary task. Compared to visual augmentation methods, acoustic navigation instructions have the advantage to be safer as they do not interfere with visual attention needed to observe the ongoing traffic (May & Ross, 2006). Ross, May, and Thompson (2004) investigated landmark-based auditory navigation instructions regarding their usability for pedestrians. The authors demonstrated the effectiveness of landmark-based auditory instructions leading to less navigation errors and increased navigator's confidence during navigation, as compared to a control group. While the study by Ross and colleagues demonstrated improved navigation performance, the authors did not test for the impact of auditory landmark information on spatial learning.

To test whether auditory landmark-based navigation instructions lead to spatial knowledge acquisition while improving navigation, Gramann and colleagues (2017) augmented landmarks at intersections in a virtual driving task. Landmark augmentation was implemented by naming landmarks at navigation relevant intersections and providing additional information about them. This resulted in incidentally learning of spatial information of the environment (Gramann et al., 2017). Improved spatial knowledge acquisition with landmark-based navigation instructions was observable even when tested three weeks after a single exposure to an unfamiliar environment (Wunderlich & Gramann, 2018). It was further found to be associated with changes in brain activity likely reflecting increased information recollection during cued-recall of landmark- and route-knowledge about the navigated environment (Wunderlich & Gramann, 2018). Landmarks and routes are

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the essential elements of spatial representations and necessary for conceiving spatial relations (Siegel & White, 1975). Augmenting landmarks in auditory navigation instructions might thus be a promising way to foster spatial knowledge acquisition during use of navigation assistance systems. The results of both virtual driving studies showed a significantly improved recognition performance for navigation relevant landmarks when navigators received landmark-based instructions as compared to standard instructions known from commercial navigation aids. Moreover, when using standard navigation instructions, recognition of relevant landmarks was reduced compared to both navigation irrelevant (salient objects in between navigation relevant intersections) and novel landmarks (landmarks that were not part of the previously navigated route).

These results point to a possible suppression of spatial knowledge acquisition as learning of the environment was reduced when standard navigation instructions were given compared to segments without navigation instructions. It seemed like spatial learning was suppressed by standard instructions that guided the users' attention to the intersection rather than to the environment around the intersection. In comparison, landmark-based instructions revealed better recognition performance for relevant landmarks with the other landmark categories remaining at comparably high levels. These results support the assumption that the inclusion of landmark information in navigation instructions was associated with directing the users' attention towards environmental features leading to an incidental spatial learning of these features. However, the cued-recall performance for relevant landmarks was not improved beyond the performance for navigation irrelevant and novel landmarks indicating that a learning suppression was overcome rather than that additional spatial learning took place (Gramann et al., 2017). Importantly, overcoming the spatial learning suppression with landmark-based instructions did not affect the subjective mental load or driving behavior (Gramann et al., 2017; Wunderlich & Gramann, 2018).

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In the previous studies using landmark-based navigation instructions, it was not tested to what extent incidental spatial learning was fostered by the landmark reference itself or by the additional information that was provided. The two versions of landmark-based navigation instructions used in Gramann and colleagues (2017) and Wunderlich and Gramann (2018) included both the name of a landmark at the intersection and additional information. In one case this information was redundant, such as, “Turn right at the bookstore. There, you can buy books.” In the other case, it included a reference to one of the participant’s personal interests, like, “Turn right at the bookstore. There, you can buy books of J.R.R. Tolkien” in case J.R.R. Tolkien was the favorite author of the tested participant. These personal-reference instructions had been individualized for each participant. By using only these two conditions, however, it was not possible to differentiate between the personal-reference or the additional more detailed information in the instructions as the cause of the spatial knowledge acquisition effect.

To answer this question, the studies reported in this paper introduced a *long* instruction condition that augmented landmarks at navigation relevant intersections and provided additional semantic information about the landmark. This instruction contained more semantic information than the previously used redundant description of the landmark, but had no relation to the personal interests of the participants (“Turn right at the bookstore. There, public readings take place every week.”). Because previous studies revealed improved spatial learning for any landmark-based navigation instructions, we also introduced a *short* instruction condition to test whether simply naming a landmark without additional information might already foster spatial knowledge acquisition (“Turn right at the bookstore.”). This condition was similar to the landmark-based navigation instructions in the usability study by Ross and colleagues (2004). In summary, the following experiments used both short and long landmark-based navigation instructions in comparison to a control group.

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The control group received standard auditory navigation instructions as known from commercial navigation aids (e.g., “At the next intersection turn right.”). None of the conditions received visual guidance alongside the auditory instructions.

Besides investigating the amount of information in the landmark-based navigation instructions, it remained an open question whether an improved incidental spatial learning in virtual driving simulations can be generalized to more realistic environments. The previous experiments took place in a highly controlled and restricted driving simulator setup (Gramann et al., 2017; Wunderlich & Gramann, 2018). This artificial scenario lacked naturalistic self-motion cues, other traffic participants, and natural visual information. Here, we report two experiments that were conducted to investigate the potential impact of more realistic navigation scenarios on spatial knowledge acquisition. In Experiment 1, the navigation paradigm was transferred to a pedestrian context using real-world visuals. An interactive movie was created showing a pedestrian’s first-person perspective while navigating through Berlin, Germany. The video was a realistic representation of city navigation while allowing control of stimulus material for all participants. Experiment 2 then investigated spatial knowledge acquisition during real-world assisted pedestrian navigation through the city of Berlin.

We expected to observe the same impact of landmark-based navigation instructions on incidental spatial knowledge acquisition in both the controlled video scenario as well as the real-world setting. Following up on the previous findings, we analyzed incidental spatial knowledge acquisition during assisted navigation with two main hypotheses. The *suppression hypothesis* postulates that standard navigation instructions lead to a suppression of spatial knowledge acquisition for landmarks at intersections (navigation relevant landmarks) as reflected in reduced cued-recall performance compared to navigation irrelevant and novel landmarks. The *learning hypothesis* posits that landmark-based navigation instructions

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overcome this suppression effect and improve spatial knowledge acquisition at navigation relevant intersections, with participants receiving long outperforming those receiving short navigation instructions. To investigate the incidentally acquired spatial knowledge, the performance in a cued recall task was analyzed using the percentage of correct responses regarding each landmark type as dependent variable. This measure represents a combination of landmark and route knowledge of the navigated environment, because correct responses require associative memory of the street outline as well as the respective route direction. As the cued-recall task was used in both experiments and had the same structure as the landmark recognition task used in previous experiments, it was the only task allowing for a comparison across experiments and testing the generalizability of the previous findings. To control for individual differences in spatial abilities, the Santa Barbara Sense of Direction test (SBSOD, Hegarty, Richardson, Montello, Lovelace & Subbiah, 2003) was applied in all experiments to be used as covariate in case of significant correlation of the subjective sense of direction measure with landmark recognition performance in the cued-recall test.

Experiment 1

The aim of Experiment 1 was to test landmark-based navigation instructions in a more realistic environment providing real-world visuals. To this end, an interactive video was created showing a pedestrian's first-person perspective during real-world navigation through an urban environment.

Method

Participants. Forty-three participants assigned to three different navigation instruction groups took part in this experiment. The recorded sample included 22 women and gender was balanced across experimental conditions (14 participants in standard, 7 females; 14 in short, 7

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females; and 15 in the long instruction condition, 8 females). The age ranged from 19 to 34 years (M = 26.2 years, SD = 2.75 years). Participants were recruited through an existing database or personal contact and were reimbursed monetarily or received course credit. To assure that participants were unfamiliar with the route, we used an online questionnaire prior to the experiment. They were asked to rank up to five metro stations of Berlin according to their frequency of personal use. If one of the stations was close to the route, the participant was excluded from the experiment. All participants had normal or corrected to normal vision and gave written informed consent prior to the study. The study was approved by the local ethics committee.

Procedure. Following the previous approach (Gramann et al., 2017, Wunderlich & Gramann, 2018), the experiments consisted of two parts. The first part was an assisted navigation phase where participants followed auditory navigation instructions to navigate along a predefined route. In the second part, participants had to solve different tasks testing their spatial knowledge about the navigated environment. Participants were not informed prior to the second part that they will be tested on the navigated environment allowing for investigation of incidental spatial knowledge acquisition. Experiment 1 took place in a controlled laboratory environment (Figure 1a) and lasted 2 hours and 40 minutes. Participants were seated in front of a display and interacted with the video scenario by using the keypad in front of them. Participants were equipped with electroencephalography (EEG; BrainAmps, Brain Products, Gilching, Germany) and eye movements were recorded with a desktop-based eye-tracker (SMI RED 5, SensoMotoric Instruments, Teltow, Germany).

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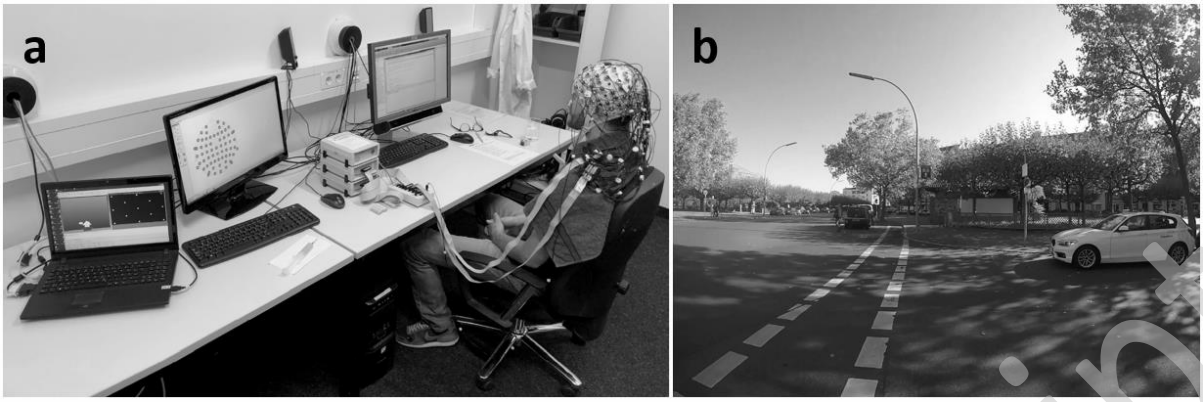

Figure 1: a) Interactive video setup of Experiment 1. The screen in front of the participant was displaying the video and was equipped with the eye-tracker, a second screen was for EEG-data and the laptop for eye-tracking data collection. b) Video snapshot at a navigation relevant landmark ("public restroom") as used in the cued-recall task (pictures were presented in color).

Navigation phase. Participants watched a video showing real world recordings complemented by auditory navigation instructions. The task was interactive as the video stopped at intersections and participants had to respond according to the navigation instructions. The video did not commence without a response. Some route characteristics changed with the paradigm shift from simulated driving to walking through an urban environment. Based on changes in locomotion speed, the definition of navigation relevant landmarks was adapted. Hitherto, only landmarks at intersections with route direction changes were defined as navigation relevant. In the pedestrian scenario, all landmarks at intersections were defined as navigation relevant even in case no route direction change was experienced. This was done because landmarks along the route can serve as confirmation and improve user confidence in pedestrian navigation assistance (May Ross, Bayer, & Tarkiainen, 2003; Rousell & Zipf, 2017). As a consequence, navigation instructions were provided prior to all intersections. In the modified navigation instruction conditions, these included information about the respective navigation relevant landmark.

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The video content was recorded with a GoPro Hero 4 (GoPro. Inc., San Mateo, USA) from a pedestrians' perspective (see Figure 1b). The cameraperson was continuously recording while walking a predefined route. During the video, various other road users were visible. Removing the real-world audio allowed for high realism of the visuals without considering other auditory stimuli than the auditory navigation instructions. The video was accelerated by 1.1 times the original speed to shorten the navigation task to approximately 35 minutes. The displayed route through Charlottenburg, Berlin in Germany, was 3.7 km long and passed twenty intersections containing 14 direction changes. Auditory navigation instructions were presented via loudspeakers prior to each intersection. When arriving at an intersection, the movie stopped and a participants' response according to the instructed direction was required. Participants indicated the navigation directions using the left (turn left), up (go straight), or right (turn right) arrow key. This interaction was implemented to ensure the participants' attention to the route. Irrespective of whether the response was correct or not, pressing one of the response keys started the video again. The stimulus material was identical for all participants and only the navigation instructions differed between the groups. Besides the standard navigation instructions, the short and long landmark-based navigation instructions were tested. After video navigation, the subjective rating of navigation task-related load was measured using the NASA-RTLX (National Aeronautics and Space Administration - raw task load index; Hart, 2006; Hart, & Staveland, 1988). In addition, participants answered questions about route familiarity and acceptance of the modified navigation instructions.

Test phase. The test phase followed the navigation phase after a short break (as in Gramann et al., 2017). This way, the EEG cap could remain on the participants' head and the electrode positions were identical for both phases. The second part consisted of a sketch map drawing, the cued-recall task, the Perspective Taking/Spatial Orientation Task (PTSOT;

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Hegarty & Waller, 2004), and the circle task (triangular pointing task). Only the cued-recall task was reported in detail here as it was the only task conducted in both current experiments as well as in the previous studies. This way, its results allowed conclusions about the generalizability of the impact of landmark-based navigation instructions for different navigation contexts.

The cued-recall task combined a simple landmark recognition with a route direction response comparable to Huang and colleagues (2012). The task of the participant was to correctly recognize pictures taken from the navigated environment as being part of or not being part of the previously navigated route. In case of recognizing a landmark, participants responded according to the respective route direction at the landmark location. To capture the overall acquired spatial knowledge, we used three landmark types which were categorized according to their relevance for navigation: a) *navigation relevant landmarks* were located at intersections and referenced in the modified navigation instructions while b) *navigation irrelevant landmarks* were located at straight route segments. In addition, c) *novel landmarks* were presented, which were from the same environment, but had not been encountered during the navigation phase. Thus, relevant and irrelevant landmarks should be indicated as known landmarks while novel landmarks should be identified as unknown.

Twenty pictures of each landmark type were randomized and presented one by one on a desktop screen. Pictures of relevant and irrelevant landmarks were screenshot from the navigation video. As novel landmarks served screenshots from additional video material taken the same day as the navigation video. All landmarks were presented from the pedestrians' point of view including their immediate surroundings (see Figure 1b). Each landmark was displayed for 3 seconds and then replaced by a figure presenting four arrow keys indicating the response options. Participants were instructed to press the right/left arrow key, in case the route had turned right/left at the displayed landmark, respectively. In case the

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route had proceeded straight ahead, the required response was to press the up-arrow key. In case the landmark had not been encountered previously, participants were asked to press the down-arrow key. The relative location of navigation relevant landmarks at intersections (left, right, before or after the intersection) did not provide any indication for the respective turning directions. Following each response, participants were asked how confident they were about the given answer on a six-point scale ranging from ‘1 - very sure’ to ‘6 - I did not know’. For the analysis of event-related activity from the ongoing EEG, the set of landmarks was randomized and presented five times to reach a sufficient number of epochs per landmark type. For the present paper, only the responses to the first presentation of each landmark picture are reported as these represent the unbiased responses of participants.

Questionnaire data about demographic characteristics, individual navigation and learning habits, and spatial abilities were collected at the end of the experiment. For the subjective individual orienting ability, the Santa Barbara Sense of Direction (SBSOD, Hegarty et al., 2003) was used.

Statistical analysis. Statistical analysis was performed using the statistics software SPSS (International Business Machines Corporation (IBM) Analytics, Armonk, USA). A mixed measure analysis of variance (ANOVA) was computed with the between-subject factor navigation instruction condition (standard, short, long) and the within-subject factor landmark type (relevant, irrelevant, novel). In case of violation of the sphericity, the Greenhouse-Geisser corrected p-values and degrees of freedom were reported (Rasch, Friese, Hofmann & Naumann, 2010). As an indicator of effect size, partial eta squared was calculated. To test the hypotheses of suppression and learning, post-hoc comparisons were computed comparing all instruction conditions within each landmark type (nine comparisons) as well as comparing all landmark types within each navigation instruction condition (nine comparisons). The resulting p-values were Bonferroni corrected by dividing the p-value by

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the total number of eighteen comparisons. Spearman correlation of the SBSOD score and the percentage of correct responses to each landmark type was computed to control for a potential covariance of subjective spatial abilities and performance.

Results

The Spearman correlation of the SBSOD score with the percentage of correct responses to each landmark type was not significant (ρ's < .176, p's > .262). Thus, the SBSOD score was not included as covariate in the ANOVA.

The group-boxplots and individual measures for the percentage of correct recognized landmarks and associated directions in the cued-recall task can be seen in Figure 2. The results of the ANOVA revealed a significant main effect of navigation instruction condition ($F_{(2,40)} = 4.33$, $p = .020$, $\eta_p^2 = .178$). Post-hoc comparisons revealed that the performance in the long navigation instruction condition was better ($M = 71.2$, $SE = 2.28$) than in the short instruction condition ($M = 62.3$, $SE = 2.36$, $p = .031$). The difference between long and standard instructions ($M = 63.6$, $SE = 2.36$) showed a trend towards significance ($p = .074$). The overall performance of standard and short instructions showed no difference ($p > .999$).

The a main effect of landmark type was also significant ($F_{(2,80)} = 18.1$, $p < .001$, $\eta_p^2 = .312$). Post-hoc comparisons revealed that the cued-recall performance was lower for navigation relevant ($M = 55.4$, $SE = 2.11$) compared to navigation irrelevant ($M = 73.2$, $SE = 2.06$, $p < .001$) and novel landmarks ($M = 68.9$, $SE = 2.45$, $p = .001$). Novel and irrelevant landmarks revealed comparable recognition performance ($p = .571$).

Finally, the interaction of both factors showed a trend towards significance ($F_{(4,80)} = 1.75$, $p = .148$, $\eta_p^2 = .080$).

To address the suppression hypothesis, landmark types were compared for each navigation instruction condition. The results for the standard instructions revealed significantly lower recognition performance for relevant ($M = 46.8$, $SE = 3.70$) as compared

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to irrelevant (*M* = 75.4, *SE* = 3.61, *p* < .001) and novel landmarks (*M* = 68.6, *SE* = 4.36, *p* = .002). In the short navigation instruction condition, recognition performance for relevant landmarks (*M* = 54.3, *SE* = 3.70) was significantly lower than for irrelevant landmarks (*M* = 68.6, *SE* = 3.61, *p* = .014). When contrasting landmark types in the long navigation instruction condition, the recognition performance for relevant (*M* = 65.0, *SE* = 3.58) approached recognition levels of irrelevant landmarks (*M* = 75.7, *SE* = 3.49, *p* = .096).

Contrasting the performance differences regarding the learning hypothesis, the percentage of correct responses for one landmark type was compared between navigation instruction conditions. The recognition rates for navigation relevant landmarks revealed that long instructions (*M* = 65.0, *SE* = 3.58) outperformed standard instructions (*M* = 46.8,

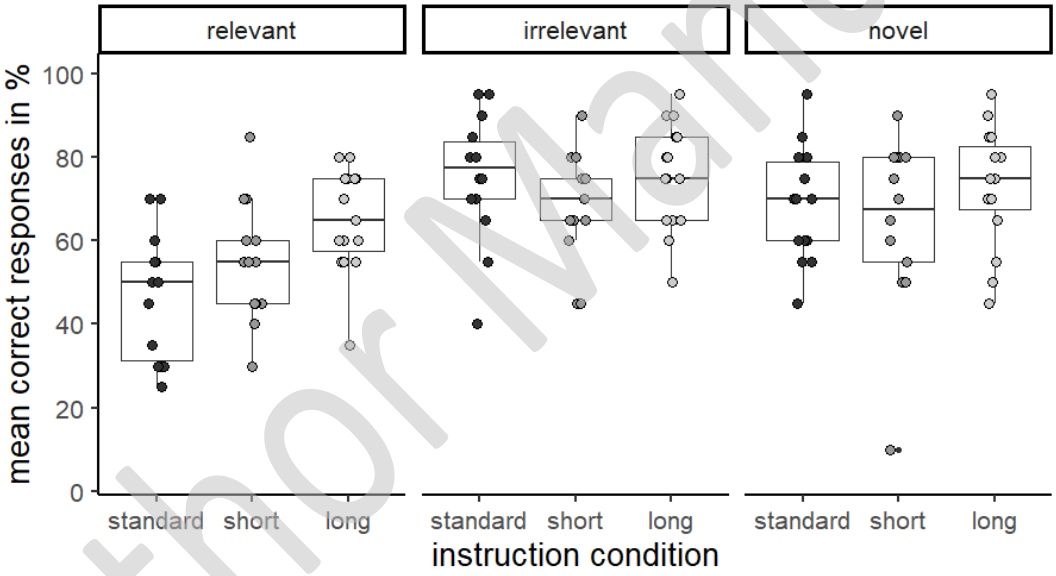

Figure 2: Boxplots and single subject performance scores in the first repetition of the cued-recall task of Experiment 1 with twenty landmarks per landmark category (relevant, irrelevant, novel). For mean correct responses, 100% equals the correct response to twenty landmarks of the respective category. The performance measure could reach twenty different values with a step-width of 5%. Whiskers display up to 1.5 standard deviations (SDs) from the mean. Small dots represent individual values above the whiskers.

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SE = 3.70, *p* = .006), but not short navigation instructions (*M* = 54.3, SE = 3.70, *p* = .262). All other post-hoc contrasts were non-significant (all *p*-values > .498).

Discussion

In Experiment 1, a paradigm shift from simulated driving to video-based pedestrian navigation was realized. This allowed us to test the incidental spatial learning effect of landmark-based navigation instructions in a more realistic setting. Two different landmark-based navigation instructions (short and long) were compared with a control group.

The performance data for all subgroups was in the same range as the performance data of previous experiments (Gramann et al., 2017, Wunderlich & Gramann, 2018). And the results revealed the positive impact of modified navigation instructions on spatial learning during navigation. It can thus be concluded that the replication was successful even though new modifications of landmark-based navigation instructions were introduced. In addition, the navigation context changed from simulated driving to an interactive video of pedestrian navigation that showed real-world visuals and included other traffic participants. This is remarkable and demonstrates that landmark-based navigation instructions lead to incidental spatial learning and that this impact is of a more general nature and context-independent. The cued-recall performance supports the assumption that incidental spatial learning at navigation relevant intersections was suppressed by standard navigation instructions and that this suppression was alleviated by landmark-based navigation instructions. This strengthens the reliability and generalizability of the effect as it was also observed in a more realistic environment using a different locomotion mode.

In more detail, the post-hoc comparisons of the main effect navigation instruction showed a better performance for the long as compared to the short navigation instructions across all landmark types. But there was no difference between the short navigation instruction and the standard instructions. This result was unexpected as we had assumed that

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performance for short would be better than for standard instructions. These results point to a difference in landmark learning based on the specifics of the landmark-based instructions. A short reference to a landmark seems to be less effective with regards to incidental spatial learning than an instruction providing additional landmark information. There was only a strong trend ($p = .07$) for better recognition performance with long landmark-based instructions compared to standard instructions. This can be explained by the very good performance for navigation irrelevant and novel landmarks in the standard instruction condition.

Regarding the factor landmark type, the least spatial knowledge was acquired for landmarks at navigation relevant intersections. As the instructions were received during these more difficult navigation phases, for example right before the turning manoeuver, less attentional resources were available for processing the surroundings. Announcing the intersection in the standard instructions seems to have shifted attention towards the intersection instead of the surroundings. This result replicates previous findings and further confirms the suppression hypothesis. Together with improved performance for landmark-based instructions approaching the performance level of other landmark types, this lends further support to the assumption that landmark-based instructions only overcome a suppression of spatial knowledge acquisition instead of fostering additional spatial learning. The post-hoc contrasts confirmed that long-modified navigation instructions were associated with the best cued-recall performance followed by short and standard instructions. The difference in performance for relevant as compared to irrelevant and novel landmarks decreased accordingly, revealing an alleviation of the learning suppression by landmark-based navigation instructions.

In summary in experiment 1, a video-based navigation paradigm replicated previous results demonstrating improved spatial knowledge acquisition at navigation relevant

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intersections when using navigation instructions with additional information about a landmark. This first replication, however, still lacked natural movement, the accompanying kinesthetic and proprioceptive information during real pedestrian navigation that might further support learning of the spatial surroundings (Gramann, 2013). To allow for multimodal information integration of all senses involved in natural navigation through the real world, Experiment 2 implemented a real-world navigation task with pedestrians actively navigating through Berlin.

Experiment 2

From the first to the second experiment, the experimental setting was changed from a stationary laboratory setup to a real-world setting allowing free movement of navigators. The second Experiment aimed at testing the full ecological validity of the previously demonstrated incidental spatial learning effects during the use of modified navigation instructions in an unrestricted, real-life setting.

Method

Participants. In this experiment, 41 participants were recorded during real-world navigation. Due to technical issues, five of the participants had to be removed from the database. The remaining 36 participants (21 females) were aged between 20 and 34 years (M = 26.6 years, SD = 3.03 years). Every experimental condition consisted of twelve participants with gender being balanced across conditions (standard instructions: 8 female; short instructions: 6 female; long instructions: 7 female participants). Participants were recruited through an existing database or personal contact and were reimbursed monetarily or received course credit. All had normal or corrected to normal vision and gave written informed consent prior to the study. The study was approved by the local ethics committee.

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Procedure. The experiment was scheduled in two sessions separated by a break of two weeks. Both experimental sessions lasted in total about 3 hours and 30 minutes. In the first part, participants navigated along a predefined route through an urban environment, the district of Charlottenburg, Berlin in Germany. The route overlapped with the route segment presented as video in Experiment 1. Each participant was guided by auditory navigation instructions. There were three groups of participants including a control group receiving standard navigation instructions. The landmark-based navigation instruction groups were either receiving the short, or long landmark-based navigation instructions. After a break of two-weeks (13 to 17 days, M = 14.1 days, SD = 0.73 days), the participants were invited to return and to solve spatial tasks in a laboratory setting. Participants were informed about the second session without providing information about its content. The relatively long break between navigation and test phase enabled us to investigate the generalizability of the previously reported long-term impact of landmark based navigation instructions on spatial knowledge acquisition (Wunderlich & Gramann, 2018). Importantly, and in contrast to Wunderlich and Gramann (2018), participants walked through a city environment during the navigation phase and were also moving through the same city during the break. Thus, they were experiencing a similar environment which could interfere with spatial knowledge about the experimental route. This way, the experiment represents an ecologically valid case of long-term spatial knowledge acquisition during assisted navigation.

Navigation phase. An experimenter met each participant at a train station close to the starting point of the route. There, the participant was informed about the upcoming navigation task. They were instructed to follow the auditory navigation instructions, to pay attention to the traffic while crossing streets, and to stop in case they did not know which direction to proceed. While navigating the route, an experimenter was walking in the vicinity of the participant to intervene in case of hazards and ensure that the participant would follow

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the correct route (see Figure 3a). The experimenter also manually triggered the auditory navigation instructions at predefined trigger points alongside the route using a browser-based application on a mobile phone. The auditory navigation instructions were provided to both, the participant and the experimenter, via Bluetooth headphones (Cheetah Sport In-Ear, Mpow, Hong Kong, China). The route consisted of 40 intersections including 22 direction changes. Participants arrived at the end of the route after approximately 60 minutes.

Following the navigation phase, navigators provided their subjective rating of the navigation task-related load as assessed using the NASA-RTLX (Hart, 2006; Hart, & Staveland, 1988). In addition, participants answered questions about route familiarity and acceptance of the modified navigation instructions.

Test phase. During the spatial test session in a controlled laboratory setting, the cued-recall task and a video-turn task were recorded. During the two tasks, participants were equipped with EEG (BrainAmps, Brain Products, Gilching, Germany) and seated at a table in front of a computer screen and keyboard. Analogous to the cued-recall task of Experiment 1, 120 landmark pictures were presented including forty pictures of each landmark type. Pictures of landmarks displayed their surroundings but in contrast to Experiment 1, landmarks were presented in a front view that deviated from the first-person perspective during walking (see Figure 3b compared to Figure 1b). Novel landmark pictures were photographs taken in a similar way and similar weather conditions in a neighboring area. Every landmark picture was shown until the participant responded by pressing one of the four possible arrow keys. After each response, participants were asked to rate how confident they had been about their answer on a six-point scale ranging from ‘1 - very sure’ to ‘6 - I did not know’.

Subsequent to the tasks, questionnaire data collected demographic characteristics, individual navigation styles, and spatial abilities. To assess individual orienting ability the

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Figure 3 a) Real-world setup of the navigation task in Experiment 2. The experimenter followed the participant and initiated the auditory navigation instructions. b) Frontal view picture of a navigation relevant landmark ("public restroom") as used in the cued-recall task (pictures were presented in color).

SBSOD (Hegarty et al., 2003) was used.

Statistical analysis. As in Experiment 1, the design was a mixed measures ANOVA with the between-subject factor navigation instruction condition (standard, short, long) and the repeated measures factor landmark type (relevant, irrelevant, novel). For additional information please see methods part of Experiment 1.

Results

The Spearman correlation of the SBSOD score and the percentage of correct responses to each landmark type was not significant (ρ*'s* < .242, *p's* > .156). Thus, the SBSOD score was not included as covariate in the ANOVA.

The ANOVA for the percentage of correctly identified landmarks and associated navigation decision revealed a significant main effect of navigation instruction condition ($F_{(1,33)}$ = 3.39, p = .036, η_p^2 =.183). The post-hoc comparisons revealed trends towards significance when comparing standard (M = 40.2, SE = 2.75) and short (M = 49.0, SE = 2.75,

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p = .090) as well as standard and long navigation instructions (M = 49.7, SE = 2.75, p = .062).

The main effect of landmark type also reached significance ($F_{(1.26,41.7)}$ = 57.4, p < .001, η_p^2 =.635) with post-hoc comparisons showing that the performance for relevant landmarks (M = 40.6, SE = 1.99) was significantly higher than for irrelevant landmarks (M = 28.0, SE = 2.98, p < .001) and significantly lower than the recognition performance for novel landmarks (M = 70.3, SE = 3.35, p < .001). Additionally, novel landmarks were significantly more often recognized than irrelevant landmarks (p < .001).

The interaction of instruction condition and landmark type did not reach significance ($F_{(2.53,41.7)}$ = 1.72, p = .184, η_p^2 =.095). The group-boxplots and individual measures can be seen in Figure 4.

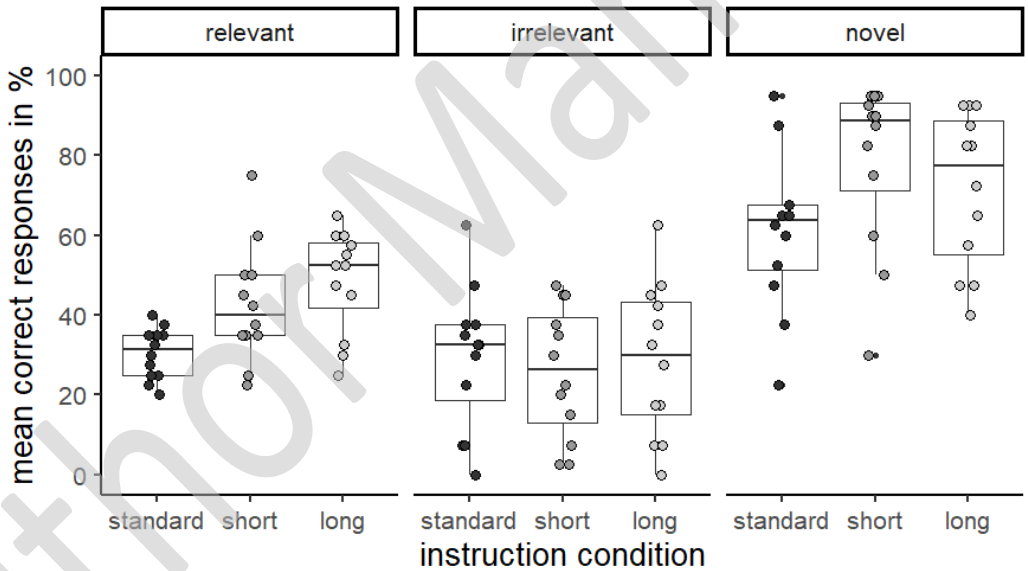

Figure 4: Boxplots and single subject performance scores of the cued-recall task of Experiment 2 taking place in real-world using forty landmarks per landmark category. Whiskers display up to 1.5 standard deviations (SDs) from mean and small dots represent individual values above the whiskers.

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According to the suppression hypothesis, the landmark types were compared within each instruction condition. For the standard navigation instruction condition the post-hoc comparisons revealed a significantly higher performance for novel (M = 60.8, SE = 5.81) as compared to relevant (M = 30.4, SE = 3.44, $p < .001$) and irrelevant landmarks (M = 29.38, SE = 5.16, p = .010). Relevant and irrelevant landmarks were statistically indifferent ($p > .999$). In the short navigation instruction condition. The cued-recall performance for relevant landmarks (M = 42.7, SE = 3.44) was significantly higher than for irrelevant (M = 25.8, SE = 5.16, p = .006) and significantly lower than for novel landmarks (M = 78.5, SE = 5.81, $p < .001$). The difference between irrelevant and novel landmarks was also significant ($p < .001$). When contrasting the long navigation instruction condition, the performance values for relevant landmarks (M = 48.5, SE = 3.44) were significantly higher compared to irrelevant landmarks (M = 28.8, SE = 5.15, p = .002) and significantly lower than for novel landmarks (M = 71.7, SE = 5.81, p = .006). Again, the difference between irrelevant and novel landmarks was significant ($p < .001$).

Testing the landmark-based learning hypothesis by comparing the instruction conditions within each landmark type revealed only significant post-hoc contrasts for relevant landmarks. The cued-recall performance for relevant landmarks was marginally lower in the standard navigation instruction condition (M = 30.4, SE = 3.44) compared to the short (M = 42.7, SE = 3.44, p = .098) and significantly lower when compared to the long instruction condition (M = 48.5, SE = 3.44, p = .004).

Discussion

Experiment 2 tested incidental spatial learning during assisted pedestrian navigation in an uncontrolled, dynamically changing real-world setting including cars and other pedestrians. Even after a break of two weeks, the results of the cued-recall task demonstrated an improved performance when navigating with landmark-based navigation instructions, in

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accordance with our learning hypothesis. The significant difference between short and long navigation instructions as observed in Experiment 1, however, was not replicated. In addition, the cued-recall results for irrelevant landmarks revealed a different pattern than all previous experiments. For the first time, navigation irrelevant landmarks revealed significantly lower recognition performance than navigation relevant landmarks irrespective of the navigation instruction condition. The recognition performance for novel landmarks was still relatively high, and comparable to the previous results (Experiment 1, Gramann et al., 2017; Wunderlich & Gramann, 2018).

The surprisingly low recognition performance for navigation irrelevant landmarks across all navigation instruction conditions was likely caused by the characteristics of the specific experimental protocol. One explanation for this performance drop is the change in perspective of the landmark pictures in the cued-recall task. In contrast to all previous experiments, landmark pictures were presented from a frontal view instead of a navigators' perspective. This might have been especially detrimental to the recognition of landmarks positioned at straight segments without junctions as participants might not have turned their heads to inspect all buildings and thus, irrelevant landmarks were less likely encountered from this frontal perspective.

Regardless of this difference in recognition performance for irrelevant landmarks, we again observed improved cued-recall performance for relevant landmarks when using landmark-based as compared to standard navigation instructions. The learning suppression was reflected in the performance differences for relevant landmarks compared to irrelevant landmarks. Whereas the recognition performance for irrelevant landmarks remained low across all navigation instruction conditions, the performance for relevant landmarks increased significantly when using landmark-based instructions. This supports the suppression

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hypothesis and that the alleviation of such a suppression effect is possible by including landmark-based information in auditory navigation instructions.

General Discussion

The focus of the reported experiments was to investigate a potential spatial learning suppression accompanying established navigation instructions as well as enhanced incidental spatial knowledge acquisition when using new versions of landmark-based navigation instructions. In addition, it was tested whether both effects can be generalized to ecologically valid scenarios. To that end, two consecutive experiments were conducted investigating the performance in a cued-recall task as an indicator for landmark- and route-level spatial knowledge acquired during a single exposure to an unfamiliar environment. The navigation contexts used were videos of (Experiment 1) as well as real-world pedestrian navigation (Experiment 2) through an unknown city area.

The results of both experiments replicated the positive impact of landmark-based navigation instructions on spatial knowledge acquisition which was shown for visual landmark augmentation (Li, Fuest, & Schwering, 2014; Löwen, Krukar, Schwering, 2019; Tom and Denis, 2003, 2004). Furthermore, they replicated the findings from Gramann and colleagues (2017) and Wunderlich and Gramann (2018) demonstrating an increased cued-recall performance especially regarding navigation relevant landmarks after navigating with auditory, landmark-based navigation instructions. This underpins the robustness and the ecological validity of the incidental spatial learning effect when using landmark information in auditory navigation instructions.

The results provided further evidence that adding detailed information about a landmark in addition to a landmark name is of advantage for incidental spatial knowledge acquisition. In Experiment 1, the benefit of the additional semantic information improved

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spatial learning compared to only naming the landmark in the instructions. It can be argued that the detailed information about the landmarks in the long navigation instructions may have helped to identify the landmark and this way eased the landmark recognition in the cued-recall task. However, the additional semantic information was mostly related to the function of the object and did not include characteristics that were visible (e.g., “Go straight at the Malteser building. This aid organization counts one million members.”). As such, the identification of landmarks was similar in both landmark-based navigation instructions and a confounding effect can be ruled out.

Following the argument that decreased spatial memory performance associated with the use of navigation aids is likely caused by divided attention between the control of movement and the navigation assistant (Gardony et al. 2013, 2015), spatial knowledge acquisition was expected to be impaired irrespective of the landmark category. In the studies of Gardony and colleagues only the retrieval of landmarks at decision points was investigated. Here, comparing memory performance for different landmark types, we demonstrated that spatial memory performance was decreased only for navigation relevant landmarks when using standard navigation instructions. This was likely caused by instructions biasing the attention towards the intersection while landmark-based navigation instructions helped to process environmental features. The augmentation of landmarks, in contrast, allowed to encode a specific landmark in association with a turning decision. The combination of both speaks for a suppression of incidental spatial learning by standard instructions that is abolished with an increasing amount of landmark-related information in the auditory navigation instructions.

Landmark-based instructions might have led to a general increase in attention towards the environment such that the instruction at relevant navigation points also impacted how the surroundings were processed during navigation irrelevant segments. Comparable

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recognition rates for navigation irrelevant and novel landmarks across navigation instruction conditions, however, ruled out such a halo-effect of landmark augmentation. Furthermore, the generally low recognition levels for irrelevant landmarks in Experiment 2 do not contradict the suppression hypothesis as the performance for novel landmarks remained on a high level. It rather raised the question whether the irrelevant landmarks were indeed recognized. The perspective in the landmark pictures changed from a first-person perspective while walking to a frontal perspective. This required a perspective-independent memory of a landmark and not just the familiarity with the street scene. Thus, it is likely that the high recognition performance for irrelevant landmarks in previous experiments was based on the street view and other features of the environment surrounding a landmark instead of the specific irrelevant landmark. This argument could be applied to navigation relevant landmarks as well. However, the data of Experiment 2 showed no impact of the changed perspective on these landmarks. The low performance for irrelevant landmarks in Experiment 2 encourages us to further investigate the auditory augmentation of navigation irrelevant landmarks in the future to better understand how this might affect incidental spatial learning during less demanding navigation phases. To further understand what kind of spatial knowledge is acquired during assisted navigation, future experiments will need to systematically manipulate the picture perspective and/or content in the cued-recall task.

An interpretation of the reported results is still restricted to incidental spatial learning after navigating one unknown route in an unfamiliar environment. A generalization to spatial knowledge acquisition based on multiple uses of landmark-based navigation instructions for the same route or different routes with overlap is not yet possible. However, the results let us expect that spatial learning would be enhanced even more. Multiple use of navigation assistance in the same area would also allow for assessing survey knowledge acquired from landmark-based navigation instructions. Fostering the acquisition of survey knowledge would

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be the ultimate goal of learning-oriented navigation assistance systems as this level of spatial knowledge would allow more flexible use of the acquired spatial knowledge. For now, the cued-recall performance allows for conclusions about the acquired landmark and route level knowledge, but not survey knowledge. Yet, this series of experiments covers both the transfer from low to high realism of the environment including visuals and other traffic participants as well as the realism of the movement dimension and allowing interfering navigation experiences. Despite the setup changes, the incidental spatial learning effects were replicated. The results indicate that landmark-based navigation instructions using additional detailed information about the landmark show improved spatial knowledge acquisition over standard navigation instructions currently used as default in available navigation assistance systems.

Conclusions

The findings of the two experiments reported here replicated the previously described incidental spatial learning associated with landmark-based navigation instructions. This effect was shown to be generalizable across different navigation contexts and types of locomotion. Thus, landmark-based navigation instructions are a promising tool to prevent deskilling of spatial abilities that comes with the use of standard navigation assistance systems. Especially the landmark reference combined with more detailed information prevailed amongst all tested modifications of auditory navigation instructions, rendering this approach the most promising. Future research should address the multiple use of landmark-based navigation instructions and the accompanying spatial knowledge acquisition. This way, navigation assistants may train the users' orientation abilities enabling them to autonomously navigate the environment in the future.

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Data Availability

Data were collected at TU Berlin. The data of single or both experiments are available on request from the corresponding author AW.

Key points

- Standard navigation instruction lead to a suppression of spatial knowledge acquisition at navigation relevant intersections
- Landmark-based navigation instructions are able to reverse this suppression effect
- This incidental spatial learning effect was tested in different experimental setups and was shown to be robust and ecological valid

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Biographies

Anna Wunderlich is a doctoral candidate and research assistant at Biological Psychology and Neuroergonomics at the Berlin Institute for Technology since she had received her master's degree in Human Factors at the same university in 2016.

Klaus Gramann is professor of Biological Psychology and Neuroergonomics at the Berlin Institute for Technology. He is also a professor at the School of Computer Science of the University of Technology Sydney and International Faculty at the University of California San Diego. In 2002, he received his PhD in Psychology from the RWTH Aachen University and habilitated 2007 at the LMU Munich in Biological and General Psychology.