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Published in:
Meeting Diversity in Ergonomics. Proceedings of the IEA 2006 congress (CD-rom, article 0398).

Differences in cognitive map-acquisition between visually impaired and sighted persons

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Abstract

This study compares visually impaired and sighted persons in their use of auditory information. It was expected that sighted persons would benefit from survey-type descriptions of an environment whereas visually impaired persons would benefit from route-type descriptions. 27 visually impaired and 28 normally sighted participants listened to a survey-type or a route-type description of a fictitious zoo. Then they answered questions about spatial relations between zoo areas. These questions were both in route-type and survey-type. The descriptions were repeated twice, and each time comparable questions were answered. Visually impaired participants did not differ in error frequency between survey-type and route-type descriptions. In contrast, sighted participants were better for the survey-type than for the route-type description. Also, the learning curve for the visually impaired was steeper that for the sighted, although at the end of the third presentation they made still more errors that the sighted. Closer examination of the data revealed the existence of two sub-groups both in the group sighted and visually impaired participants. They may be called good learners and bad learners and they showed marked differences in their ability of acquiring a cognitive map from auditory descriptions of an environment.

Keywords: experimental study, visually impaired, auditory information, way-finding, cognitive maps

1. Introduction

Acquiring a mental representation of our surrounding world is vital for performing elementary tasks such as going to work or school, shopping, going home, going anywhere. Gaining and using such a representation is termed “cognitive mapping”… a cognitive map comprises “the internal representation of perceived environmental features or objects and the spatial relations among them” [1]. The notion of a cognitive map was introduced by Tolman [2] in his study of rats in maze learning, but proved very useful in humans too. Information in a cognitive map may consist of landmark knowledge, route-based knowledge or survey-based knowledge (e.g. [3]). It is assumed that the latter two representations originate from the two possible ways environments can be learned or viewed: moving around in them versus looking upon them (assisted by a map or a high position). Having a survey representation appears to benefit cognitive-mapping tasks because it has more power to solve occurring problems. With only route-based knowledge unexpected obstructions cannot be circumvented, whereas with survey-based knowledge an alternative route can be calculated.

Generally, for the acquisition of the cognitive map visual information is used, and wayfinding aids are predominantly visual (signs and arrows). However, visually impaired people (VIPs) have to rely on vestibular, haptic and auditory information. VIPs access the information in a much more sequential way, since they cannot "look around". Therefore their information resembles more route information. Nonetheless VIPs are able to do cognitive-mapping tasks; they manage to learn mutual spatial relations between locations in the environment and are able to reach destinations. Thus it appears that they are able to generate a cognitive map from their non-visual sequential information sources.

The question arises whether there is a difference between normally sighted and visually impaired people in their ability to form a cognitive map and to convert their general information type (more survey-like versus more sequential, route-like) into an abstract representation, that in turn allows them to convert route-like to survey-like information and vice versa if needed. It may be that this map built-up is slower and less precise in VIPs compared to normally sighted [4].

Noordzij et al. [5] conducted a pilot study in which they gave participants a survey-type or a route-type description of a fictitious zoo. They asked subjects to estimate whether the distances between one pair of animal cages was larger or smaller that the distance between another pair. e.g. "the distance between giraffe and rabbit compared to the distance between giraffe and hyena". This study was done with normally sighted subjects and repeated with VIPs afterwards. The results suggested that normally sighted people were faster with route descriptions versus survey descriptions, but their accuracy was reversed, whereas the VIPS showed equal proficiency for route and survey descriptions.

In the Noordzij et al. study, distance estimation was the issue; in the present study the focus is on rate of learning and information-type conversion from one type to applicable knowledge of the other type. Therefore the set-up is different from Noordzij et al., although these is a resemblance with a more recent study by Noordzij and Postma[6]. Participants were given a verbal description of either a route through a (fictitious) zoo or a overview of the zoo. The route description consisted of terms like "to the left, to the right", whereas the survey description had terms like "to the north" "to the west". This description was repeated once. Then they had to answer both route-like and map-like questions. The description was given again, and questions were asked again. For a third time the description was presented, followed by questions. In this way both the possibility of the built-up of a particular kind of knowledge was assessed, as well as the possibility of information-type conversion, and learning rate.

The following hypotheses were tested:

1) Normally sighted participants will do better than VIPs with survey-type information; this may be reversed with route-type information.
2) Normally sighted participants will do better with survey-type information than with route-type information; this difference may be reversed for VIPs.
3) Normally-sighted participants will learn the environment more quickly than VIPs, especially in the first and second exposure to the information.
4) Normally sighted participants will be able to use survey-type information better to answer route-type questions that reversed;
5) VIPs will be able to use route-type information better to answer survey-type questions that reversed.

Of course the results will be explored for other interesting effects. Performance was measured in terms of proportion correct answers to the questions.

2. Method

2.1. Participants

The VIPs (n=27) were recruited from the volunteer list of the Laboratory of Experimental Ophthalmology, University Medical Centre Groningen (LEO-UMCG). They beforehand gave a record of their impairment type and severity, added with some biographical data. The sighted participants (n=28) were recruited by asking volunteers from the acquaintances of the experimenters and were matched as good as possible with a VIP in age, gender, and education. Participants were treated according to common ethical standards; they gave informed consent prior to the experiment, and received travel expenses.

2.2. Material

The descriptions were tape-recorded on cassette, read by a neutral male voice. Each description consisted of approximately 270 words, lasting 2'34". A sample of the route-like description (original in Dutch): "... At your right is the children's farm. After the children's farm you turn right, and then left. You are in a path with right the aquarium. Left is the reptile home. Go straight on to the monkey rock. …"

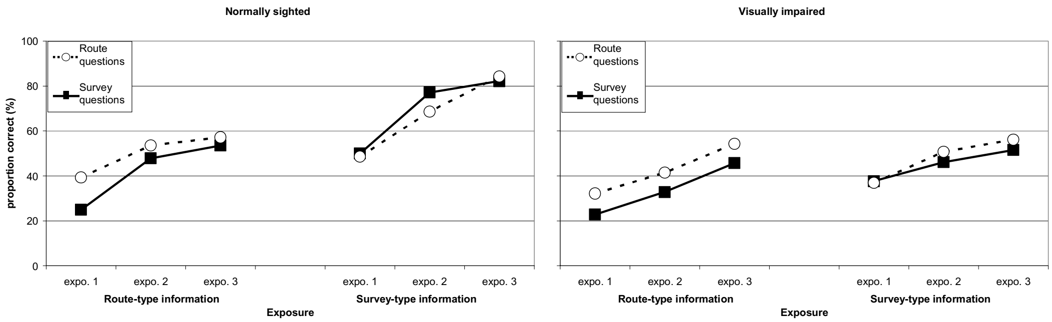

Figure 1: average proportion correct answers for each vision group (separate panels), separated for information type, question type and exposure.

Part of the survey-type description: "… The area of inside animals is north of the children's recreational area. It is divided in three parts. At the east is the aquarium and at the west the insects home. In between is the reptile home. …"

The questions were listed and read aloud by the experimenter. There were 20 questions each time, 10 were route-like and 10 survey-like. Examples of route-like questions: "Standing in a path with your back to the children's farm and facing the monkeys, which animals are left of you?", "You are between the reptiles and the aquarium, heading for the children's farm. To go to the insects home, you will turn left or right?" . Examples of survey-like questions: "Which animals are east of the insects?", "which animals are west of the aquarium?" The full information can be obtained from the first author.

2.3 Set-up

Two groups of participants (VIPs or normally sighted) were matched for age, gender and education. Matched couples were assigned at random to an information type: survey or route information, but the type and severity of the visual impairments were more or less equally distributed across information type. All four groups received the same questions consisting of both survey-type and route-type questions. There were three measurements, each time after a new exposition of the information. The design therefore was: 2 (between: visual condition) × 2 (between: information type) × 2 (within: question type) × 3 (within: exposure repetition).

2.4. Procedure

After being welcomed participants were seated at a table. They were informed and could ask questions. They gave their consent. The auditory information was played back which they heard on headphones, as loud as they preferred. The first exposure consisted of two times listening to the tape. After that the questions were asked and the answers were recorded on paper. A second exposure followed, consisting of one time listening to the information. The second list of questions was given. The third exposure was listening again once to the information, followed by the third question list. After finishing some additional questionnaires for another study, and debriefing, they received travel expenses and were gratefully dismissed.

3. Results

The average number of correct answers on each type of questions was calculated after each exposure and for each of the four (visual × information type) groups. These numbers were recalculated as percentages, and subjected to repeated-measures ANOVAs (SPSS-GLM) with various post-hoc comparisons according to the hypotheses and the design presented in the set-up section. Figure 1 presents the averages in separate panels for each vision group.

Normally sighted people answered more questions correctly than VIPs ($F_{(1,51)} = 5.89$; $p < 0.05$; $\eta^2 = 0.103$). And participants with survey-type information had more questions correct than participants with route-type information ($F_{(1,51)} = 6.26$; $p < 0.05$; $\eta^2 = 0.106$).

Figure 1 suggest an interaction between vision and information type; this was not significant ($F_{(1,51)} = 1.31$; n.s.; $\eta^2 = 0.025$). However, in post-hoc paired comparisons, based on reliability intervals with Bonferroni-correction for number of tests, it was found that normally sighted people with survey-type information did better than VIPs with survey-type information; since this was to be expected from hypothesis 1, the test was one-tailed. (*mean difference (md)* = 21.9%; $p < 0.05$). The difference between vision and route-type information was not significant (*md* = 7.9; n.s.), thus the reversal in hypothesis 1 was not supported.

Normally sighted people did better with survey-type information than with route-type information, as was predicted from hypothesis 2, hence tested one-sided (*md* = 22.4; $p < 0.05$). The difference for the VIP-group between information-types was not significant (*md* = 8.3, n.s.), thus the reversal for VIPs in hypothesis 2 was not supported.

Figure 1 shows a clear improvement with increasing exposure ($F_{(2,102)} = 42.23$; $p < 0.001$; $\eta^2 = 0.628$). The normally sighted people improved faster than the VIPs; since this was hypothesis 3 a one-sided test could be performed ($F_{(2,102)} = 2.90$; $p < 0.05$; $\eta^2 = 0.104$). Within this interaction both the linear and the quadratic trends were significant ($F_{(1,51)} = 2.91$; $p < 0.05$ one-sided, and ($F_{(1,51)} = 3.08$; $p < 0.05$ one-sided respectively). The improvement was steeper for normally sighted people between exposure 1 and 2, but levelled off between exposure 2 and 3. For the VIPs, the improvement was less steep, but remained more or less equal across exposures. These findings support hypothesis 3. This is confirmed when the analysis is repeated for each vision group separately. In the ANOVA for the normally vision people both the linear and quadratic trend are significant ($F_{(1,26)} = 56.66$; $p < 0.001$ and $F_{(1,26)} = 8.08$; $p < 0.01$ respectively), whereas in the ANOVA for the VIPs only the linear trend is significant ($F_{(1,25)} = 27.74$; $p < 0.001$).

There was a main effect of question type: survey-type questions were generally answered better than route-type questions ($F_{(1,51)} = 5.31$; $p < 0.05$; $\eta^2 = 0.094$). Figure 1 shows an interaction between information-type and question-type ($F_{(1,51)} = 5.06$; $p < 0.05$; $\eta^2 = 0.090$); for route-type information the route-type questions were answered better than the survey-type questions. For survey-type information there was no difference between the answers on the two types of questions. Higher-order interactions, as predicted by hypothesis 4 and 5, were not significant, hence these were not supported.

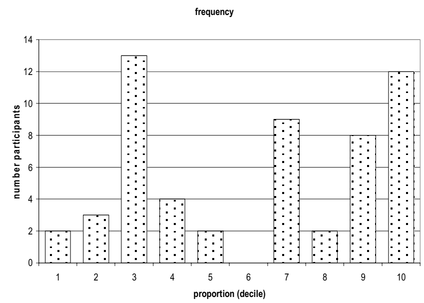

Figure 2: frequency distribution of proportion correct answers after three expositions to the information.

In inspecting the data it appeared that there may be a division between participants who were well able to learn the relative positions of objects in the fictitious zoo, and those who did not improve across exposures. Figure 2 shows the distribution of participant's correct answers after exposure 3.

In order to explore the influence of being a good or bad performer, it appears justified to divide the participants' group into two subgroups, having answered correctly more or less than 60% of the final 20 questions. The GLM-analysis on the complete design was repeated with an additional factor: learning group (good, bad). Of course the main effect of learning group was highly significant ($F_{(1,47)} = 121.93$; $p < 0.001$; $\eta^2 = 0.722$.). Especially, the first-order interactions between learning group and the other independent variables were interesting. It appeared that the difference between good and bad learners in each vision group were equal ($F_{(1,47)} = 1.60$; n.s.; $\eta^2 = 0.033$). However, the interactions between learning group and question type ($F_{(1,47)} = 8.56$; $p < 0.01$; $\eta^2 = 0.154$), learning group and information type ($F_{(1,47)} = 8.09$; $p < 0.01$; $\eta^2 = 0.147$), learning group and exposition ($F_{(2.94)} = 17.89$; $p < 0.001$; $\eta^2 = 0.276$), and learning group, question type and information type ($F_{(1,47)} = 11.63$; $p < 0.001$.; $\eta^2 = 0.198$) were significant. Figure 3 shows the results. As can be seen, in the good-learners group the use of route-type information leads to better performance on the route-type questions, whereas the use of survey-type information gives better answers for survey-type questions. Also, the performance on questions is better with survey-type information than with the route-type information. And furthermore, the good learners still improved after the third exposure. In contrast, the bad learners correctly answer more questions of the route-

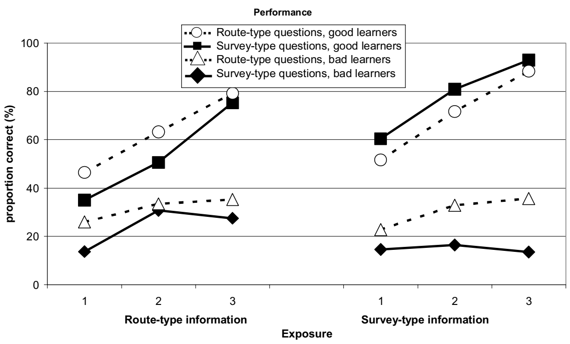

Figure 3: average proportion correct answers for each type of information (separate panels), separated for learners group, question type and exposure.

type irrespective of the type of information they received. Also there is no difference in performance between route-type and survey-type information. And finally, they do not improve as a result of exposure.

Table 1 shows the frequency distribution across the four categories of participants for good-learners and bad-learners. The difference between normally sighted people and VIPs was marginally significant ($\chi^2 = 3.06$, $df = 1$, $p = 0.080$), and did not differentiate between information type ($\chi^2 = 2.29$, $df = 1$, $p = 0.130$).

4. Discussion

In this study the built-up of a cognitive map of a fictitious environment was studied in normally sighted and in visually impaired participants (VIPs). The information of the environment was presented auditory with a route-type or survey-type description, and it was repeated two times. After each information exposure the participants answered route-type and survey-type questions about the relative locations of elements in the environment.

It was found that normally sighted participants were better in answering these questions than VIPs, especially with survey-type information. With route-type information these was no difference between normally sighted people and VIPs. This supports partially the first hypothesis. In the normally sighted people group it was found that performance was better with survey-type than with route-type information, whereas in de VIPs-group there was no difference between performance for the two information types. This supports partially he second hypothesis. It means that VIPs are relatively better in using route-type information than survey-type information, compared to normally sighted people. Since VIPs receive much, if not all, information in other ways than by vision they have to rely more on senses that are much more sequential and egocentric in nature. This appears to result in a relative advantage of sequential, route-type information above survey-type information in the build-up of a cognitive map for VIPs, whereas normally sighted people who are used to review an environment literally in one glance benefit from survey-type information. The fact that people are able to transform one type of information in to another is a replication of older results (e.g. [7]).

For normally sighted people the improvement by learning was much steeper in the first than in the second part of the curve, whereas for VIPs it showed an equal slope. Furthermore, the VIPs learned slower than the normally sighted people. This supported the third hypothesis. For normally sighted people a ceiling effect may have caused the learning curve to level off after the second exposure, whereas the VIPs had still possibilities for improvement.

An important issue in this study was the difference in performance between question types with respect to information type. The route-type information group answered route-type questions better than survey-type questions. This pattern was not reversed for the survey-type information group. Also there was no clear difference between normally sighted people and VIPs. Therefore the differentiating hypotheses, four and five, were not supported.

However, closer inspection of the data showed that the group was far from homogenous. It appears that there was a subgroup of participants who did show marked improvements, whereas in another subgroup there were virtually no improvements at all. When

Table 1
Frequency distribution of good and bad learners across groups. NR = Normally sighted, route-type information; NS = normally sighted, survey-type information; VR = visually impaired, route-type information; VS= visually impaired, survey-type information.

Group	Good learners	Bad learners
NR	7	7
NS	12	2
VR	6	8
VS	6	7

these two groups were separated, the effects of information type and question type showed a striking diversion. In the bad-learners group route-type questions were answered better than survey-type questions, irrespective of information type. Also the performance did not differ between the two information types. For the good-learners group this pattern was completely different. Route-type questions were answered better with route-type information, whereas survey-type questions were answered better with survey-type information. Furthermore, survey-type information gave a generally better performance than route-type information. There were no differences between normally sighted people and VIPs.

This means that the differentiating effects of information type on question type from hypothesis four and five were only found for those participants who were able to use the information and learn from it.

The aforementioned results are in line with ideas of Millar [8] (see also [9]). She proposes that spatial knowledge is composed of multi-modal information, which can be retrieved to address both survey-type and route-type issues. VIPs may be as effective as normally sighted to form and use such coding and retrieval, but in this study VIPs appear effective but not as efficient as normally sighted [10]. Efficiency in VIPs may be improved by the fact that in real environments they may be engaged in active and locomotive exploration of the spatial relations between objects and pathways between them [11].

Acknowledgements

Thanks are due to Ankie Sijbenga, Inge Vredegoor, Joep Hofhuis, Sandra Flammand, and Teun Trompert for running the experiment as part of their bachelor thesis in psychology, and the UMCG-LEO for using the volunteers list of VIPs and the facilities to do the experiment.

References

[1] Golledge RG. Human wayfinding and cognitive maps. In: Golledge RG, (Ed.) *Wayfinding behavior - cognitive mapping and other spatial processes*. Johns Hopkins University Press, Baltimore, 1999, pp 5-45.

[2] Tolman EC. Cognitive maps in rats and men. *Psychological review* 55 (1948) 189-208.

[3] Siegel AW, White SH. The development of spatial representations of lage-scale environments. In: Reese HW, (Ed.) *Advances in child development and behavior*. Academic press, New York, 1975, pp 9-55.

[4] Thinus-Blanc C, Gaunet F. Representation of space in blind persons: Vision as a spatial sense? *Psychological Bulletin* 121 (1997) 20-42.

[5] Noordzij ML, Zuidhoek S, Van Meggelen C, Petersen R, Prinsen G, Postma A. The influence of perspective on the properties of spatial mental models. Unpublished manuscript, Utrecht, University of Utrecht, 2003.

[6] Noordzij ML, Postma A. Categorical and metric distance information in mental representations derived from route and survey descriptions. *Psychological Research-Psychologische Forschung* 69 (2005) 221-232.

[7] Tversky B. Levels and structure of spatial knowledge. In: Kitchin RM, Freundschuh S, (Eds.) *Cognitive mapping: past, present and future.* Routledge, New York, 2000, pp 24-43.

[8] Millar S. *Understanding and representing space: theory and evidence from studies with blind and sighted children.* Oxford University Press, Oxford, 1995.

[9] Taylor HA, Tversky B. Perspective in spatial descriptions. *Journal of Memory and Language* 35 (1996) 371-391.

[10] Ungar S. Cognitive mapping without visual experience. In: Kitchin RM, Freudschuh S, (Eds.) *Cognitive mapping: past, present and future*. Routledge, London, 2000, pp 221-248.

[11] Klatzky RL, Loomis JM, Beall AC, Chance SS, Golledge RG. Spatial updating of self-position and orientation during real, imagined, and virtual locomotion. *Psychological Science* 9 (1998) 293-298.