Exploration of Unknown Spaces by People Who Are Blind Using a Multi-sensory Virtual Environment

Orly Lahav
David Mioduser
Tel Aviv University, School of Education

Exploration of unknown spaces is essential for the development of efficient orientation and mobility skills. Most of the information required for the exploration is gathered through the visual channel. People who are blind lack this crucial information, facing in consequence difficulties in mapping as well as navigating spaces. This study is based on the assumption that the supply of appropriate spatial information through compensatory sensorial channels may contribute to the spatial performance of people who are blind. The main goals of this study were (a) the development of a haptic virtual environment enabling people who are blind to explore unknown spaces and (b) the study of the exploration process of these spaces by people who are blind. Participants were 31 people who are blind: 21 in the experimental group exploring a new space using a multi-sensory virtual environment, and 10 in the control group directly exploring the real new space. The results of the study showed that the participants in the experimental group mastered the navigation of the unknown virtual space in a short time. Significant differences were found concerning the use of exploration strategies, methods, and processes by participants working with the multi-sensory virtual environment, in comparison with those working in the real space.

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 an individual's 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). This research 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 the ability of people who are blind to explore unknown environments (Mioduser, in press).

The research on the exploration process of known and unknown spaces by people who are blind refers to the use of both low and high technologies. These technologies serve as alternative sensorial or cognitive channels to the impaired visual channel. There are two types of information-technology devices: (a) passive devices - providing the user with information before her/his arrival to the environment (e.g., verbal description, tactile maps and physical models) and (b) dynamic devices - providing the user with information in-situ (e.g., Sonicguide, Kaspa, Talking Signs and Personal Guidance System). Ungar, Blades and Spencer, (1996) report on differences in exploration performance of people who are blind using various technologies (e.g., verbal description, tactile maps and physical models). Warren and Strelow (1985) studied the use of the Sonic-guide device and Easton and Bentzen (1999) focused on the users' ability to navigate using the Kaspa laser-guided device. Additional examples of O&M support under study are the talking signs embedded in the environment (Crandall, Bentzen, Myers, & Mitchell, 1995), and the global positioning system (GPS), based on satellite communication (Golledge, Klatzky, & Loomis, 1996).

Research on mobility in known and unknown spaces by people who are blind (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, 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 spaces people who are blind can use echo feedback (i.e., by whistling, clapping hands, or talking) to estimate distances (Hill, Rieser, Hill, Hill, Halpin & Halpin, 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 encompassing touch along with kinesthetic information, or a sense of position, motion, or force. For people who are 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 indoor environment familiarization process by people who are blind 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 acquisition of orientation and mobility (O&M) skills by people who are blind, 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 people who are blind 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; Darken & Peterson, 2002; Waller, Hunt & Knapp, 1998; Witmer, Bailey, Knerr & Parsons 1996), and perception of virtual textures and objects by people who are blind (Colwell, Petrie, & Kornbrot, 1998; Jansson, Fanger, Konig, & Billberger, 1998;).

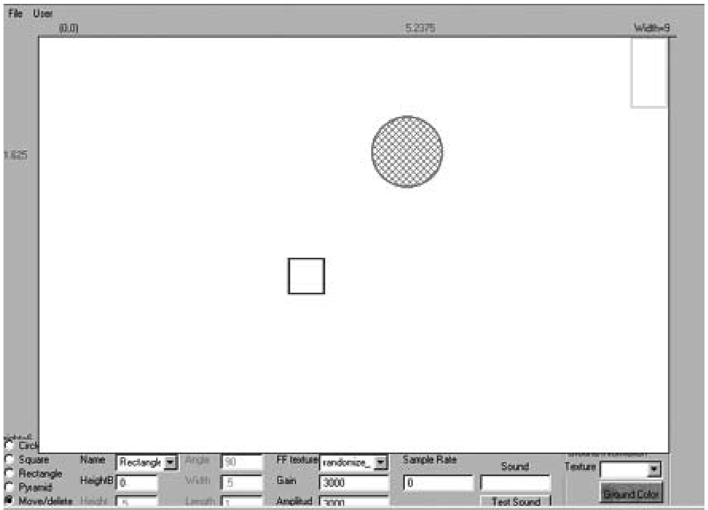
The research reported in this paper follows the assumption that the supply (via technology) of compensatory perceptual and conceptual information may contribute to effective acquaintance with unknown environments by people who are blind. This approach differs from previous research lines and practices in several ways. First, it integrates existing knowledge from different disciplines (namely O&M, learning processes by people who are blind, virtual environments and haptic devices R&D) into a common conceptual framework for the study of O&M skills acquisition using technology. At an additional level it deals with two main drawbacks of technologies currently in use: (a) the need for prerequisite knowledge about the space to be navigated (e.g., the talking signs or GPS systems) and (b) the lack of appropriate resolution of the information supplied about the unknown space (e.g., verbal descriptions or tactile maps). The virtual tool used in this study supplies all required prerequisite knowledge, at a resolution compatible with the features of the simulated environment. To examine the above assumption we developed a multi-sensory virtual environment (MVE) and studied the exploration process of an unknown space by subjects who are blind using the MVE. Their performance was compared to that of a control group of people who are blind who explored the *real* environment simulated in the MVE. The main research questions of this study were:

1. What exploration strategies do people who are blind use working with the MVE, in comparison to those used by people whom are blind working directly in the real environment?
2. What characterizes the exploration processes used by people whom are blind working with the MVE, in comparison to the exploration processes used by people whom are blind working in the real environment?
3. What information collection and storage did participants use, in both the experimental and control groups?

The Haptic Virtual Environment

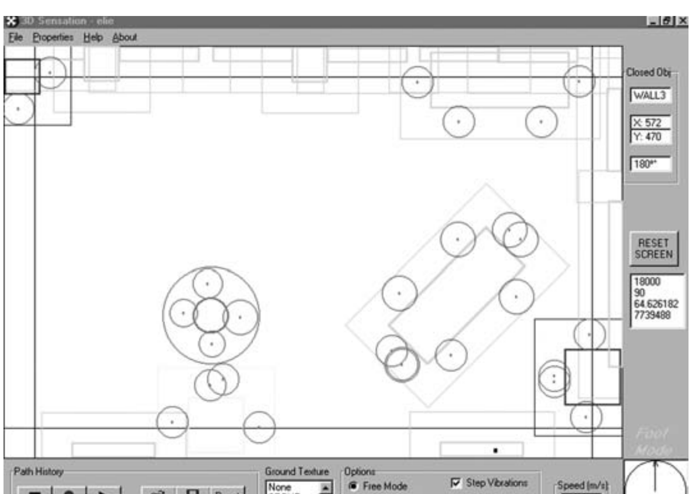
The MVE prototype developed for this study comprised two modes of operation: (a) developer/teacher mode and (b) learning mode. The core component of the developer/teacher mode was the virtual environment editor, which included three tools: (a) a 3D environment builder, (b) a force-feedback effects editor, and (c) an audio feedback editor (see Figure 1). By using the 3D-environment editor the developer can define the physical characteristics of the space, e.g., size and shape of the room, or type and size of the objects (i.e., doors, windows and furniture). Using the force feedback effects (FFE) editor the developer was able to attach haptic effects to all objects in the environment. Examples of FFE's were vibrations or attraction/rejection fields surrounding objects. The audio editor allowed the attachment of three kinds of auditory feedback to the objects: (a) labels (e.g., bird chirps) as representative for the windows, (b) explicit names (e.g., first door or second cube), and (c) a guiding agent reporting on features of the objects (e.g., the proximity of corners or required turns). All environments used in this study were composed by the researchers using the system editing tools.

Figure 1. Multisensory environment editor



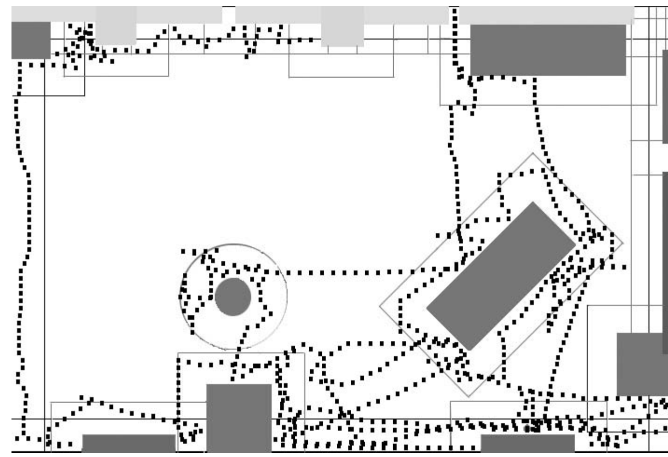
In the learning mode, the users navigated the environment by means of the force feedback joystick (FFJ). While walking via the FFJ they interacted with the simulated space components (i.e., they perceived the form, dimensions, and relative location of objects; or identified the structural configuration of the room including presence and location of walls, doors, and windows. As part of these interactions the users got haptic feedback through the FFJ along with audio feedback. Figure 2 shows the user-interface screen. The red circles indicate the hot spots that triggered the guiding agent's intervention.

Figure 2. The user interface



Several additional features were offered to the teachers during and after the learning session. Monitoring frames, for example, presented updated information on the user's navigation performance (e.g., position or objects already reached). Another feature allowed the recording of the user's navigation path and its replay for analysis and evaluation purposes, as shown in Figure 3.

Figure 3. Recorded log and monitoring data



Method

Participants

The study included 31 participants who were selected on the basis of the following seven criteria: (a) total blindness, (b) minimum of 12 years old, (c) not multi-handicapped, (d) received O&M training, (e) Hebrew speaker, (f) onset of blindness at least two years prior to the experimental period, and (g) comfortable with the use of computers. The participant age range was 12-70 years old. We defined two groups that were similar in gender, age and age of vision loss (i.e., congenitally blind or late blind. The experimental group included 21 participants who explored the unknown space by means of the MVE, and the control group had 10 participants who explored the real unknown space (see Table 1).

To evaluate the participants' initial O&M skills, all completed a questionnaire on O&M issues. The

Table 1.
The study's participants

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

questionnaire results showed no differences in initial ability among both groups' participants.

Variables

The independent variable in this study was the type of environment (i.e., the multi-sensory virtual environment (MVE) and the real environment.

Three groups of dependent variables were defined, concerning (a) exploration strategies, (b) characteristics of the exploration process, and (c) the use of information and storage aids during the exploration.

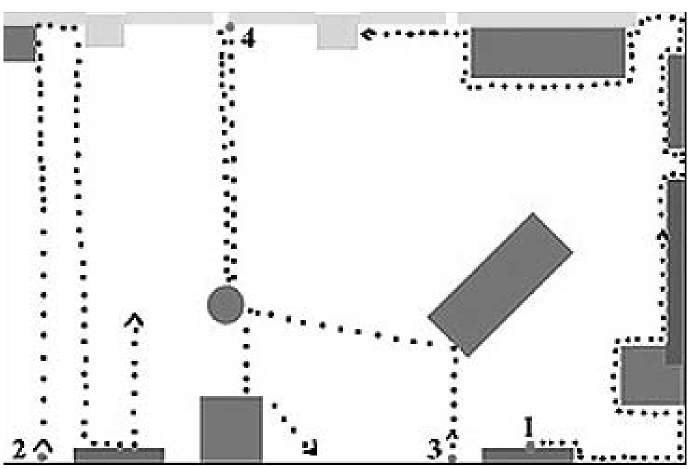
Variables related to the exploration strategies included:

1. Exploration strategies – alternative strategies used by the subjects in their navigation: the "perimeter" strategy – walking along a room's walls (see Figure 4, Route 1); the "grid" strategy – exploring a room's interior by scanning the room (see Figure 4, Route 2); the "object-to-object" strategy – walking from one object to another (see Figure 4, Route 3); the "points-of-references" strategy – walking in the environment and creating landmarks (see Figure 4, Route 4), or other (new) strategies.

2. Frequency – the number of times each strategy was implemented during the exploration.

3. Distance traversed – distance traversed using each strategy.

Figure 4. Exploration strategies



Variables related to the characteristics of the exploration process:

1. Total duration – the total time spent accomplishing the task.

2. Total distance – the total distance traversed.

3. Strategy-switch – the frequency of strategy changes during the exploration task.

4. Sequence – the first sequence of two strategies used in the exploration (e.g., pattern strategy first then grid strategy).

5. Stops – the number of pauses made during the exploration. Two values were defined: short pauses (4-10 seconds) introduced for technical purposes (e.g., changing the hand that holds the joystick) and long pauses (more then 10 seconds) supposedly used for cognitive processing (e.g., memorization or planning).

Variables related to the use of information and storage aids included:

1. Aids – use of aids of two types: measurement aids (e.g., counting steps or using echo feedback) and information-retaining-aids (e.g., producing a verbal reconstruction of landmarks or using metaphors).

Research instruments

The main instruments used in the study were:

1. The unknown space – the space to be explored, both as real physical space and as virtual representation in the MVE (see Figures 5-6). The space 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.

2. 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 a set of three instruments was developed for the collection of quantitative and qualitative data:

1. Orientation and mobility (O&M) questionnaire – comprising 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). The O&M

Figure 5. The Virtual Environment

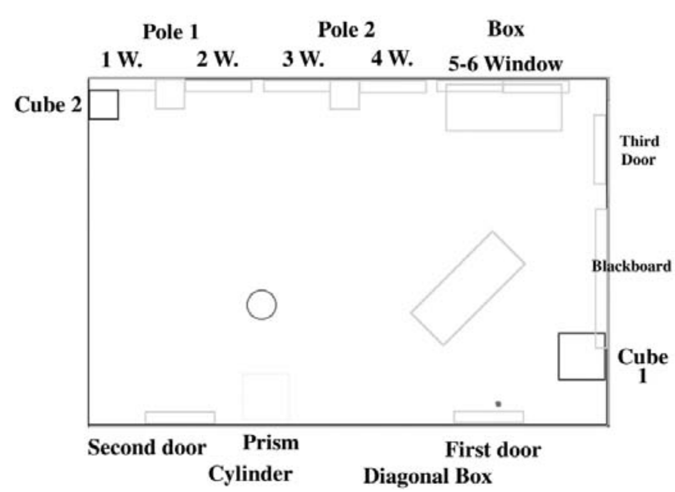


Figure 6. The Real Environment

questionnaire included four parts: (a) 19 descriptive questions (e.g., age; gender; age of vision loss); (b) 8 questions on the subject's O&M ability in known indoor environments (e.g., home; school; work; etc); (c) 12 questions about the subject's O&M ability in known outdoor environments (e.g., street crossing; using public transportation; walking in shopping centers; etc); (d) 7 questions on subject's O&M ability in unknown indoor environments (e.g., what are the O&M devices you use in unknown indoor environments?; next week you are going to move to a new office or classroom. You will be visiting the new place today. What do you need to do to ensure yourself appropriate orientation in the new space next time?). Among the questions 23 O&M-related questions were answered in a four-level ability scale: (i) I cannot do the task, (ii) I need assistance from a sighted person, (iii) I need to use an O&M device, (iv) I can do the task independently.

2. Observations were video-recorded – the participant's exploration was video-recorded during the task. The information from these recordings was combined with the computer recording.

3. Computer recording – The computer's recording data enabled the researchers to track the user's exploration in the MVE, in two ways: through a data log and through a film. This enabled the researcher to collect information about users' exploration strategies, distances, total duration, switches of strategies and stops (see Figure 3).

Two data evaluation and coding schemas were developed, one for the participant's O&M skills and the other for his or her acquaintance process with the new space.

Procedure

All participants worked and were observed individually. The study was carried out in three stages. The first stage focused on the evaluation of the participants' initial O&M skills using the O&M questionnaire. In the second stage the experimental group became acquainted with the virtual environment's components and operation modes. The series of tasks administered at this stage included (a) free navigation, (b) directed navigation, and (c) a task aimed to introduce the auditory feedback. This stage lasted about three hours (two meetings). At the end of it participants learned to work independently with the FFJ, were able to walk directly toward the objects, could say when they bumped into an object or got to one of the room's corners, and could walk around the objects and along the walls by using the FFJ and the audio feedback. 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 directly explored the real environment. This stage lasted about 1.5 - 2.5 hours, the task was video-recorded. For the experimental group the video-recording was combined with computer-recording. The last stage consisted of the processing and analysis of the collected data.

The research results and conclusions are based and represent only the research participants' performance and achievements (n=31). The population target on this research were Israeli people who are blind, selected using the seven criteria above mentioned and that agree to take a part on this study. The actual size of the study's population did not allow a detailed examination of the effect of otherwise relevant variables (e.g., gender or age).

Results

The results regarding the exploration strategies, methods, and processes manifested by the participants working with the MVE, in comparison with those working in the real space, are presented according to our main research questions.

Research Question 1: What exploration strategies do people who are blind use working with the MVE, in comparison to those used by people whom are blind working directly in the real environment?

The participants in both groups implemented similar exploration strategies, mostly based on the ones they used in their daily navigation in real spaces. Examples of strategies implemented were: (a) perimeter (e.g., walking along the room's walls and exploring objects attached to the walls), (b) grid (e.g., exploring the room's inner-space), (c) object-to-object (e.g., walking from one object to another), and (d) points-of-references (e.g., walking in the environment and creating landmarks). However, an interesting additional finding surfaced in that several participants in the experimental group developed a few new strategies while working within the virtual environment. A *constant scanning* strategy was identified by which the user collected information about the room's interior while simultaneously collecting perimeter information (e.g., resembling the use of a long cane in real space - as shown in Figure 7). Those strategies could be generated only within the MVE, representing an important added value of the work with the computer system.

As already mentioned, no substantial difference between groups was observed as regards the types of strategies used, but significant difference was found concerning the frequency of use of the strategies, and distance traversed using each strategy. Data in Table 2 indicate that the strategy most frequently used by the experimental group was grid, followed by the perimeter strategy. In contrast, the control group preferred to explore the room's perimeter, and next to use the object-to-object strategy. Examining the distance traversed using each strategy, we found that both groups traversed the longest distance using the perimeter strategy.

Table 2.
Exploration strategies, frequency and length

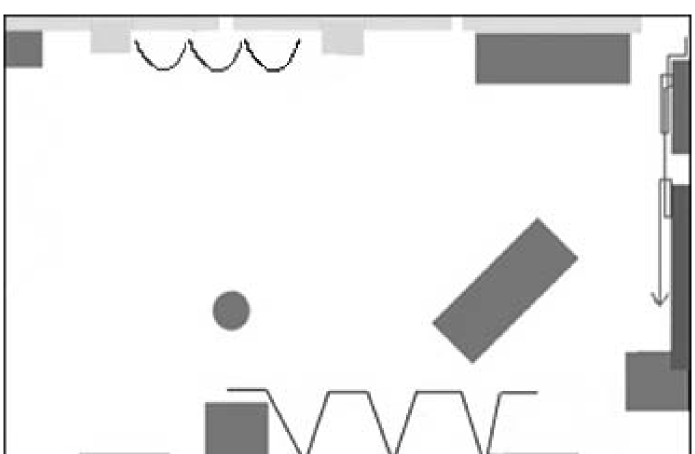
	Experimental group (n=21)		Control group (n=10)	
Exploration patterns	Frequency	Length of the path (in meters)	Frequency	Length of the path (in meters)
Perimeter	86	53.9	28	14.6
Grid	116	26.3	9	.97
Object to object	22	7.8	14	2.3
Points of reference	50	26.6	13	1.8
New strategies	18	18.2	–	–
Sum	292	132.8	64	19.67
Mean	14	6.3	6.4	1.9

Research Question 2: What characterizes the exploration processes used by people who are blind working with the MVE, in comparison to the exploration processes used by people whom are blind working in the real environment?

Five aspects are of interest as regards to the exploration processes used in the two groups: (a) the duration of the exploration, (b) the distance traversed, (c) the number of switches among strategies, (d) the sequence of main implemented strategies, and (e) the number and kinds of stops made while examining the new space.

Concerning the duration of the exploration, it should be noted that the participants were not limited in time for accomplishing the task. Participants from the experimental group needed four times more time to explore the new environment (average time of 38 minutes) than the ones from the control group (average time of 10 minutes). This difference was significant (t (28)=7; p=.000). Significant difference was found also for the total length of the exploration path (t (29)=5.44; p=.000). Participants in experimental group traversed an average of three times more distance (M=6.3 m) than the control group subjects (M=1.9 m).

Figure 7. New exploration strategies



The experimental group made frequent switches of strategy during their walk in the MVE, in contrast with the control-group performance in the real space. This behavior is reflected in the total and average frequency of use of the various strategies by both groups (see Table 2), total frequency of 292 and mean of 14 for the experimental group, and total frequency of 64 and mean of 6.4 for the control group.

Significant difference was also found between the groups in the sequence of main strategies implemented (c2(2)=7.55; p<.05). Data in Table 3 indicate that most experimental-group participants (62%) used the grid strategy first and then the perimeter strategy. In contrast, most control-group participants (90%) preferred first to explore the room's perimeter and then the objects located in the inner space of the room.

Table 3.
Sequence of strategies

Group	Perimeter then grid	Grid then perimeter	Grid
Experimental group (n=21)	8	8	5
	38%	38%	24%
Control group (n=10)	9	1	
	90%	10%	–
(x^2 (2)=7.55; p<.05)			

Participants from both groups made many pauses during their walk, suggesting that different cognitive operations related to the task in process were activated during these intervals. In terms of duration and function, we defined two types of pauses, short and long. Short pauses (i.e., 4-10 seconds) were used for technical purposes (e.g., changing the hand that holds the force-feedback joystick) or for reflection on a recent action. Long pauses (i.e., more than 10 seconds) were used for memorizing spatial information, reflection on a recently implemented exploration strategy, or planning. As shown in Table 4, significant difference was found between the groups ($t(26)=7.65$; $p<.001$; $t(25)=2.56$; $p<.05$) for both short and long pauses. The experimental group made about 3 times more short pauses, and 6 times more long pauses.

As the results indicate, significant differences were found between the experimental group and the control group concerning the characteristics of the exploration process. These differences were related to four dependent variables: (a) the total duration of the exploration, (b) the total distance traversed, (c) the sequence of main implemented strategies, and (d) the number of pauses made while exploring the unknown space. The experimental group participants, in comparison with the control group, used a more varied range of strategies to explore the room, walked a longer distance to complete the exploration, and made more pauses for technical or reflective purposes.

Table 4.
Short and long breaks

Group	Long stops	Short stops
Experimental group (n=21)	17	81
Control group (n=10)	6	13
	*	**

*p<.05; **p<.001

Research Question 3: What information collection and storage did participants use, in both the experimental and control groups?

The collection and storage of relevant information is inherent to the process of exploring an unknown space. Although only a few participants in this study reported explicitly on the use of tactics and aids for performing these functions, their account on this matter is of interest. Excerpts of these participants' references to the use of such aids follow.

One important category of information-collection aids was related to measurement to support the estimation of dimensions and distances. One example is the case of T, a 25-year-old, late blind, woman who explored the room using the MVE. After 2 minutes in the system T began to walk and count out aloud steps: "The blackboard… ok, the wall, one, two, three, four, five…".

The use of echo was another useful measurement aid. For example, the control-group participants used echo for measuring their distance from the wall or from other objects, or the room size. During their exploration those participants spoke, sang or whistled to get echo information.

The participants in this study used various kinds of information-retaining means. One was verbal reconstruction of landmarks, by which the subject recalled out loud her/his exploration of the space. For example, G, a 25-year-old, late blind man who explored the room by using the MVE, after examining the room's perimeter for 13 minutes said: "I had door, a prism, a corner, when I walked I had a window at the left side and then I reached the cube, I passed it and in front of it I had a window, column, window, window, column, window…". A variant of this was to complement the verbal reconstruction with virtual drawing (i.e., accompanying the verbal description with hand movements mimicking the physical presence and distribution of spatial components). For example, G, a 12-year-old, congenitally blind girl working with the MVE, after 22 minutes of exploration discovered the second cube in the room and began to describe out loud: "second cube, this cube is in the corner of the lower wall, and the wall is here…so the cube is in this corner...of the left wall…[during this verbal reconstruction G moved with her hand on the table indicating where the surveyed objects were located] yes the left wall, yes this wall corner and that wall corner ...there is a cube...".

Another interesting aid for the reinforcement of acquired information was the use of metaphors. For example, M, a 39-year-old, congenitally blind woman, after 32 minutes of exploration said: "…now I am a tourist guide, you are standing in front of the room entrance, now you are going to follow me, we are turning to the left, ok follow me... you have reached the prism, look at the prism, it is a beautiful object. We can not walk to the left, we are stuck in… we are walking forward… and we are arriving at the wall…".

Only some of the participants explicitly reported on the use of any aid. Table 5 indicates that the participants from the experimental group who reported on the use of aids mentioned mainly retention reinforcement aids (54%). In contrast, half of the control group mentioned such aids (50%), and even more mentioned the use of measuring aids (70%).

Discussion

The research reported here is part of an effort aimed to understand if and how, the work with a MVE supports the exploration of unknown environments by people who are blind . Gathering comprehensive information about new spaces is a prerequisite for the construction of effective cognitive maps of these spaces, and for supporting people's ability to navigate them. The results of this study helped uncover several issues concerning the contribution of the MVE to the exploration strategies and learning process of unknown spaces by people who are blind.

Exploration Strategies in the Virtual Environment.

Walking in the MVE gave participants a comprehensive and thorough acquaintance with the target space. The high degree of compatibility between the components of the virtual system and of the real space on one hand and the exploring methods supported by the MVE on the other, contributed to

Table 5.
Exploring aids

	Information-retaining			Measurement	
Group	Verbal reconstruction of landmarks	Verbal reconstruction with virtual drawing	Use of metaphor	Measuring units	Echo
Experimental group (n=21)	3 15%	5 24%	3 15%	1 5%	–
Control group (n=10)	4 40%	1 10%	–	4 40%	3 30%

the users' relaxed and safe walking. These features also enabled participants to implement exploration patterns they commonly used in real spaces, but in a qualitatively different manner. The use of real walking strategies in virtual environments was reported in previous studies on spatial performance by sighted participants (Darken & Peterson, 2002; Witmer, Bailey, Knerr & Parsons 1996). But this study's MVE participants applied the known strategies in novel ways. For example, they preferred to explore the inner part of the room first and only then its boundaries, in contrast with the exploration patterns described by Jacobson, 1993. Moreover, the MVE participants created new exploration strategies, such as the one simulating walking with a long cane enabling them to walk the perimeter of the room and at the same time to explore its corresponding inner areas – a strategy only possible within the MVE.

Exploration process in the Virtual Environment.

Operation features of the MVE (e.g., the game-like physical interface, various types of feedback) contributed to participants' performance with the system while exploring the unknown space. As a result, the exploration process showed interesting qualities concerning spatial, temporal, and thinking-related aspects. Examples of spatial and temporal qualities were the range of scanning strategies implemented, the inclusion of a large number of long and short breaks, or the time spent in examining the space. In addition, the MVE users traveled as much as three times more distance than the control-group participants, allowing them to collect information about the environment at different resolution levels, and to re-evaluate the information already gathered. All these were indications of the richness and comprehensiveness of the exploration process as accomplished by the MVE participants. Although the time measures collected were similar to those reported in Darken and Banker (1998) and Waller et al. (1998), both studies of sighted participants exploring spaces by means of VEs, it could be expected that exploration time would become shorter as participants got gradually used to working with these systems as tools for learning unknown spaces.

Concerning thinking-related aspects of the process, interesting examples were the long breaks made by the participants with the aim to reflect on the exploration steps or to memorize data concerning an explored area, or the use of virtual drawing of spatial features under examination on the table's surface as a reinforcement aid.

An important byproduct of the study is related to the definition of specifications and constraints for the appropriate design of haptic virtual learning environments for people who are blind (e.g., force-feedback in high resolution, audio feedback). We expect these virtual environments to become powerful tools for people who are blind in learning processes in which spatial information is crucial, both for understanding new concepts and phenomena, as well as for acting and performing in the real world.

Further Research

Further studies should examine the participants' construction of spatial cognitive maps of spaces using the MVE and, consequently, their use of these maps for navigating in the real environments. Additional variables to be studied should relate to properties of the environment (e.g., indoor or outdoor spaces, complex public spaces, and irregular surfaces). Finally, a comparison with traditional methods used by people who are blind to learn about unknown environments (e.g., tactile maps, verbal descriptions, human guidance) may serve for comprehensive evaluation of the contribution of the virtual tools to people's spatial performance.

Finally, at the implementation level the virtual tool could play a central role in training and rehabilitation processes as well. One possible application is for supporting the acquisition of O&M skills and strategies by persons who are late blind as part of their rehabilitation process. At another level, the development of more comprehensive environment-editing tools for the MVE will support the creation of a variety of models of spaces (e.g., public buildings, shopping areas) enabling pre and post-visit exploration and recall of unknown spaces by people who are blind. These implementations may also serve the research and practitioners community as models for the further development of technology-based tools for supporting learning processes and performance of people with special needs.

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.

Crandall, W., Bentzen, B.L., Myers, L., & Mitchell, P. (1995). *Transit accessibility improvement through talking signs remote infrared signage, a demonstration and evaluation.* San Francisco, CA: The Smith-Ketlewell Eye research Institute, Rehabilitation Engineering Research Center.

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.

Darken , R.P., & Peterson, B. (2002). Spatial orientation, wayfinding and representation. In K. M. Stanney (Ed.), *Handbook of virtual environments design, implementation, and applications* (pp. 493-518). Hillsdale, NJ: Erlbaum.

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.

Easton, R.D., & Bgentzen, B.L. (1999). The effect of extended acoustic training on spatial updating in adults who are congenitally blind. *Journal of Visual Impairment and Blindness, 93*(7), 405-415.

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.

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. *Educational Technology Review.*

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.

Warren, D.H., & Strelow, E.R. (1985). *Electronic spatial sensing for the blind.* Boston: Martinus Nijhoff.

Witmer , B.G., Bailey, J. H., Knerr, B. W., & Parsons, K.C. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies, 45,* 413-428.

Orly Lahav is a researcher at the School of Education, Tel-Aviv University and is currently a postdoctoral fellow at the Massachusetts Institute of Technology. David Mioduser is Professor of Communication and Computers in Education at the School of Education, Tel-Aviv University. *This research was partially supported by grants from the Israeli Ministry of Education, Microsoft Research Ltd., and Israel Foundation Trustees.* *Send correspondence to Orly Lahav, Knowledge Technology Lab, School of Education, Tel-Aviv University, Ramat Aviv, Tel Aviv, 69978, Israel. Email to: lahavo@post.tau.ac.il.*