American Journal of Applied Psychology
2014; 3(6): 131-137
Published online November 17, 2014 (http://www.sciencepublishinggroup.com/j/ajap)
doi: 10.11648/j.ajap.20140306.13
ISSN: 2328-5664 (Print); ISSN: 2328-5672 (Online)

Effects of marked routes in You-are-here maps on navigation performance and cognitive mapping

Sarah Lukas*, Victor Mittelstaedt, Gabriel Olaru, Cedric Sachser, Julia Seibold, Anke Huckauf

Institute of Psychology and Education, Ulm University, Ulm, Germany

Email address:
Lukas@ph-weingarten.de (S. Lukas), anke.huckauf@uni-ulm.de (A. Huckauf)

To cite this article:
Sarah Lukas, Victor Mittelstaedt, Gabriel Olaru, Cedric Sachser, Julia Seibold, Anke Huckauf. Effects of Marked Routes in You-are-Here Maps on Navigation Performance and Cognitive Mapping. *American Journal of Applied Psychology.* Vol. 3, No. 6, 2014, pp. 131-137.
doi: 10.11648/j.ajap.20140306.13

Abstract: A You-are-here map (YAH map) is a popular way to guide way-searchers (i.e. a person who is navigating in a more or less unknown area to a specific goal) through a designated area. With current technologies, information such as the current position and the optimal route to a chosen destination can be provided easily by marking the route in a map. In our study, we investigated the advantages and disadvantages of such marked routes on navigation performance in desktop virtual environments. 24 participants navigated through a 2 ½ D virtual environment. Navigation performance was measured by navigation time and number of deficiencies. In order to separate effects of cognitive maps from those of navigation performance, participants were asked to draw sketch maps after each trial. The results showed that participants who were shown the optimal route marked in the map beforehand, exhibited impaired knowledge of the environment and impaired navigation performance compared with those viewing the map without the route, independent of route complexity or viewing time of the map. Although map goodness was only slightly better when the route was not marked, the representation of the periphery was rated significantly better. Only route accuracy was better in the condition in which the route was marked. The results are interpreted in such way that basic impairments arise in cognitive mapping when reading a map of the designated area with a marked route, resulting in worse navigation performance.

Keywords: Way-finding, Navigation, You-Are-Here Maps, Cognitive Map, Marked Routes

1. Introduction

In everyday life, orientation and navigation through unknown areas are common challenges for humans. In order to provide effective and efficient way-finding aids to support this difficult task, the processes underlying orientation and navigation have to be understood. The current study aims to contribute in gaining further insight into the interaction of these processes.

Orientation and navigation are assumed to be based on a cognitive map. In such a cognitive map, a certain environment is mentally represented, either as a verbal description about spatial features or as a schematic map, that is, a conceptual visual representation of the environment consisting of points, lines, areas, surfaces [1]. Way-finding is defined as the reaching of a desired physical destination from a certain origin. It is a purposive, directed, and motivated activity [1], [2]. To facilitate this challenging process, humans have developed diverse aids. Maps are one of the most used way-finding aids. According to [3], a map already gives the conceptual structure of the environment. Therefore, maps are an external aid for the way-finding process, as it relieves the way-searcher from cognitive effort. A way-searcher is defined as a person who is navigating in a more or less unknown area to a specific goal. A good map supports the four subtasks of way-finding: 1. orientation, 2. choosing the route, 3. keeping the right track, 4. discovering the goal [4].

One established way to guide way-searchers through a designated area is a you-are-here map (YAH map). A YAH map is usually affixed in the area and contains a symbol that indicates at which position the map and therefore also the way-searcher is located. YAHMs are mainly used for walking on foot through an environment, in contrast, for example, to navigation systems equipped with GPS that help drivers to find their way [4]. Although a research movement also exists aimed at minimizing visual input and increasing auditory input [5], the visual representation of a map will still be the main navigation aid. There are already several principles about how to place and design YAH maps in the real world [6].

However, it is still unclear whether and how useful it can be to individually adapt a map with the way to a desired goal, that is, to mark the route.

With the help of current technologies like navigation systems in cars or smartphones, maps can be augmented and individually adapted, for example by marking a specific route directly into the map. These technologies are so convenient because they take over the effortful processes of orienting, route choosing, and track keeping. Augmenting the potential of a map, with navigation systems, not only the respective environment and the current position are represented but also the route is marked. Thus, with navigation aids, cognitive load can be reduced. For instance, it is assumed that marking a route facilitates processes like spatial chunking, which is the grouping of spatial information of which a route consists [7].

However, integrating an individual route can also be of disadvantage. It had been assumed that marking a route can hinder the way-searcher in building up a cognitive map, which allows for the most inferences of the environment ([4], [8], [9]). In this respect, previous research has revealed ambiguous findings. For instance, in the study of Münzer and colleagues [9], route recognition and survey knowledge were investigated. The findings showed that a map with a marked route was advantageous over navigation assistance technology that provided location dependent direction commands for building up a cognitive map. Unfortunately, there was no direct comparison between marked and not-marked routes. Neither did the authors investigate way-finding performance, but tested route recognition and survey knowledge. Schlender, Peters, and Wienhöfer [10] examined the usability of maps for desktop virtual environments. Their participants had to navigate to four destinations in a virtual world either after having studied a map for 90 sec before or when the map was available throughout navigation. One might assume that learning environmental information and having to keep this information in mind during navigating should encourage the construction of a cognitive map. But the data showed that information, which is available throughout way-finding, was advantageous for performance. However, as the authors assume, 90 sec might have been too short to construct a cognitive map consisting of four destinations.

A comparison of different navigation aids in a desktop virtual environment was made by Burigat and Chittaro [11]. The authors provided only essential information to the test subjects in terms of 2D and 3D arrows which point in the direction of the target in a virtual environment. Moreover, experienced and unexperienced users were investigated. The authors found that providing arrows was advantageous for navigation performance compared to providing no further information for experienced and unexperienced user and that 3D arrows were specifically useful for unexperienced users.

Only recently, Corcoran, Mooney, and Bertolotto [12] compared the workload required to create an *Interactive Route Description* (an annotated or marked route on a base-map) and a sketch map (a raw sketch of a route), respectively. In addition, navigation performance for both created navigation aids was tested. All participants preferred being provided with a route description by the Interactive Route Description. Navigation performance was analyzed by the amount of participants (way-searchers) having gotten lost, by the experienced workload of the way-searchers and by the preferred navigation aid of the way-searchers. Interactive Route description outperformed a sketch map in all variables. Basically, in this study, a map with a marked route was compared with a marked route without a map.

However, taking these results into account, a careful investigation of the costs and benefits of marked routes for navigation performance compared to maps without a marked route is still missing. This study aims to close this gap. One might suspect that marked routes are beneficial for way-finding efficiency, but come at the cost of establishing a cognitive map (see also [9]). Such an elaborated cognitive map would be of help, for example, in case the way-finding aid breaks down or if the constitution of a cognitive map is desirable (for example if the way-searcher will repeatedly move in the respective environment).

In the current study, we examined the question of how useful it is to provide the route to the desired goal. With respect to the four subtasks of way-finding, marked routes are hypothesized to hinder orientation due to impaired environmental knowledge. But they might be helpful in choosing a route by speeding up the process, especially when fast orientation is required. They should also facilitate keeping track of the route. We further assumed that effects of marked routes might be dependent of the complexity of the environment and of the viewing time of the map. The more complex an area is, the more important a cognitive map should be. The longer a way-searcher views a map of a specific area, the more detailed the cognitive map should be.

These hypotheses were investigated in our experiment. It is known that landmarks are used as orientation aids in real world navigation ([3], [10], [14]). Landmarks are noticeable objects situated at certain points in space. In order to investigate orientation performance, influenced only by certain features of a map, a virtual environment in which landmarks are controlled is the method of choice. As test-bed, we thus used the game Minecraft for constructing our virtual environments.

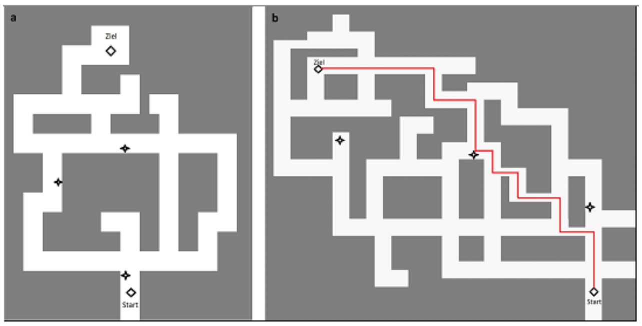

Figure 1. *The easy map without marked route (a) and the complex map with marked route (b).*

Participants performed a way-finding-task in a 2½ D desktop virtual environment after viewing a map. For half of the participants, the shortest route in the map was marked; the other half only saw the map without the marked route. According to [10], the maps were presented for 35s (short presentation duration) or for 70s (long duration; cf. [14]). Two environments were constructed, and respective maps were presented to each participant. They are referred to as easy and complex map (see Figure 1) to investigate potential effects of map complexity on the helpfulness of a marked route [13]. In order to separate effects of cognitive maps from those of navigation performance, participants were asked to draw sketch maps of the respective environment after each trial.

Concerning the quality of a cognitive map, all above mentioned findings suggest that marked routes impair the elaboration of such a map. With other words, forcing way-searchers to elaborate their own route might stimulate mental processes of constructing a cognitive map. A good cognitive map needs time to be built up. For this reason, we hypothesized that the quality of the cognitive map is increased for the long map presentation time compared to the short presentation time.

Concerning way-finding, two outcomes can be suggested: Given that marked routes hinder the construction of a cognitive map, way-finding behavior might suffer from the less elaborated cognitive map. This result would support the considerations of Johns [18], who assumes that the accuracy of orientation in an environment depends on the quality of the mental image of the surroundings. This effect would especially emerge for the difficult conditions, namely for a complex environment when the map could be studied only for a short time. On the other hand, one might argue that with marked routes it is less effortful to choose the route and to keep the track, resulting in faster navigation. This effect is to be assumed to be equal for simple as well as complex environments, but might be more prominent in the long map viewing time condition.

2. Method

2.1. Participants

24 psychology students (24 female; mean age of *M*= 20.4, *SD*=1.0) of Ulm University took part in the experiment. They received partial course credits for their participation. Earlier studies have shown that video gaming can improve navigation skills through immersive as well as desktop virtual environments ([11],[15]). Because women show less interest and report less participation in video gaming ([16], [17]) only female students were recruited to not confound video gaming training effect. Indeed, none of the participants reported to play video games on a regular basis.

2.2. Stimulus Material

By means of the PC game Minecraft 1.0 (https://minecraft.net/), three 2 ½ D virtual environments were created. One environment was used as practice trial, and the two experimental environments differed in their complexity. The environments consisted of cubes of the same size and texture. As mentioned above, effects of landmarks were to be excluded. However, pilot data showed that participants easily got lost and frustrated. Therefore, three landmarks were included into each environment to make them more distinguishable.

The complexity of the environments was composed of the length of the optimal route, the number of decision points, the number of branches at decision points, and the number of necessary turns, cf. [4]. The practice environment route consisted of 21 segments, five decision points with altogether eleven branches, and ten turns. The easy environment route consisted of 21 segments, six decision points, 13 branches and seven turns. The complex environment route consisted of 28 segments, nine decision points, 20 branches, and eleven turns (see Figure 1). Navigating was executed by use of the arrow keys of the keyboard.

2.3. Procedure

Participants first received an instruction that they should navigate towards a predefined destination through three environments. During instruction, they trained how to navigate through the virtual environment by means of the keyboard in a simple four-sided environment. Participants were allowed to repeat the training as often as they wished, but none failed to find her way through this training environment, and all reported to feel comfortable when controlling the input devices after having completed the first training.

Subsequently, participants were randomly assigned to one of the four different conditions (no route – long map presentation; no route – short map presentation; marked route – long map presentation; marked route – short map presentation). Participants were instructed to reach each destination as quickly as possible in the desktop virtual environment.

In the following practice trial, participants received the map for the practice environment printed in A3-size. Afterwards, they started the navigation through the virtual environment. The time needed to get from the starting position to the destination was measured. In case participants did not arrive after a maximum time of 3 minutes at the destination, the trial was aborted and counted as lost. The 3 minutes threshold was based on piloting experience showing that all environments could be traversed within one minute. By triplicating this time, it was ensured that even for novices, enough time was available. However, it was assumed that after 3 minutes, the way-searcher was completely lost and would find the destination only by luck and not by having achieved a cognitive map.

Navigation behavior was recorded online. According to O´Neill [19], it was categorized into fluent navigation, stopping and looking, wrong turns, backtracking (retracing of a path in the opposite direction of how it was first travelled). The three latter types were summarized to a total deficiency score.

After reaching the destination (or after 3 min elapsed), participants were asked to draw a sketch map of that environment. The same procedure as for the practice environment was repeated for the experimental environments. For each participant, the maps were shown for either 35s or for 70s. The order of the easy and the complex environment was counterbalanced across participants.

2.4. Design

The independent within-subject variable was map complexity (easy vs. complex), the independent between-subject variables were route (no route vs. marked route) and duration of map presentation (35s vs. 70s). The dependent variables were navigation time and deficiency score. Significance was tested at $\alpha = .05$.

3. Results

3.1. Navigation Time and Deficiency Score

All navigation times exceeding 180 seconds (3 minutes) were regarded as lost and excluded from analysis. This was the case for two participants for the easy map and for seven participants for the complex map. Thus, data were analyzed based on 22 participants for the easy and 17 participants for the complex map. The navigation times for each environment were entered into a three-way analysis of variance (ANOVA) with the within-subject variable map complexity (easy vs. complex) and the between-subject variables route (no route vs. marked route) and duration of map presentation (35s vs. 70s). The same three-way ANOVA as for the navigation time was conducted for the deficiency score (see Figure 2). In the following, the results of the navigation time and the deficiency score are reported.

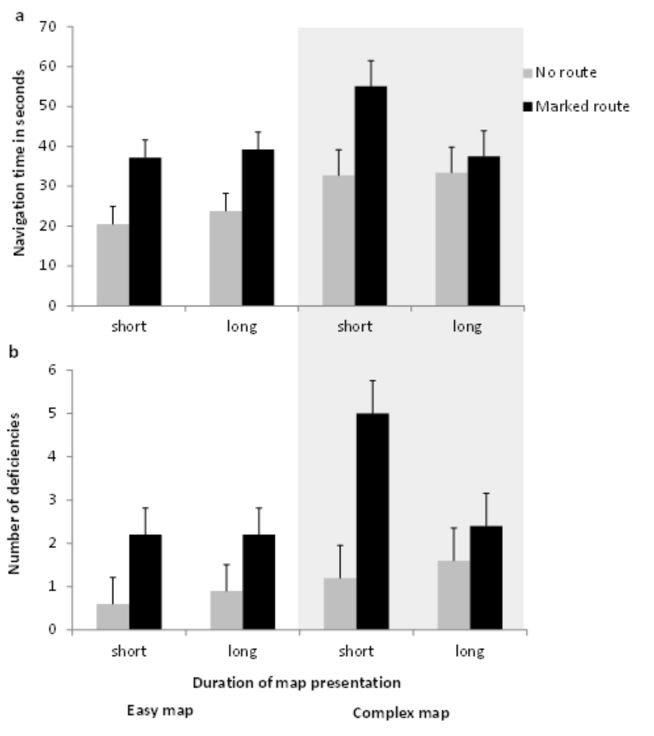

Figure 2. *Navigation time (a) and number of deficiencies (b) as a function of map (easy vs complex [highlighted in grey]), route (no route vs. marked route) and presentation time (short - 35s vs. long - 70s).*

Navigation time was longer for the complex map (39.7s) than for the easy map (30.2s; $F(1, 36) = 6.8$, $p <. 05$, $\eta^2 = .16$). Also, the complex map elicited more deficiencies (2.6) than the easy map (1.5; $F[1, 36] = 5.63$, $p < .05$, $\eta^2 = .14$).

Contrary to our expectations, participants were significantly faster when the route was not marked (27.6s) than when the route was marked (42.3s; $F[1, 36] = 12.6$, $p = .001$, $\eta^2 = .26$).

Again, the effect was corroborated by the deficiency score ($F[1, 36] = 13.1$, $p < .001$, $\eta^2 = .27$): When the route was not marked, less deficiencies were observed (1.1) than when the route was marked (3). The duration of map presentation was not significant, neither for navigation time, nor for the deficiency score *(Fs*< 1). No interactions were significant (all $Fs < 2.4$, $ps > .05$).

3.2. Rating of the Drawn Sketch Maps

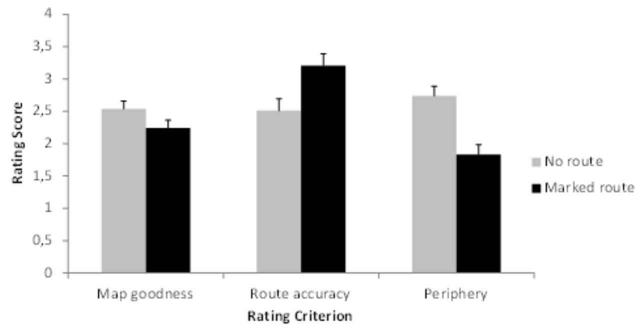

Figure 3. *Rating of the sketch maps drawn by the participants regarding Map goodness, Route accuracy, Periphery, differing in whether the route was marked in the map or not.*

To rate the sketch-maps drawn by the participants, we adapted the analysis method of Billinghurst and Weghorst [20] who suggested using the criteria *map goodness*, *object classes* and *relative object positioning*. The rating was performed by two independently acting raters, who were uninformed about the participant's identity, but who knew the original maps. They first rated the map under the consideration of how helpful the sketch-map would be to find the destination (*map goodness*, cf. [20]). For all ratings, a Likert scale reaching from one to five was used.

The original criterion *object classes* is defined as consisting of landmarks (e.g., trees, rocks, mountains) and present local arrangements. As we did not use landmarks that could be used as object classes this class was adapted to our own criterion *route accuracy*. Route accuracy reflects correct relations of the sketch-map's route, turns and directions.

Analogously to the criterion *relative object positioning*, which was defined as the correct position of objects, the criterion *map periphery* was created. It indicated if landmarks, crossways, and alternative routes were added to the sketch-map.

The inter-rater-reliability, Kendall's tao, for the rating of map goodness was $\tau = .603$ ($p < .001$), for the reliability of route accuracy $\tau = .775$ ($p < .001$), and for the periphery-rating it was $\tau = .815$ ($p < .001$). Overall, a good inter-rater-reliability of $\tau = .737$ ($p < .001$) was achieved.

The rating scores were entered into a three-way ANOVA with the within-subject variable rating criteria (map goodness, route accuracy, map periphery) and the between-subject variables route marking (no route vs. marked route) and duration of map presentation (35s vs. 70s). Reported post-hoc t-tests were Bonferroni-Holm corrected. For an overview of the results, see Figure 3.

While the rating score for route accuracy was significantly better in the marked route condition compared to the no-route condition ($t[46] = 2.776$, $p < .01$, $d = 0.8$), a marked route significantly lowered the ratings for the periphery ($t[46] = 4.367$, $p < .001$, $d = 1.3$). This was reflected in the two-way interaction between criterion and route ($F(2,88) = 18.03$, $p < .001$, $\eta^2 = .29$). Overall, ratings for map goodness were marginally lower with marked routes relative to no-route condition ($t[46] = 1,764$, $p < .1$, $d = 0.5$). Map presentation time did not have any effect on the rating of the sketch maps ($F < 1$).

4. Discussion

The aim of the present study was to shed light on the question of how the optimal route marked in a map affects way-finding and the process of constructing a cognitive map. This question is relevant with respect to technologies supporting navigation which can provide the way-searcher with such a route.

We hypothesized that marking routes might help navigation performance, but might impede the construction of a cognitive map. We expected to find differences in the sketch maps, especially for the difficult condition when the map prior to navigation was presented only for a short time. In order to test our hypotheses, participants traversed a 2 ½ D desktop virtual environment of which a map was presented beforehand. For half of the participants, the shortest route was marked in the map. After having viewed the maps, participants had to find their way through the virtual environment to a predefined destination. The time they needed to fulfill the task was measured, as well as the deficiencies made on the way. Moreover, the participants had to draw the map of the environment. The maps were rated according to map goodness, route accuracy and the representation of the periphery.

Contrary to our assumption that marked routes would help navigation performance, the results showed that the navigation time as well as the deficiency score was lower when the route was not marked compared to when the route was marked in the map. This finding shows that navigation performance is impaired by marking routes already early, during map viewing. This result was independent of the presentation time of the map as well as the complexity of the environment. That is, we found that when orientation was easy (i.e., in case of an easy environment with a long duration of map presentation) as well as when it was difficult (i.e., within complex environments when maps were presented for a short duration), marked routes did not produce any benefits. Assuming that maps without marked routes promoted the construction of a cognitive map ([4], [8], [9]), our finding indicates that navigation performance increases if a better cognitive map can be elaborated.

The results of the sketch maps drawn by the participants in fact corroborate the assumption that a more elaborated cognitive map was built up when the route was not marked. Although map goodness was only slightly better when the route was not marked, the representation of the periphery was rated significantly better. We assume that this was the important factor for the better navigation performance. As in the condition without marked route a good mental representation of the periphery was created, participants could better find back to the chosen route in case they got lost. Only route accuracy was better in the condition in which the route was marked. This is not surprising, considering that in the condition in which the route was marked, the focus of attention was drawn on the route. However, even when drawing the route benefitted from a previous viewing of a marked route, navigation performance did not. Interestingly, the duration of presentation time had no effect on the quality of the sketch maps.

Participants were not instructed to follow the route. Hence, the current findings have to be carefully interpreted. In addition, the number of participants is still small. Thus, we cannot exclude that non-significance of statistical effects is just a matter of power and does not demonstrate that some factors do not affect orientation and navigation performance. Another limitation of our study is that only women were tested. This fact is defensible given that it was not our intention to investigate gender differences in way-finding. Though, it is also eligible to argue that gender differences often result in navigation tasks. These differences also arise when comparing young and old participants or experienced and unexperienced users [11]. Moreover, navigation performance was tested in a relatively simple 2 ½ D environment. Hence, our findings are up to date limited to these constrictions. To generalize our findings, a broader group of participants as well as a transfer to navigation in 3 D environments or in the real-world are required. Our study provides a basic for that kind of follow-up research.

One can further question whether the results can be generalized to other routes and other conditions. We tested easy and complex routes as well as short and long map viewing times. Our results concerning route complexity strongly indicate that we succeeded in varying complexity: in the complex map, more participants were lost and navigation time as well as deficiency rates were higher. An even more complex map would be difficult for the way-searcher to capture and to remember. For an even easier environment than the one we used, no map would be needed. Hence, we strongly assume that with respect of complexity, our results can be generalized.

Concerning the map viewing time, we presented maps either for 35s or for 70s. There was no influence of map viewing time. 70s were at least for our participants a long time for viewing a map. However, it was well below the 90s which were assumed to be too short for orienting within a map [10]. For follow-up studies, we suppose that shorter viewing times would strengthen our effects.

Concerning the selection of our sample, we admit that for the time being, our results can only be generalized for female way-searchers. Given the operationalization of our experiment, it was important to us to not confound navigation abilities in 2½ D environments, which is often found in males who have a higher affinity to video games than females. However, to further generalize our results, one has to test males as well in a follow-up study. Still, we believe that the basic processes underlying orientation and navigation hold true for all humans, being male or female, old or young.

Given our results, for stationary YAH maps, it does not seem to be useful to create an adaptive system that indicates the route to the desired goal. However, we did not examine conditions in which way-searchers have a map at hand during the complete way-finding process. Based on the current findings, we can suggest that when the construction of a cognitive map is desired, marking routes should be omitted. Probably, this leads to more active route planning which is supposed to make path integration more accurate [21].

5. Conclusion

Our study provides new insight in how cognitive mapping and way-finding behavior interact. A map without a marked route supports the construction of a cognitive map, which improves navigation performance. This is at least valid if the map has to be kept in mind and if the environment does not provide any salient landmarks. To confirm this conclusion, more research with a broader pool of participants as well as the transfer in real-world is needed. Based on our findings, we can conclude that for the construction of adaptive stationary YAH-maps systems, marked routes cannot necessarily be recommended. Our results give a first hint that individual adaptation is not in any case beneficial for way-searchers. For way-finding, and especially for the construction of a cognitive map, general and less information can be more helpful.

Acknowledgments

We would like to thank an unknown reviewer for his/her helpful comments on an earlier version of this paper as well as Klaus Eder for proofreading.

References

[1] R. G. Golledge. Human wayfinding and cognitive maps. In R. G. Golldege, editor, *Wayfinding behavior: cognitive mapping and other spatial processes*, pages 5-46. Baltimore: Johns Hopkins University Press, 1999.

[2] R. Passini. Sign-posting information design. In R. Jacobson, editor, *Information design*, pages 83-98. Cambridge, MA.: MIT Press, 2000.

[3] C. Freksa. Spatial aspects of task-specific wayfinding maps. In J. S. Gero and B. Tversky, editors, *Visual and spatial reasoning in design*, pages 15-32. University of Sydney: Key Centre of Design Computing and Cognition, 1999.

[4] K.-F. Richter and A. Klippel. You-are-here-maps: Wayfinding support as location based service. In J. Moltgen and A. Wytzisk, editors, *Gi-Technologien für Verkehr und Logistik. Beiträge zu den Münsteraner GI Tagen*, *Vol. 13*, pages 21-39. Münster: IfGI Prints, 2002.

[5] B. N. Walker, J. Lindsay, A. Nance, Y. Nakano, D. K. Palladino, T. Dingler, M. Jeon. Spearcons (speech-based earcons) improve navigation performance in advanced auditory menues. *Human Factors,* 55: 157-182, 2013.

[6] M. Levine. You-are-here maps: Psychological Considerations. *Environment and Behavior*, 14: 221-237, 1982.

[7] A. Klippel, H. Tappe, C. Habel. Pictoral representations of routes: chunking route segments during comprehension. In C. Freksa, W. Brauer, C. Habel, K. Wender (Eds.) *Spatial Cognition III. Lecutre notes in computer science, Vol. 2685*, pp 11-33. Berlin: Springer, 2003

[8] A. Parush, S. Ahuvia and I. Erev. Degradation in spatial knowledge acquisition when using automatic navigation systems. In S. Winter, B. Kuipers, M. Duckham, & L. Kulik, editors, *Spatial Information Theory. 9th International Conference. COSIT 2007, Proceedings,* (Melbourne, Australia, September 19-23, 2007), pages 238-254. Berlin: Springer, 2007.

[9] S. Münzer, H. D. Zimmer, M. Schwalm, J. Baus and I. Aslan. Computer-assisted navigation and the acquisition of route and survey knowledge. *Journal of Environmental Psychology*, 26: 300-308, 2006.

[10] D. Schlender, O. H. Peters and M. Wienhöfer. The effects of maps and textual information on navigation in a desktop virtual environment. *Spatial Cognition and Computation*, 2: 421-433, 2000.

[11] S. Burigat and L. Chittaro. Navigation in 3D virtual environments: Effects of user experience and location-pointing navigation aids. *International Journal of Human-Computer Studies, 65*, 945-958, 2007.

[12] P. Corcoran, P. Mooney and M. Bertolotto. Interactive cartographic route description. *Geoinformatica*, 18, 1-26, 2014.

[13] S.Hirtle, K.-F. Richter, S. Srinivas. This is the tricky part: When directions become difficult. *Journal of Spatial Information Science*, 1: 53-73, 2010.

[14] W. S. Albert, R. A. Rensink and J. M. Beusmans. Learning relative directions between landmarks in a desktop virtual environment. *Spatial Cognition and Computation,* 1: 131-144, 1999.

[15] A. E. Richardson, M. E. Powers and L. G. Bousquet. Video game experience predicts virtual, but not real navigation performance. *Computers in Human Behavior,* 27, 552-560, 2011.

[16] S. M. Ogletree and R. Drake. College students' video game participation and perceptions: gender differences and implications. *Sex Roles*, 56, 537-542, 2007.

[17] K. Lucas and J. L. Sherry. Sex differences in video game play: A communication-based explanation. *Communication Research,* 31, 499-523, 2004.

[18] C. Johns. Spatial learning: cognitive mapping in abstract virtual environments. *Proceedings of the 2nd international conference on computer graphics, virtual reality, visualisation and interaction in Africa*, pages 7-16. New York: ACM, 2003.

[19] M. J. O'Neill. Effects of signage and floor plan configuration on wayfinding accuracy. *Environment and Behavior*, 23: 553-574, 1991.

[20] M. Billinghurst and S. Weghorst. The use of sketch maps to measure cognitive maps of virtual environments. *Proceedings of the Virtual Reality Annual International Symposium 1995,* pages 237-288. Research Triangle Park, NC: IEEE Computer Society Press, 1995.

[21] J. M. Loomis, R. L. Klatzky, R. G. Golledge and J. W. Philbeck. Human navigation by path integration. In R. G. Golledge, editor, *Wayfinding behavior: cognitive mapping and other spatial processes*, pages 125-151. Baltimore: Johns Hopkins Univ. Press, 1999.