Anticipatory Cognitive Mapping of Unknown Spaces by People who are Blind Using a Virtual Learning Environment

David Mioduser & Orly Lahav
School of Education, Tel Aviv University
Ramat Aviv, 69978, Tel Aviv, Israel
Tel: 972-3-6408465, Fax: 972-3-6407752
Email: miodu@post.tau.ac.il

Abstract: Mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel. People who are blind lack this crucial information and in consequence face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating proficiently within these spaces. The work reported in this paper follows the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may contribute to the anticipatory mental mapping of unknown spaces and consequently, to blind people's spatial performance. The main goals of the study reported in this paper were: (a) The development of a virtual learning environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings); (b) A systematic study of blind people's acquisition of spatial navigation skills by means of the virtual learning environment; (c) A systematic study of the contribution of this anticipatory mapping to blind people's spatial skills and performance in the real environment. In the paper a brief description of the virtual learning environment is presented, as well as findings regarding blind persons' learning process and actual performance in the real space.

Introduction

The ability to explore unknown spaces independently, safely and efficiently is a combined product of motor, sensory and cognitive skills. Normal exercise of this ability directly affects individuals' quality of life. Mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility (O&M) skills. Most of the information required for this mental mapping is gathered through the visual channel (Lynch, 1960). People who are blind lack this information, and in consequence they are required to use compensatory sensorial channels and alternative exploration methods (Jacobson, 1993). The research reported here is based on the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may help to enhance blind people's ability to explore unknown environments (Mioduser, in press).

Research on blind people's mobility in known and unknown spaces (Golledge, Klatzky, & Loomis, 1996; Ungar, Blades, & Spencer, 1996), indicates that support for the acquisition of spatial mapping and orientation skills should be supplied at two main levels: perceptual and conceptual. At the perceptual level, the deficiency in the visual channel should be compensated with information perceived via other senses. Hearing, smell and touch are powerful information suppliers about known as well as unknown spaces. The auditory channel supplies essential information about events, or the presence of other people (or machines or animals) in the environment. In indoor space the blind can use echo feedback (by whistling, clapping hands or talking) to estimate distances (Hill, et al, 1993). The smell channel supplies additional information about particular situations (e.g., perfumery, bookstore or bakery in a shopping center) or about people. Haptic information appears to be of great potential for supporting appropriate spatial performance. Fritz, Way and Barner (1996), define haptics as follows: "tactile refers to the sense of touch, while the broader haptics encompasses touch as well as kinesthetic information, or a sense of position, motion and force." For the blind, haptic information is commonly supplied by the cane for low-resolution scanning of the immediate surroundings, by palms and fingers for fine recognition of objects' form, texture and location, and by the feet regarding surface information.

As for the conceptual level, the focus is on supporting the development of appropriate strategies for the efficient exploration of the space and the generation of efficient navigation paths. For example, Jacobson (1993), described blind people's indoor environment familiarization process as one that starts with the use of a perimeter-recognition-tactic -walking along the room's walls and exploring objects attached to the walls- followed by a grid-scanning-tactic -aiming to explore the room's interior.

Advanced computer technology offers new possibilities for supporting blind people's acquisition of O&M skills, and the development of alternative navigation strategies, at both the perceptual and conceptual levels. Current Virtual Reality (VR) technology facilitates the development of rich virtual models of physical environments and objects to be manipulated, offering blind people the possibility to undergo learning or rehabilitation processes without the usual constraints of time, space, and a massive demand of human tutoring (Loomis, Klatzky & Golledge, 2001; Schultheis & Rizzo, 2001; Standen, Brown & Cromby, 2001). Research on the implementation of haptic technologies within VR spatial simulation environments reports on its potential for supporting rehabilitation training with sighted people (Darken & Banker, 1998; Waller, Hunt & Knapp, 1998), and perception of virtual textures and objects by blind people (Colwell, Petrie, & Kornbrot, 1998; Jansson et al, 1998).

The research reported in this paper follows the assumption that the supply (via the technology) of compensatory perceptual and conceptual information may contribute to blind persons' cognitive mapping of spaces. To examine the above assumption we developed a multisensory-virtual-learning-environment (MVLE) and studied the exploration process of an unknown space by blind subjects using the MVLE. Their performance was compared to that of a control group of blind people who explored directly the real environment simulated in the MVLE. The main research questions of this study were:

1. Does the walking in the virtual learning environment contribute to the construction of an efficient cognitive map of the unknown space?
2. How does this cognitive map contribute to the blind person's O&M performance in the real space?

The Haptic Virtual Learning Environment

For the study we developed a virtual environment simulating real-life spaces. This virtual environment comprises two modes of operation:

Developer/Teacher Mode

The core component of the developer mode is the virtual environment editor. Figure 1 shows the environment-editor screen. The developer mode allows the researcher or teacher to build navigation environments according to instructional or research needs. This module includes three tools:

(a) Environment builder - by this tool the developer defines the physical characteristics of the space, e.g., size and form of the room, type and the size of objects (e.g., doors, windows, furniture pieces) and their location.

(b) Force-feedback editor - by this editor the developer is able to attach Force-Feedback Effects (FFE) to all objects in the environment. Examples of FFE's are vibrations produced by force fields surrounding objects, or tactile characteristics of structural components such as walls and columns (e.g., friction).

(c) Audio-feedback editor - this editor allows the attachment of sounds and auditory feedback to the objects, e.g.: "you are facing a window" or realistic sounds (e.g., steps). Additional auditory feedback is activated whenever the user enters an object's effect field, supplying important information related to the objects.

Learning Mode

The learning mode, or the environment within which the user works, includes two interfaces:

(a) The user interface consists of the virtual environment simulating real rooms and objects to be navigated by the users using the Force Feedback Joystick (FFJ).

(b) The teacher interface comprising several features that serve teachers during and after the learning session. On-screen monitors present updated information on the user's navigation performance, e.g., position, or objects already reached. An additional feature allows the teacher to record the user's navigation path, and replay it aftermath to analyze and evaluate the user's performance. Figure 2 shows a user's monitor data, and her navigation paths within the room's space and around the objects.

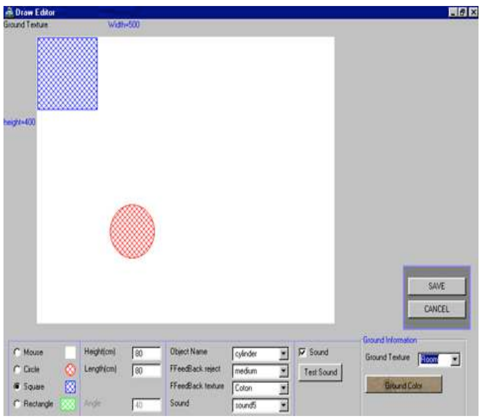

Figure 1. 3D environment builder

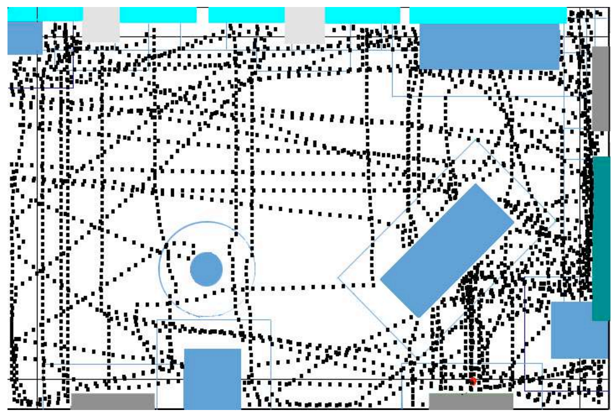
Figure 2. M.'s exploration path

Method

Participants

The study included 31 participants who were selected on the basis of the following seven criteria: total blindness; at least 12 years old; not multi-handicapped; received O&M training; Hebrew speakers; onset of blindness at least two years prior to the experimental period; comfortable with the use of computers. The participants' age range was 12-70 years (see Table 1), mostly adults in the age range of 24-40. We defined two groups that were similar in gender, age and age of vision loss (congenitally blind or late blind): The experimental group, including 21 participants who explored the unknown space by means of the MVLE, and the control group, 10 participants who explored directly the real unknown space.

Table 1. The study's participants

Group	Gender		Age		Age of vision loss	
	Female	Male	Adult (24-70)	Teenage (12-20)	Congenitally blind	Late blind
Experimental group (n=21)	11	10	15	6	11	10
Control group (n=10)	6	4	8	2	6	4

Research Instruments

The main instruments that served the study were:

The Unknown Target Space

The space to be explored, both as real physical space and as virtual space in the MVLE (see Figures 3-4), was a 54 square meters room with three doors, six windows and two columns. There were seven objects in the room, five of them attached to the walls and two placed in the inner space.

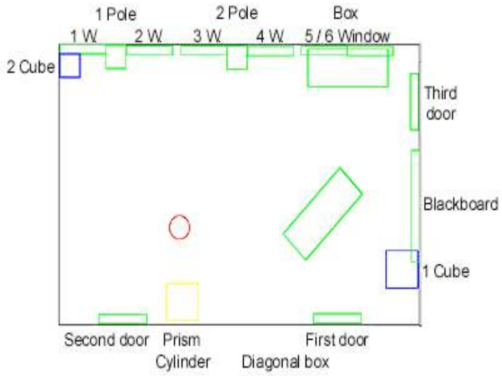

Figure 3. The MVLE representation of the target space

Figure 4. The Real space

Exploration Task

Each participant was asked individually to explore the room, without time limitations. The experimenters informed the participants that they would be asked to describe the room and its components at the end of their exploration.

In addition three instruments were developed for the collection of quantitative and qualitative data:

Orientation and Mobility (O&M) Questionnaire

The questionnaire comprised 46 questions concerning the participants O&M ability indoors and outdoors, in known and unknown environments. Most of the questions were taken from O&M rehabilitation evaluation instruments (e.g., Dodson-Burk & Hill, 1989; Sonn, Tornquist & Svensson, 1999).

Computer Log

The Log allowed the researchers to track the user's learning and exploration process in the MVLE, as regards to their exploration strategies, distances traversed, duration, switch of strategies and stops.

Evaluation and Coding Schemes

These instruments served the experts analysis of the participant's O&M skills and capabilities and his or her acquaintance process with the new space.

Procedure

All participants worked and were observed individually. The study was carried out in four stages. The first stage focused on the evaluation of the participants' initial O&M skills using the O&M questionnaire. In the second stage (two meetings, about three hours) the experimental group became acquainted with the virtual learning environment's components and operation modes. The third stage, the main part of the study, focused on participants' exploration of the unknown space. The experimental group explored the space using the virtual environment, while the control group explored directly the real environment. This stage lasted about 1.5 - 2.5 hours. In the last stage both groups performed O&M tasks in the real target space. In the last two stages all participants' performances were video-recorded.

Results

Although in this paper we focus on questions related to the anticipatory cognitive mapping of an unknown space and its role in actual O&M performance (stages two and three), we will briefly summarize our observations during the exploration stage (stage 1) as necessary background for the subsequent results. A detailed presentation of the findings of the exploration stage can be found in Lahav & Mioduser, (in press). Significant differences were found between the experimental group and the control group concerning the characteristics of the exploration process. These differences are related to four variables: the total duration of the exploration, the total distance traversed, the sequence of main strategies implemented and the number of pauses made while exploring the unknown space. The participants in both groups implemented similar exploration strategies, mostly based on those used for their daily navigation of real spaces. However, the experimental group participants, in comparison with the control group, used a more varied range of strategies and several participants developed a few new strategies while working within the virtual environment (e.g., a "constant scanning" strategy by which the user activates probes to collect information about the room's interior while collecting perimeter information -somehow resembling the use of a long cane in the real space). These strategies could be generated only within the MVLE, representing an important added value of the work with the computer learning system. The participants from the experimental group walked a longer distance to complete the exploration, and made more pauses for technical or reflective purposes. Summarizing the results of the exploration stage we can claim that the participants learning with the MVLE completed a more comprehensive, detailed and reflective examination of the unknown space than the control group. How this learning process affects the cognitive mapping of the unknown space, and the subsequent performance in the real space, are at the core of this paper's research questions

Research Question 1: Does the walking in the virtual learning environment contribute to the construction of an efficient cognitive map of the unknown space?

After the exploration process the participants were asked to give a verbal description and to construct a physical model of the explored space. Four variables of the participants' verbal and physical representations were examined: room size, room shape, structural features and components' location. The control group participants (who explored directly the real space) performed better in verbally describing the rooms' size ($\chi 2(2)=9.07$; $p<0.05$) and the rooms' shape ($\chi 2(2)=7.02$; $p<0.05$). The participants from the experimental group performed better in describing the structural components ($\underline{t}(28)=4.63$; $p<0.001$) and their location ($\underline{t}(29)=2.85$; $p<0.001$). However in the physical model, most participants in both groups constructed an appropriate model of the room and its components.

The experimental group's representation was more specific and elaborated, in the verbal description as well as in their models. For example, 29% of the experimental group participants placed all the seven objects located in the environment, and 43% placed six objects. In contrast, none of the control group participants placed all seven objects in their models and only 30% placed six objects.

The participants used four types of spatial features to describe the environment: <u>perimeter description</u> (e.g., N. -33 years old/late blind/male/experimental group- described: "on one of the wall there is the first door, the prism, another door… the prism between them…continuing with this wall you can reach the cube, blackboard, door…"); <u>object-to-object description</u> (e.g., G. –12 years old/congenitally blind/female/experimental group- described the environment: "at the lower wall there are two doors and near one of them there is a cube and near the other one there is a prism…"); <u>items list</u> (e.g., V. –17 years old/congenitally blind/female/experimental group- described the environment: "I found a prism, a door and there is also a pole, a diagonal box and a square"); and descriptions from the entrance-door-perspective (e.g., M. -39-years old/late blind/female/experimental group- described the environment: "if you are walking left from the door, when the door is behind you you can reach to the prism… walking forward you can find five or six windows at the wall that is in front of the door…").

Data related to varied aspects of the participants' descriptions are shown in Table 2. Most of the participants from the experimental group generated two main types of descriptions of the environment: perimeter description (38%) and object-to-object description (34%). In contrast, 40% of the control group participants described the environment in the form of a list of items.

Participants of both research groups generated three types of spatial representation (route model; map model and integrated representation) in similar distribution.

As regards to the sequence of item-types included in the verbal descriptions, the results show a significant difference between the groups ($\chi 2(1)=10.60$; $p<0.005$). Most participants in the experimental group (81%) described first the rooms' structure and later on its content. In contrast, control group participants described first the inner components and later on the rooms' structural components.

Examination of the physical models shows significant difference between the groups in overall quality ($\chi 2(8)=7.35$; $p<0.05$) and in particular features as well. For example, looking at first-itemplacement in the physical model significant difference was found in building sequence -similar to that observed in the verbal descriptions- ($\chi2(7)=11.32$; $p<0.05$).

Table 2. Descriptions generation

		Experimental group (n=21)	Control group (n=10)
Spatial description	Perimeter description	8 (38%)	2 (20%)
	Object-to-object description	7 (34%)	2 (20%)
	List of objects description	4 (19%)	4 (40%)
	Entrance door point of view	2 (10%)	1 (10%)
	Other	--	1 (10%)
Spatial representation	Route model	8 (38%)	3 (30%)
	Map model	7 (33%)	5 (50%)
	Integrated representation	6 (29%)	2 (20%)

* $\chi2(8)=7.35$; $p<0.05$

The findings for the first question indicate that the experimental group participants constructed fairly complex cognitive maps of the unknown space, as reflected in their verbal and physical descriptions. These maps comprise multiple layers, e.g., structural layer (referring to the overall configuration and dimensions of the room), compositional layer (in relation to the identification of inner components and they arrangement in space), relational layer (focusing location of objects relative to each other, or distances among objects). A procedural component complements the previous layers in the form of strategies for exploration/recall of the target space (e.g., perimeter, object-to-object). The learning process within the MVLE, by its unique features, supported the construction of a knowledge-rich model at all its different layers.

Research Question 2: How does this cognitive map contribute to the blind person's O&M performance in the real space?

After the exploration process and the construction of the cognitive map, the participants were asked to perform two orientation tasks in the real space. It should be recalled that the experimental group participants entered the real space for the first time to perform the tasks, and were not given the option to first explore the room –they did that in the MVLE only. Five variables were examined: successful completion of the tasks, use of direct paths to the target location, time spent on task, number and duration of stops (short stops and long stops) and total length of the path. Most of the subjects of the experimental group successfully performed both orientation tasks in the real space. Significant difference was found between the groups in the subjects' performance in the target-object task. Most subjects of the experimental group successfully performed the target-object task while choosing a more direct and shorter path than the control group participants. When examining the perspective-taking task, most subjects of the experimental group successfully performed the task in shorter time and path length.

Table 3. Performance in the real environment

	Target-object task			Perspective-taking task	
	Experimental group (n=21)	Control group (n=10)		Experimental group (n=21)	Control group (n=10)
Success (%)	81%	40%	*	71%	60%
Direct path (%)	67%	20%	**	34%	30%
Time (Seconds)	66	118		153	191
Short stops (mean)	3	6		3	5
Long stops (mean)	1.5	2.7		1.5	3
Length of the path	28	47	***	86	95

* $\chi2(2)=7.02$; $p<0.05$; ** $\chi2(3)=8.20$; $p<0.05$; *** $p<0.05$

The results are clearly indicative of the contribution of the learning with the MVLE to the participant's anticipatory mapping of the target space and consequently to their successful performance in the real space. Moreover, they show that such a mapping resulted in greater capability of the subjects of the experimental group in performing the real-space tasks.

Main Conclusions

Construction of Cognitive Maps as a Result of Learning with the MVLE

Participants in the experimental group were able to construct complex maps of the unknown space while working with the MVLE, prior to their acquaintance with the real space. As a result of their intensive interaction with the components of the virtual learning environment, the users were exposed to a wide range of haptic and audio feedbacks. This information allowed them to devote most of their attention and resources to the consolidation of the structural, compositional and relational aspects of the space's overall map. In addition, it seems that the participants developed particular perspectives of the space, and strategies for approaching it, as a result of the features and affordances of the MVLE (e.g., the tendency to describe the space from the perimeter to the inner space, in a whole and holistic manner). In contrast, we found that the exploration of the real space contributed to the control group's ability to estimate the objects' size and distances among them, functions not supported yet in the MVLE.

Performance in Orientation and Mobility Tasks as a Result of Learning with the MVLE

The first real space walking experience of most subjects in the experimental group was a confident and resolved one. It was noticeable that this walking was based solely on spatial knowledge acquired as a result of their acquaintance with the room in the virtual environment. We found many evidences of the robustness of the constructed map and its contribution to the subjects' performance. One example is their frequent use of the "Object to Object" strategy while accomplishing the tasks. Previous research (e.g., Golledge et al., 1978; Hill et al., 1993) reported that successful navigators among people who are blind make recurrent use of this strategy. The often use of it by participants in the experimental group is indicative of the holistic nature of their inner representation of the space, allowing them to construct efficient navigation paths based on isolating sub-sets of objects and their relative location.

This internal representation represented a powerful tool for guiding the secure navigation in the real space immediately after entering it, and for locating all spatial components required to perform the task in the shortest possible time and ambulation path.

Current Constraints and Future Implications

In this first attempt to examine the cognitive mapping process and its effect on actual performance we had to define its limits as first stage of a more comprehensive research agenda. For example, one set of limits relates to features offered by the environment (e.g., besides steps and scale representation there are no measurement tools that allow users to get accurate information about dimensions or distances; or a feature permitting scanning of objects at different heights that was disabled for this study to constrain the number of variables under consideration). Other aspects deliberately constrained relate to the characteristics of the target space: in this first stage we focused on a closed space without complicated topographical traits (which again represent a complete set of additional variables that might lead to different results).

Based on this first stage our research agenda includes the modeling of increasing open and highly complex spaces (e.g. a building, University campus, museum, shopping mall), the offering of additional exploration tools, and the study of overall exploration and mapping strategies by people who are blind who use recurrently the MVLE for different spaces. We believe these studies are of theoretical and practical value as well, for (a) training and rehabilitation processes requiring the acquisition of orientation and mobility skills and strategies, and (b) learning processes of subjects involving spatial information, by congenital and late blind people.

References

Colwell, C., Petrie, H., & Kornbrot, D. (1998). *Haptic virtual reality for blind computer users*. Paper presented at the Assets '98 Conference, Los Angeles, CA. Available in: http://phoenix.herts.ac.uk/sdru/pubs/VE/colwell.html

Darken , R.P., & Banker, W. P. (1998). *Navigating in natural environments: A virtual environment training transfer study*. Paper presented at the IEEE Virtual Reality Annual International Symposium. Atlanta, GA.

Dodson-Burk, B., & Hill, E.W. (1989). Preschool orientation and mobility screening. *A publication of division IX of the association for education and rehabilitation of the blind and visually impaired.* New York, NY: American Foundation for the Blind.

Fritz, J., Way, T., & Barner, K. (1996). *Haptic representation of scientific data for visually impaired or blind persons*. Proceedings of the Eleventh Annual Technology and Persons with Disabilities Conference, California State University, Northridge, Los Angeles, CA.

Golledge, R., Klatzky , R., & Loomis, J. (1996). Cognitive mapping and wayfinding by adults without vision. In J. Portugali (Ed.), *The construction of cognitive maps* (pp. 215-246). The Netherlands: Kluwer.

Hill, E., Rieser, J., Hill, M., Hill, M., Halpin, J., & Halpin R. (1993). How persons with visual impairments explore novel spaces: Strategies of good and poor performers. *Journal of Visual Impairment and Blindness*, 295-301.

Jacobson, W. H. (1993). *The art and science of teaching orientation and mobility to persons with visual impairments*. New York, NY: American Foundation for the Blind.

Jansson, G., Fanger, J., Konig, H., & Billberger, K. (1998). Visually impaired persons' use of the PHANToM for information about texture and 3D form of virtual objects. In J. K. Salisbury & M. A. Srinivasan (Ed.) *Proceedings of the Third PHANToM Users Group Workshop*, MIT, Cambridge, MA.

Lahav, O., & Mioduser, D. (in press). Exploration of Unknown Spaces by People who are Blind, Using a Multisensory Virtual Environment (MVE). *Journal of Special Education Technology*.

Loomis, J. M., Klatzky, R. L., & Golledge, R. G. (2001). Navigating without vision: Basic and applied research. *Optometry and Vision Science, 78*, 282-289.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press.

Mioduser, D. (in press). From real virtuality in Lascaux to virtual reality today: cognitive processes with cognitive technologies.

Schultheis, M. T., & Rizzo, A. A. (2001). The application of virtual reality technology for rehabilitation. *Rehabilitation Psychology, 46*(3), 296-311.

Sonn, U., Tornquist, K., & Svensson, E. (1999). The ADL taxonomy - from individual categorical data to ordinal categorical data. *Scandinavian Journal of occupational therapy, 6*, 11-20.

Standen, P.J., Brown, D.J., & Cromby, J.J. (2001). The effective use of virtual environments in the education and rehabilitation of students with intellectual disabilities. *British Journal of Education Technology 32*(3) 289-299.

Ungar, S., Blades, M., & Spencer, S. (1996). The construction of cognitive maps by children with visual impairments. In J. Portugali (Ed.), *The construction of cognitive maps* (pp.247-273), The Netherlands: Kluwer.

Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. *Presence: Teloperators and Virtual Environments 7*(2), 129-143.