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Rehabilitation Program Integrating Virtual Environment to Improve Orientation and Mobility Skills for People Who Are Blind

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Abstract

This paper presents the integration of a virtual environment (BlindAid) in an orientation and mobility rehabilitation program as a training aid for people who are blind. BlindAid allows the users to interact with different virtual structures and objects through auditory and haptic feedback. This research explores if and how use of the BlindAid in conjunction with a rehabilitation program can help people who are blind train themselves in familiar and unfamiliar spaces. The study, focused on nine participants who were congenitally, adventitiously, and newly blind, during their orientation and mobility rehabilitation program at the Carroll Center for the Blind (Newton, Massachusetts, USA). The research was implemented using virtual environment (VE) exploration tasks and orientation tasks in virtual environments and real spaces. The methodology encompassed both qualitative and quantitative methods, including interviews, a questionnaire, videotape recording, and user computer logs. The results demonstrated that the BlindAid training gave participants additional time to explore the virtual environment systematically. Secondly, it helped elucidate several issues concerning the potential strengths of the BlindAid system as a training aid for orientation and mobility for both adults and teenagers who are congenitally, adventitiously, and newly blind.

Keywords

human-computer interface; virtual reality; simulation

1 Introduction

People who become blind face great psychological and cognitive difficulties in the process of losing sight. Orientation and mobility (O&M) rehabilitation programs support the acquisition of O&M skills by supplying perceptual and conceptual information. Perception

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through touch, auditory, and olfactory senses helps compensate for the shortage in visual information. Amendola (1969) based his pioneering work in sensory training (Campbell, 1992a, 1992b) on the systematic collection of information from the immediate environment through all senses. Conceptually, the focus of such training lies in supporting the development of appropriate orientation strategies to achieve efficient cognitive mapping of a space and applying that mapping during navigation. Jacobson (1993) described the indoor environment familiarization process as starting with perimeter strategy (walking along the walls of a room), followed by a grid strategy (scanning the interior of a room). Research on spatial models has shown that people who are blind mainly use a route model when exploring and navigating spaces (Fletcher, 1980). The route model is based on linear recognition of spatial features, while the map model is holistic and encompasses multiple perspectives of the target space (Siegel & White, 1975). Similar results emerged in previous research on construction of a cognitive map by people who are blind (Lahav & Mioduser, 2008).

The current study examines two principal issues: (a) if and how the BlindAid system can support people who are newly, adventitiously, and congenitally blind in their O&M rehabilitation program by enhancing their O&M skills training; (b) if and how the BlindAid system can provide spatial information about unfamiliar spaces that can prepare people who are blind and have just graduated from a rehabilitation program to navigate independently in unfamiliar spaces, as they will need to do in their everyday life activities. The system provides training in a safe learning environment without the stress associated with exploration of real spaces (RSs) and with extra time to practice. In addition, the system allows O&M instructors to monitor clients' progress during training and thereby adapt subsequent sessions to emerging needs. This approach could promote a more independent exploration of an unfamiliar RS, potentially allowing teachers to devote more time to other aspects of the rehabilitation curriculum.

For decades, long cane and dog guide were the primary O&M aids used by people who are blind in exploring RS. Over the years, more than 146 secondary O&M electronic aids have been developed (Roentgen, Gelderblom, Soede, & de Witte, 2008). These aids are not a replacement for primary aids. There are two major types of O&M aids: in-situ aids that provide the user with information while in the environment itself (e.g., obstacle detectors, information systems that use sensors in the environment, and global positioning systems) and preplanning aids that provide the user with information before arriving in an environment (e.g., verbal descriptions, tactile maps, physical models, digital audio and tactile screens, and sound and haptic-based VE systems). However, there are a number of limitations in the use of these in-situ and preplanning aids. The major limitation of in-situ aids is that the user must gather spatial information in the explored space, making it impossible to build a cognitive map in advance, thus causing a feeling of insecurity and dependence upon first arrival in a new space (Lahav, 2003; please see 2.3 Participants - O&M questionnaire results). From the perspective of safety and isolation, the in-situ aids are based mostly on auditory feedback, which in RS can reduce users' attention and isolate them from the surrounding space, especially from auditory information (Arons, 1992). Moreover, the limited dimensions of tactile maps and models may result in poor resolution of the provided spatial information. There are difficulties in publishing and acquiring updated

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spatial information, and, furthermore, they are rarely available. As a result of these limitations, people who are blind are less likely to use in-situ or preplanning aids in everyday life.

The use of VE training for learning and rehabilitation for people with disabilities has been on the rise in recent years (Schultheis & Rizzo, 2001). Sound-based VEs have been investigated and developed for people who are blind (Halko, Connors, Sánchez, & Merabet, 2014; Gonzalez-Mora, 2003; Seki & Sato, 2011); however, this research showed that successful exploration using only sound requires a very high level of attention. "Haptics," which refers to sensing and manipulation through touch, is another modality for interacting with a VE that can provide the user with tactile, kinesthetic, and reaction force information about the environment, as well as a means of controlling events in the VE. Use of a virtual smart cane based on haptic and audio has been reported for people who are blind (Chaudary, & Pulli, 2014; Evett, Battersby, Ridley, & Brown, 2009; Lahav, et al., In Press; Lahav & Mioduser, 2004; Simonnet, Guinard, & Tisseau, 2006). These research results have expressed the validity and potential of such systems for use by people who are blind.

The current work, which was done in collaboration with the Carroll Center for the Blind (CCB), is part of a larger research effort comprising the design, development, and evaluation of BlindAid for people who are blind (Lahav & Mioduser, 2008; Lahav, Schloerb, & Srinivasan, 2012). To our knowledge, this study presents the first system supporting O&M rehabilitation for persons who are blind through VE training. The study examined the following main research questions:

1. What exploration strategies and processes did the experimental group use in the VEs when exploring familiar spaces, in comparison to their exploration in unfamiliar space?
2. What were the participants' cognitive mapping characteristics in familiar spaces (experimental and control groups), in comparison to their cognitive mapping characteristics in unfamiliar space (experimental group)?
3. What orientation strategies and processes did the experimental participants perform in orientation tasks in familiar VEs, in comparison to their performance in unfamiliar space?
4. What orientation strategies and processes did the experimental and control participants perform in orientation tasks in familiar RS, in comparison to unfamiliar RS (experimental and control groups)?

2 Material and Method

2.1 BlindAid System

The BlindAid system presented the VEs that the participants explored in the experiment (see Figure 1). The BlindAid application software ran under Windows XP on a personal computer (Pentium 4, 2.8 GHz), equipped with a haptic device (SensAble Technologies, Desktop Phantom®) and stereo headphones (Sennheiser, HD580). A simple graphic display allowed sighted persons to observe the user's movements in VE.

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The Phantom® haptic device enabled the user to control the user's avatar position within the VE and provided haptic feedback about the space through its stylus. The arrangement was somewhat like probing the VE with a miniature white cane, with the avatar being the point at the tip of the cane. Each component in the VE was represented both haptically and auditorially. For example, the user could feel virtual objects (e.g., tile, marble, or rubber floors) with a range of haptic properties (e.g., hard, bouncy, smooth, or rough). The VE included different sounds; for example, when the avatar contacted an object, the system would typically play an earcon that represented the general type of object. Additionally, spatialized audio made it possible for the user to hear the direction and distance of virtual sound sources and helped him or her stay oriented in the VE. Background sounds that played automatically whenever the avatar was within specified regions of the VE (e.g., sound of the lobby) also assisted in user orientation. Alternatively, the user could hear more detailed audio information about the object on contact by pressing a command key. In the current study, participants used five command actions on the computer's numeric keyboard to control other aspects of the system while interacting with the VE: restart, pause, zoom-in, zoom-out (controlled whether objects were rendered with the structure), and additional audio information. Movement of virtual workspace within the VE was accomplished using the Phantom stylus-button. This feature allows exploration beyond limits created by the finite size of the Phantom's physical workspace.

BlindAid includes an evaluation mode that allows researchers to record the user's behavior in the experimental sessions for later analysis. The data collected can be viewed directly as a text file or replayed as a screen recording. As shown in Figure 2, the central display demonstrates the user's path and the large dot represents the user's avatar. The upper right keyboard shows the user's execution of command actions. Schloerb et al. (2010) provide further technical details about the BlindAid system.

2.2 O&M Rehabilitation Program

Many who have lost vision participate in a rehabilitation program at a rehabilitation center. Rehabilitation centers provide programs tailored to a client's age and abilities. We conducted this research at CCB, a private nonprofit agency, which provides intensive, campus-based rehabilitation programs to help people who are blind. CCB includes two rehabilitation programs: (a) Independent Living Program, an 8-12 week course for adults; and (b) Transition to College Program, a 5-6 week course for incoming or current college students planning to live on campus. The programs are designed primarily to help adults make the physical and emotional adjustments to living with blindness, with the goal of achieving or maintaining personal independence. Both programs are intensive, campus-based with eight sessions per day, 50 minutes per session, and three to five O&M sessions per week.

CCB practitioners followed Amendola's (1969) notions for developing a sensory training methodology and curriculum for O&M skills. After two weeks of functional assessment, O&M instructors recommended three segments: orientation, mobility, and cane technique. The orientation segment had six components: (a) use of sensorial landmarks: auditory, haptic, olfactory, and kinesthetic; (b) use of audible signals to cross a street; (c) use of

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landmarks, such as buildings and door numbers; (d) use of cardinal directions; (e) ability to recover when disoriented; and (f) construction of a cognitive map. The mobility segment had four components: (a) basic mobility skills that include a human guide; (b) indoor navigation within CCB buildings; (c) outdoors campus navigation; and (d) community travel. The third segment focused on cane technique and had three components: (a) exploring the path surface; (b) utilizing the cane in a systematic way; and (c) using the cane as substantial protection from objects below waist level. In the current study, we used BlindAid to expand the participant's training hours for the above skills (excluding street crossing and public transportation).

The participants who still had some limited visual capability wore a blindfold during all O&M and BlindAid sessions to avoid reliance on residual vision and to learn how to collect information via other senses. This is normal practice during CCB rehabilitation programs.

2.3 Participants

The study included 16 participants selected from CCB's two rehabilitation programs. They were chosen based on five criteria: enrolled in one of two rehabilitation programs, totally blind or blindfolded during O&M rehabilitation program, no additional handicaps, English speaking, and comfortable using a computer. We defined two groups: experimental and control.

Experimental group—This group included 11 participants, who received additional training during their O&M program using the BlindAid system. Two participants began the BlindAid training but were later excluded: one was unwilling to continue with the experiment (although he did not have problems operating BlindAid in the sessions in which he participated) and the second left the rehabilitation program. As a result of this, the study included nine participants.

Six participants were from the Independent Living Program and three from the Transition to College Program (see Table 1). The participants' age range was 18-66; seven participants were female, three were congenitally blind (birth to 24 months), and six were adventitiously blind (24 months and later). The adventitiously blind group included people who had been blind more then two years before the research period commenced (n=3) and a subgroup of newly blind (n=3) - people who had become blind within two years of the beginning of the research period or who would be blind in the near future. Three participants were totally blind; six had residual vision, such light, shadow, or colors, and as a result of this ability they were asked to be blindfolded in O&M program and BlindAid training; seven were students or employed; and six had formerly received rehabilitation training in a community mobility and rehabilitation program. Most participants reported previous experience with computer applications, but no previous experience with VEs or the Phantom device. Five participants had been long cane users before their arrival at CCB, and four participants started to use long cane at the CCB rehabilitation program.

Control group—This group included five participants who received only the O&M program. Four were from the Independent Living Program and one was from the Transition to College Program. The age range was 18-48 years and included four females; two were

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congenitally blind; three were adventitiously blind, two of whom were newly blind; two were totally blind; and three were blindfolded. Two were long-cane users before arrival at CCB and three began long-cane use at CCB.

Researchers assigned the participants randomly to the research group without any advance knowledge about them. The researcher asked participants to complete an O&M questionnaire to help in evaluation of initial O&M skills. The participants' O&M questionnaire results showed no O&M ability differences in familiar and unfamiliar indoor environments.

2.4 Variables

The independent variable was type of space: familiar, a space used by all participants during their rehabilitation program, and unfamiliar, a location the participants had never entered or explored before the experiment. All of the spaces simulated in this study were indoor spaces at the CCB campus.

Four groups of dependent variables were defined concerning: (a) strategies and process of the exploration task, (b) cognitive map, (c) VE orientation task performance, and (d) RS orientation tasks performance.

2.4.1 Strategies and process of the exploration task—The process of exploration in the simulated environment included seven variables, six related to the participant's exploration tasks and one related to the researcher: (a) total *duration* of VE exploration; (b) s*patial exploration strategies* used by the participant: perimeter (walking along a room's walls), grid (scanning room's interior), object-to-object (walking from one object to another), exploring object area (walking around an object and exploring the space around it), and random (walking without pattern)—this variable included number and duration of usage for each strategy type; (c) *systematic exploration* of the environment to acquire spatial information: excellent (a planned, methodical pattern of exploration), restless but systematic (wandering around in the space in a systematic pattern), or poor; (d) *command actions,* the use of command actions while interacting with the VE; (e) *problems* that arose during exploration: technology problems (e.g., holding the Phantom, finding a key on the numeric keyboard), orientation problems (e.g., disorientation at the starting point, disorientation in the space), and other problems (e.g., concentration, continuing use of visual components and ignoring audio or haptic information); (f) *self-motivated behavior*: setting a target to find, using orientation problem solving, and asking the researcher for an orientation task; and (g) *researcher interventions*: the researcher's providing technology or orientation instructions to the participant.

2.4.2 Cognitive map—The participants' spatial cognitive map included seven variables: (a) *structural components*; (b) *structural component location*; (c) *objects* within the environment; (d) *object location*; (e) the participant's preferred *spatial strategy* for describing space: perimeter, object-to-object, list, and starting-point perspective descriptions; (f) the participant's *spatial model* used for describing the space: a route model, a map model, or a list; and (g) *chronology* of the descriptive process.

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2.4.3 VE orientation task performance—The participants' orientation task performances in the VE included eight variables, seven related to the participant and one related to the researcher: (a) *duration;* (b) *spatial strategies* used by the participant (perimeter, grid, object-to-object, exploring object area, or random); (c) *task completion* (failed, arrived at the target zone with verbal assistance, arrived at the target zone, or successful); (d) *type of path* that the participant chose to take (wandering around, indirect, direct with limited walking around, and direct); (e) *orientation problem-solving strategies* (object landmark, ground landmark, audio landmark, cardinal direction, verification of starting point, reversing to starting point, traveling toward more spatial information, and stopping and thinking about the available spatial information); (f) c*ommand actions* (restarting and accessing detailed audio information); (g) *problems* that arose during task performance (technology and orientation problems); and (h) *researcher interventions* (technology or orientation instructions given to the participant during task performance).

2.4.4 RS orientation task performance—Participants' performances on orientation tasks in RS included six variables (similar to above): (a) *duration*; (b) *spatial strategy*; (c) *task completion*; (d) *type of path*; (e) *using second hand* to support orientation; and (f) *orientation problem-solving strategies*.

2.5 Instrumentations

2.5.1 Simulated RSs—O&M instructors and the researcher chose ten spaces on the CCB campus to be modeled as simulated VEs. Nine spaces were chosen as familiar spaces; these were the areas most used during the rehabilitation program, including O&M sessions. These spaces included eight indoor spaces (four floors of the main building and four floors of the dormitory) and one outdoor space (CCB campus), which was not part of the current study. One space was chosen as an unfamiliar space (St. Paul building, first floor), which had never been explored by the participants. The unfamiliar space was not unique; it was more like the main building basement (MB) and dormitory basement (DB) spaces. Figures 3-6 below describe the simulated spaces' blue print: privet door (red line), public door (green line), object (blue), the participants' entrance point (red octagon), and exploration area (gray). During the design stage, O&M instructors and the researcher collaborated in determining the level of VE spatial detail.

2.5.2 VE exploration tasks—The participants were asked to explore each of the nine VEs using BlindAid. Each VE was explored separately within given time restrictions. These restrictions were defined by the O&M instructor equal to the estimated average time required for physically exploring the corresponding RS.

2.5.3 VE orientation tasks—O&M instructors helped the researcher to design VE orientation tasks that would resemble those given during the O&M sessions. After each exploration task, the participants were asked to perform up to six object-oriented tasks. In each task, they were asked to find a different object in the VE.

2.5.4 RS orientation tasks—O&M instructors helped the researcher design RS orientation tasks resembling those of the O&M sessions. The participants performed nine

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orientation tasks: two 2-part object-oriented tasks (find an object, then return to starting point ("reverse"); two 2-part perspective-taking tasks (go from location A to location B, then reverse); pointing task (on the location of five to six different objects).

2.6 Data Collection Tools

2.6.1 Participant's O&M Questionnaire—The questionnaire had 50 questions regarding the participant's O&M abilities indoors and outdoors in familiar and unfamiliar spaces (Dodson-Burk & Hill, 1989; Lahav & Mioduser, 2004; Sonn, Tornquist, & Svensson, 1999).

2.6.2 Participant's Verbal Description—Before the exploration task for familiar spaces, participants gave verbal descriptions of the spaces. At the unfamiliar space participants gave a verbal description after the exploration task. All verbal descriptions were video-recorded and transcribed.

2.6.3 Observations—Observations of participants performing their VE and RS orientation tasks were video-recorded and transcribed.

2.6.4 Computer Logs—BlindAid enables the researcher to collect information about a user's behavior in the VE and to present this data in the evaluation mode.

2.7 Data Analysis

To evaluate a participant's performance, we applied coding schemes that had been developed in previous research by four O&M instructors (Lahav & Mioduser, 2004). They designed and constructed four coding schemes: cognitive map, exploration process, and VE and RS orientation task performances. All of the participant's recordings (video, transcriptions, and computer logs) were coded simultaneously using Interact© qualitative video coding and statistical software. The computer log data were also parsed and analyzed using quantitative software (Excel). Table 2 presents how the different variables were measured by the data collection tools.

To assess the validity of the data, a non-CCB O&M instructor analyzed the videos of 17 RS orientation task performances. Interjudge reliability was 93% and was therefore considered valid. Based on results from an earlier pilot study that examined all eight spaces (Lahav et al., 2012), we decided to use cluster-sampling methodology in this research. We examined, coded, and analyzed the participants' tasks in four out of the ten spaces. In this paper we examined three familiar indoor spaces: first space -- main building third floor (M3), third space -- main building basement (MB), seventh space -- dormitory basement (DB), and one unfamiliar space -- St. Paul first floor.

It should be noted that because the St. Paul building was not part of the traditional rehabilitation program we were not able to change the participants' O&M curriculum and ask their O&M specialists to enter with them to this space. We chose to not ask the control group to explore the space by themselves in this stage of rehabilitation without O&M specialist because we were afraid that it might stress the participants to ask them to perform the RS tasks without exploring it first. As a result of these limitations the control group did

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not performed the exploration and orientation tasks in the unfamiliar indoor space. This research included a control group (n=5) only for the familiar spaces. These comparison results are relevant partially to the second and fourth research questions about familiar spaces.

2.8 Procedure

Throughout the O&M rehabilitation and BlindAid training all participants were observed individually and arrived independently at the experiment room. Participants started to work with BlindAid during the first or third week of their rehabilitation program. In addition to the O&M sessions, they attended an average of 15 BlindAid sessions, 50 minutes per session, with two to three sessions per week, spanning five to ten weeks. In the first session all participants completed consent forms and an O&M questionnaire. Next, they attended two sessions (sessions 2 and 3) of training on the operation of BlindAid. Each of the remaining 13 sessions was dedicated to one of ten different simulated environments. As the research progressed, indoor familiar spaces increased in complexity (shape, size, structures, and objects) from simple (M3) to complex (DB) spaces, and the last session was dedicated to unfamiliar indoor space (the St. Paul building's first floor). The familiar space session started with a verbal description of the targeted space, followed by an exploration task. The unfamiliar space session started with exploration in the VE, followed by a verbal description of the targeted space. The familiar and unfamiliar space sessions were followed by up to six orientation tasks in the VE, followed by orientation tasks in RS. Each session was videorecorded, transcribed, and coded. In addition to these sessions, every seven to ten days the four CCB O&M instructors and the researcher together observed and evaluated the participants' exploration and orientation task performance.

Integrating BlindAid into the rehabilitation program as a research project had positive and negative effects for the experiments. Since the participants stayed at CCB only for the program duration, the length of each session and the research process were defined by the CCB schedule. On the other hand, the ability to evaluate BlindAid in a real rehabilitation program was immensely beneficial to the research.

3 Results

3.1 Research Question 1. What exploration strategies and processes did the experimental group use in the VEs when exploring familiar spaces, in comparison to their exploration in unfamiliar space?

The data sources for this question were the participants' observations and computer logs about their explorations in the VEs. Seven aspects are of interest regarding the exploration processes used: duration of the exploration, spatial exploration strategies, systematic exploration, command actions, technology and orientation problems, self-motivated behavior, and researcher interventions.

Table 3 shows the participants' average exploration time. For two out of the three familiar spaces, the duration was lower by 26%-21% than the O&M instructors' estimate of the time

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needed to explore RS corresponding to the VE. A higher difference was found in the unfamiliar space (45%).

During the exploration task in familiar spaces, participants mainly used perimeter strategy (80%-89%); similar results were found in the unfamiliar space in which 91% used perimeter strategy. In the familiar spaces participants also used grid (7%-8%), object-to-object (0-1%), exploring object area (1-5%), and random (1-8%) strategy; similar results occurred in the unfamiliar space. Most participants began their exploration with perimeter strategy (80%), 15% started their exploration with grid strategy mainly in M3, and one participant started with random strategy in DB. Similar results were found in the unfamiliar space: 66% began their exploration with perimeter strategy, 22% started their exploration with grid strategy, and one participant started with random strategy (see Table 4). The participants in both types of spaces changed strategies frequently with an average duration between changes of 35-39 seconds (see Table 3).

Table 4 presents findings for the participants' systematic exploration to obtain spatial information in spaces. In the first familiar space, 64% of the participants' exploration time was excellent systematic exploration; in the third space, 54% of time exploration was excellent systematic and 40% was restless but systematic. Systematic explorations improved with time from 64% to 82% in DB. In the unfamiliar space (St. Paul building-first floor), the systematic explorations improved further to 89%. In the first two evaluated familiar spaces 89% of the participants performed different types of systematic explorations (excellent, restless but systematic, and poor). Over the course of the research a pattern emerged: the time spent in restless or poor exploration decreased until this behavior disappeared completely; better results were found in the unfamiliar space.

During the VE exploration the most commonly used command action in both types of spaces (familiar and unfamiliar) was for additional audio feedback. All participants used this command action 46%-68% (familiar spaces) and 79% (unfamiliar space) of their exploration time, and the use of this command increased with time. All participants in both research spaces used the additional audio key in two ways. They either held the key down while they explored a space, thus requesting constant access to additional audio feedback for large blocks of time, or they pressed the additional audio key following their interaction with a component. Another command action that participants often used was "restart," which allowed them to return to the starting point; this action was employed mainly in the first familiar spaces and in the unfamiliar space. BlindAid allowed participants to pause their exploration, and in the first space 44% of the participants used the "pause" command, although the use of this command action decreased over time and was not used in the unfamiliar space. Very few participants (11%-22%) used the "zoom-in" or "zoom-out" command action. Those who did used these command actions in familiar spaces did so for 22%-57% of their exploration time; in the unfamiliar spaces participants did not use them.

During the exploration process, technology, orientation, and other types of problems arose. Technology problems appeared at greatest frequency in the first familiar spaces (M3 and MB) and appeared more rarely in later environments (DB and St. Paul). In addition, there were orientation problems, such as disorientation in starting point or space, transferring spatial information between RS and VE, concentration, difficulties in constructing cognitive map, and using the visual channel as the main channel to collect spatial information. These problems were experienced in familiar spaces by 11%-33% of the participants (an average of 0-3 times during exploration), but almost totally disappeared in unfamiliar space.

Regarding self-motivated behavior, starting with the third space (DB), some of the participants became more aware of their exploratory behavior and began to participate and plan more actively. Different results were found in St. Paul space, where the participants displayed less self-motivated behavior.

Throughout the participants' exploration process, the researcher initiated two types of interventions in response to encountered problems. Technology interventions appeared with greatest frequency in the first familiar spaces and much more rarely in the later environments, including the unfamiliar space. The frequency of technology interventions decreased over time, and was almost nonexistent in the unfamiliar space. The O&M instructors and the researcher collaborated to develop orientation interventions for instruction in the BlindAid sessions.

In exploration tasks in familiar spaces, age of vision loss did not affect duration of exploration, spatial strategies, or command actions, but effects were noticeable in systematic exploration, technology and orientation problems, researcher interventions, and self-motivated behavior. Compared with participants who were congenitally and adventitiously blind, participants who were newly blind explored in a way that was more restless but systematic or poor.

In the unfamiliar space, age of vision loss did not produce differences in spatial strategies, systematic exploration, command actions, technology and orientation problems, researcher interventions, or self-motivated behavior. But differences occurred in duration, mainly in that participants who were newly blind needed more time than those who were congenitally blind and adventitiously blind.

3.2 Research Question 2. What were the participants' cognitive mapping characteristics in familiar spaces (experimental and control groups), in comparison to their cognitive mapping characteristics in unfamiliar space (experimental group)?

The data source for this second question was the participants' verbal descriptions. Seven aspects are of interest as regards to the construction of the cognitive map: the room's structural component, the structural component location, objects located in the space, object location, the participant's preferred spatial strategy, the participant's spatial mode, and the chronology of the descriptive process.

All participants in both groups gave verbal descriptions of each of the three familiar spaces before beginning VE exploration. These descriptions were quantified based on the number of components (structure and objects) described and identification of location, compared to the total components presented. The average percentages were calculated across participants and are presented in Table 5 as the participants' score. Both groups provided poor average verbal descriptions in M3 and MB; most of the participants specified 12% to 24% of the

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spaces' components and their location. In DB they improved, identifying an average of 47% (experimental group) and 52% (control group) of the space's components and locations. In all research spaces, all participants gave more details about structural components. For example in M3, experimental participants included 29% of available information about structural components and only 1% about objects. Over time participants' description of components increased. The participants who were newly blind provided more details about all the spaces as compared to those who were congenitally blind and adventitiously blind. In the unfamiliar space the experimental participants verbally described the space after VE exploration, seven participants out of nine provided better verbal descriptions than in their earlier description of DB. The unfamiliar space included 17 structure components and only one object; participants depicted more details about the components than about their locations. In slight contrast to familiar spaces, the participants who were adventitiously blind gave more details about the unfamiliar space, as compared to those who were congenitally blind and newly blind.

In the verbal descriptions of familiar spaces, experimental participants employed list strategy as their main spatial strategy (59%); in 35% of the descriptions they used perimeter strategy. Control group results differed: 64% perimeter strategy and only 36% list strategy. In verbal descriptions of the unfamiliar space the participants employed mainly perimeter strategy (67%); only 33% chose list strategy. As spatial model most research participants used a route model in their descriptions, in familiar spaces 71% of experimental group used a route model, none used map model, and 24% gave a list of components. In the control group 64% used a route model, none used map model, and 36% gave a list of components. In the unfamiliar space 67% used a route model and 33% gave a list of components. Age of vision loss did not produce differences in spatial strategy or spatial model in either type of space. No data were available for 12% of the verbal descriptions of familiar spaces as a result of time limitations imposed by the CCB's session schedule.

3.3 Research Question 3. What orientation strategies and processes did the experimental participants perform in orientation tasks in familiar VEs, in comparison to their performance in unfamiliar space?

The data sources for this question were the participants' observations and computer logs about his or her tasks' performances in the VE. Eight aspects are of interest as regards to the participant's orientation task performance in the VE: the duration, the spatial strategies, the task completion, the type of path, the orientation problem-solving strategies, the command actions, the technology and orientation problems, and researcher interventions.

After exploring each of the familiar spaces, the participants performed five tasks in each space except MB where they did four; five tasks were preformed in the unfamiliar space (see Table 6). In familiar spaces most of participants succeeded in arriving at the target objects, except in MB, where about half of the participants failed or needed verbal assistance to arrive at the target zone. Regarding spatial strategy, 57% used only perimeter strategy and 39% used perimeter strategy with another strategy, mainly object-to-object and grid. Most of the participants first used perimeter strategy, then located a landmark, and then used object-to-object strategy aimed directly at the target. Spatial strategy percentages in Table 6

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represent the average time of using a particular spatial strategy in the overall task duration. No differences were found based on participants' age. Participants showed improvement in choice of path to the target object. Examination of the five object-oriented tasks in each VE showed that in the first two examined VEs, more participants chose direct path in the first task than in the last task. These results improved in the last familiar VE.

In comparison to the results above, the participants in unfamiliar space achieved similar or better performances in the VE object-oriented tasks. 96% of the participants, succeeded in arriving at the target objects. Regarding the spatial strategy, 50% of the participants used only perimeter strategy, 38% used perimeter strategy with another strategy, mainly object-to-object and grid, and 12% used only object-to-object strategy. At St. Paul the perimeter strategy was in use for 80% of the task duration, with use of object-to-object and grid strategies only 20% of the time each. Adults mostly used perimeter only strategy, while teenagers tended to use perimeter with other strategies. No differences were found to correlate with participants' age of vision loss or the use of spatial strategies. In path type, participants improved their choice of path to the target object over the course of the experiment, with 74% choosing a direct path in the unfamiliar space.

In familiar spaces, participants mainly used two problem-solving strategies: following a reverse path to the starting point (17 times) and using object landmarks as references (10 times). Evaluating the use of orientation problem-solving strategies by the participant's age, we found that adult participants on average used strategies five times, while teenagers used them twice. In command action, the participants employed additional auditory feedback in all tasks for most of their performance time (72%-89%). Results were different in the use of the "restart" key; only a few participants used this command, mostly in the first VE. They preferred to "walk" virtually to the starting point rather than activate the "restart" command. Participants had few problems during their performances and there was little need for intervention by the researcher. As shown in Table 6, the number of problems and interventions also diminished with time.

In unfamiliar space the participants sparingly used only two problem-solving strategies: reversing to starting point (4 times) and object landmark (2 times). Similar results were found in using command action; participants employed additional auditory feedback for 87% of their performance and none used the "restart" key. During their performances, very few technology and orientation problems arose and the researcher instructed on technology and orientation topics a few times.

In familiar space, no differences were found for age of vision loss in task completion, spatial strategies, type of path, orientation problem-solving strategies, or command actions. But differences occurred in problems that arose during task performance and researcher interventions. Compared with participants who were congenitally and adventitiously blind, those who were newly blind experienced more technology and mobility problems, mainly in the first spaces. Similar differences were found with regard to researcher intervention. Participants who were newly blind needed 34 researcher interventions compared with those who were adventitiously blind (27) or congenitally blind (11). In unfamiliar space no

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differences were found for participants' age of vision loss in VE orientation task performance variables.

3.4 Research Question 4. What orientation strategies and processes did the experimental and control participants perform in orientation tasks in familiar RS, in comparison to unfamiliar RS (experimental and control groups)?

The data source for this question was the participants' observations during their tasks' performances in the RS. Six aspects are of interest as regards to the participant's orientation task performance in the RS: the duration, the spatial strategies, the task completion, the type of path, using second hand to support orientation, and the orientation problem-solving strategies. The experimental group performed the orientation tasks after exploring the corresponding VE. All research participants explored and walked in these RSs during everyday activities, including O&M rehabilitation sessions. Table 7 and 8 presents the average RS task performances across participants.

Comparison of success in familiar spaces between the research groups present that in the first orientation tasks the control group preformed the tasks in less time than the experimental group, e.g., in M3 the control participants were faster in five of eight tasks. Opposite results were found in the later sessions (e.g., in DB the experimental group required less time in six of eight tasks). Similarities were found among object-oriented, perspective-taking, and reverse tasks. The experimental participants successfully completed more than the control participants in 73% of tasks, especially in the perspective-taking and reverse tasks. Comparing task performance with reverse tasks shows more experimental participants improving their performance in the reverse tasks than the control group (in MB 73% performed object-oriented tasks successfully and 88% succeeded in reverse tasks, while in perspective-taking tasks 52% succeeded in the initial tasks, and 100% succeeded in reverse tasks, while of the control group 50% performed object-oriented tasks successfully and 70% succeeded in reverse tasks, while in perspective-taking tasks 40% succeeded in the initial tasks, and 40% succeeded in reverse tasks). Comparison of success between object-oriented and perspective-taking tasks reveals that all participants were more successful in the object-oriented tasks. For example the experimental participants in M3 76% succeeded in object-oriented tasks compared to 65% succeeding in perspective-taking tasks. In DB there was equal success in both tasks (92%); the difference was greater for the control group. Most experimental participants used direct paths to the targets (in M3-all tasks, 70% of the experimental group used direct paths compared to 43% of the control group). Both research groups improved their direct path from tasks to reverse tasks. Both research groups used direct path more in object-oriented tasks, for example, in the experimental group, in M3 object-oriented tasks, 69% of the participants used direct paths compared to 59% in perspective-taking tasks; in DB object-oriented and perspective-taking tasks 92% of the participants used direct paths. In both types of spaces the participants improved their direct path from tasks to reverse tasks. Wider differences were found in the control group performance (in MB object-oriented tasks 70% of the participants used direct paths compared to 20% in perspective-taking tasks; in DB object-oriented tasks 70% of the participants used direct paths compared to 50% in perspective-taking tasks). The perimeter strategy was most used during all tasks by both research groups. However, experimental

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participants briefly used other spatial strategies, mainly in the seventh space (DB). In both types of tasks the participants used the perimeter strategy more in tasks than they did in reverse tasks. During orientation tasks participants held the long cane in their dominant hand and used their second hand to explore the space. All participants used their second hand in the same duration percentages, but the experimental group used it most in the tasks and control group used it mainly in the reverse tasks. Use of the second hand decreased in later sessions. For example, the experimental group (Table 8) in M3 object-oriented tasks 48% of the duration of performance tasks compared to only 18% of duration in DB. In these first spaces second hand was used mainly in object-oriented tasks rather than in perspective-taking tasks.

During the tasks, participants used orientation problem-solving strategies. Experimental participants used three times more landmarks (object, ground texture, audible, or cardinal) during task performance than did control participants. Landmarks were used mainly in initial tasks as opposed to reverse. A comparison between object-oriented and perspective-taking tasks reveals that experimental participants used more landmarks than did control participants, especially in perspective-taking tasks. “Travel for more information” was used more by experimental participants, especially in the initial spaces (M3, MB). “Walked to the starting point” was used four times more by experimental participants, especially in M3 and MB. The “stop and think” was used more by the control group in object-oriented tasks and by the experimental group in perspective-taking tasks, and used less by both groups in the reverse tasks.

A comparison of the above results to orientation performances in unfamiliar space (St. Paul) shows that most of the experimental group participants successfully performed orientation tasks (object-oriented, perspective-taking, and reverse), although it was the first time walking in this space for all participants. They performed better in reverse tasks (89%) and perspective-taking tasks (73%) than in object-oriented tasks (67%). As in the first familiar spaces, half of the participants used direct path. Similar results were found in comparing performance of tasks with performance of reverse tasks. Examinations of the other variables results (spatial strategy, support by the second hand, and the use of orientation problem-solving strategies) are similar to behavior in DB space. The participants used mainly a perimeter strategy (53%-86%) and used other spatial strategies according to their needs. Although it was their first walking in unfamiliar space for all participants, they used their second hand less to collect spatial information during their performances.

In the familiar and unfamiliar spaces minor differences were found based on age of vision loss in RS orientation task performances. Participants who were adventitiously and newly blind performed orientation tasks better than did those who were congenitally blind. In familiar spaces reverse tasks performances were equal, but in unfamiliar space participants who were adventitiously and newly blind performed tasks better than did those who were congenitally blind.

As the last task, each participant was asked to point at five to six objects. In the familiar spaces the experimental group pointed more accurately (81%, 76%, and 97%) compared to the control group (56%, 68%, and 79%) and in unfamiliar spaces the experimental group

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pointed accurate for 81% of the objects. No data were available for 19% of experimental group in familiar spaces task performances and 1% of unfamiliar space task performances due to time limitations imposed by the CCB session schedule.

4 Discussion

This long-term research is the first to examine the integration of a virtual system in a rehabilitation program to support people who are blind in training and obtaining O&M skills. This is also the first research to study the use of VE by participants who are newly blind. These results help elucidate three main issues concerning the contribution of BlindAid to the O&M rehabilitation process.

4.1 From O&M Novices to O&M Expert Users

At the end of the O&M rehabilitation sessions most of the participants were ready for the challenge of the unfamiliar space, exploring it only through the VE and later applying this knowledge in RS. The participants achieved the ability to explore, construct a cognitive map, and apply this spatial information in an unfamiliar space. These new O&M skills will support independent navigation needs in their communities and everyday demands in the future. Supporting participants in exploring unfamiliar spaces through use of BlindAid will enhance independent O&M behavior and will safely bridge the knowledge acquired in rehabilitation and the return to their communities. It will also fulfill the need to continue living independently in social, workplace, and everyday spheres. This ability of people who are blind to employ VE to master simple and complex unfamiliar RS corroborates results found in previous research (Lahav & Mioduser, 2004).

4.2 BlindAid as Simulator to Support People Who Are Blind in a Rehabilitation Program

The training with BlindAid is not meant to replace a rehabilitation program but to complement it with external support, without the limitations of budget, O&M instructors' time and effort, participants' practice time, and the stress associated with exploration in RS. Each participant received approximately 20 hours in the O&M sessions and additionally an average of 15 hours using the BlindAid. This system enabled the practice of basic O&M skills in exploration, employment of spatial strategies other than perimeter, and collection of perceptual information, and enabled the participants to apply this spatial knowledge successfully in RS.

Research results show that participants used perceptual information such as auditory and haptic feedback during their VE exploration and orientation tasks as in the O&M curriculum (Campbell, 1992a, 1992b). After practice in O&M sessions and BlindAid sessions, VE exploration methods improved. Better results were found in the unfamiliar space; participants mainly used perimeter strategy, with excellent systematic exploration. Similar research has shown that the main characteristic of successful scanning is being systematic, which leads to improved learning of useful information (Geruschat & Smith, 1997). Previous research on using VEs for spatial exploration has depicted individuals' difficulties and unsuccessful performance of subsequent orientation tasks in RS (Munro, Breaux, Patrey, & Sheldon, 2002). Our previous research (Lahav & Mioduser, 2008; Lahav, Schloerb, Kummar, & Srinivasan, 2011), resembling the current findings, described participants' ability to manipulate spatial information and proceed confidently and successfully to the target during orientation tasks in RS. This research demonstrates the positive effect of BlindAid in the unfamiliar space. Research results revealed no differences between the space types. Participants who explored the unfamiliar space were able to acquire spatial information and apply it in RS orientation tasks. Additionally, the BlindAid system allows people who are newly blind to perform orientation tasks equally well or better compared with those who are congenitally or adventitiously blind.

4.3 Implications for Researchers and Practitioners

The encouraging results of the current study indicate the potential advantages of using a VE for both adults and teenagers who are congenitally, adventitiously, or newly blind. VE can serve as a training aid in the rehabilitation process. It is also an important tool for familiarization with unfamiliar spaces, where the ability to orient oneself independently is essential to carry on with life after the rehabilitation program ends.

In regards to research, further studies in a different setup should examine these research questions of "traditional" O&M methods versa VE and include several complex unfamiliar indoor and outdoor spaces. After further research, BlindAid could play a central role in four potential applications. First, a training simulator during O&M rehabilitation sessions could allow extra practice of O&M skills in a safe environment. Second, BlindAid could serve as an O&M simulator, preparing people who have just graduated from a rehabilitation program to explore their community environments and working areas in advance of arrival. Third, an O&M diagnostic tool could allow O&M specialists to track and observe participants' spatial behavior, such as O&M skills, spatial strategy, and O&M problem solving. Finally, for long-term use, the BlindAid could be made available on the Internet to support people who are blind in exploring unfamiliar spaces in advance.

Acknowledgments

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- BlindAid enabled training of basic orientation and mobility (O&M) skills
- This research demonstrates positive effect of BlindAid to explore unfamiliar space
- These new O&M skills will support future independent navigation needs
- Research results revealed no differences between familiar and unfamiliar spaces
- BlindAid allows newly blind perform O&M tasks equally compared to congenitally and adventitiously blind

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Figure 1.
BlindAid user interface.

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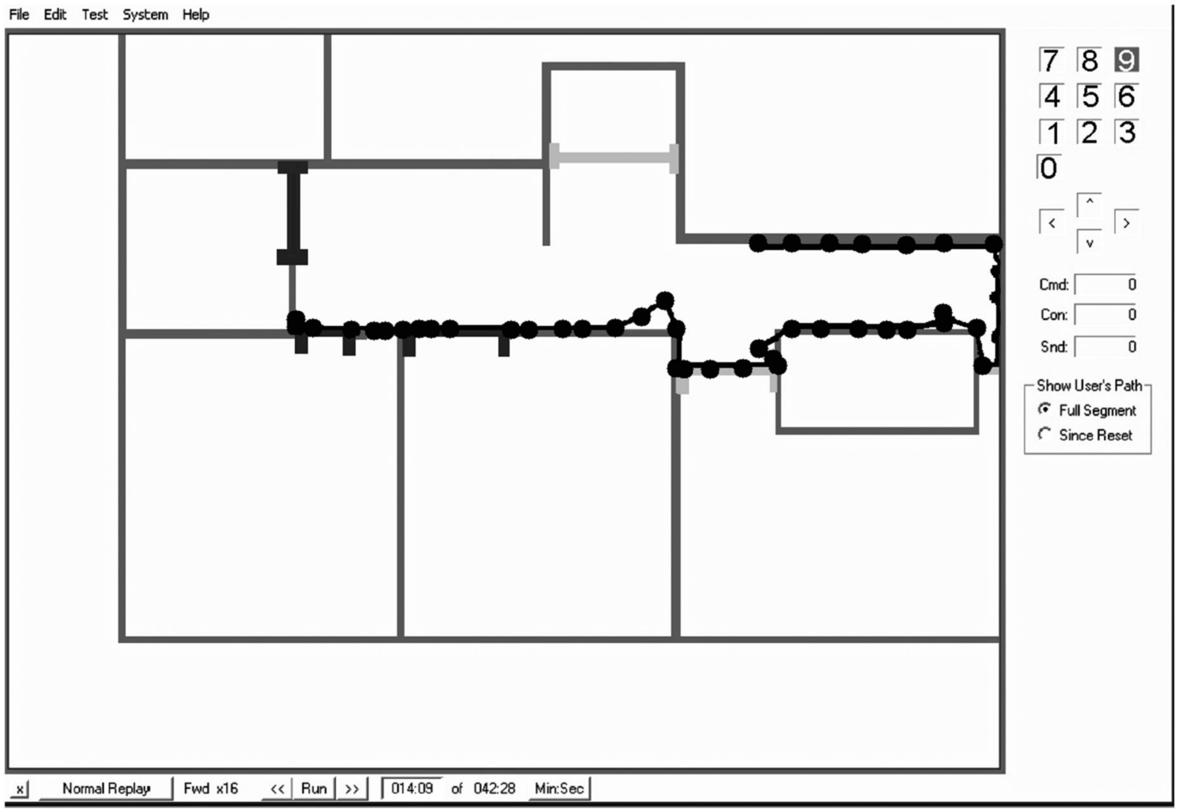

Figure 2.

Evaluation display of the third floor of the main building (user's path shows exploration of the main corridor space surrounded by rooms).

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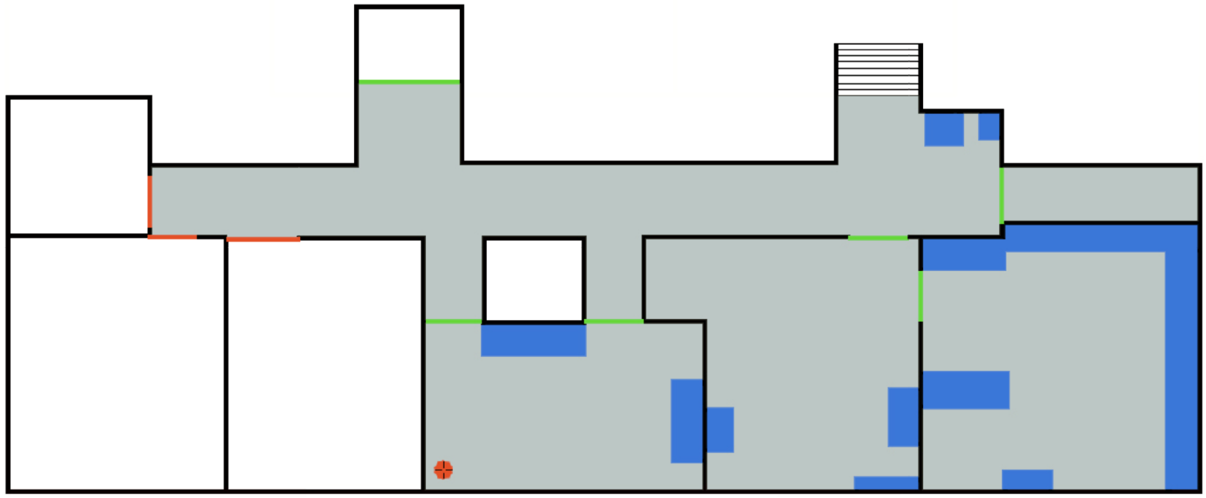

Figure 3.
Main building third floor.

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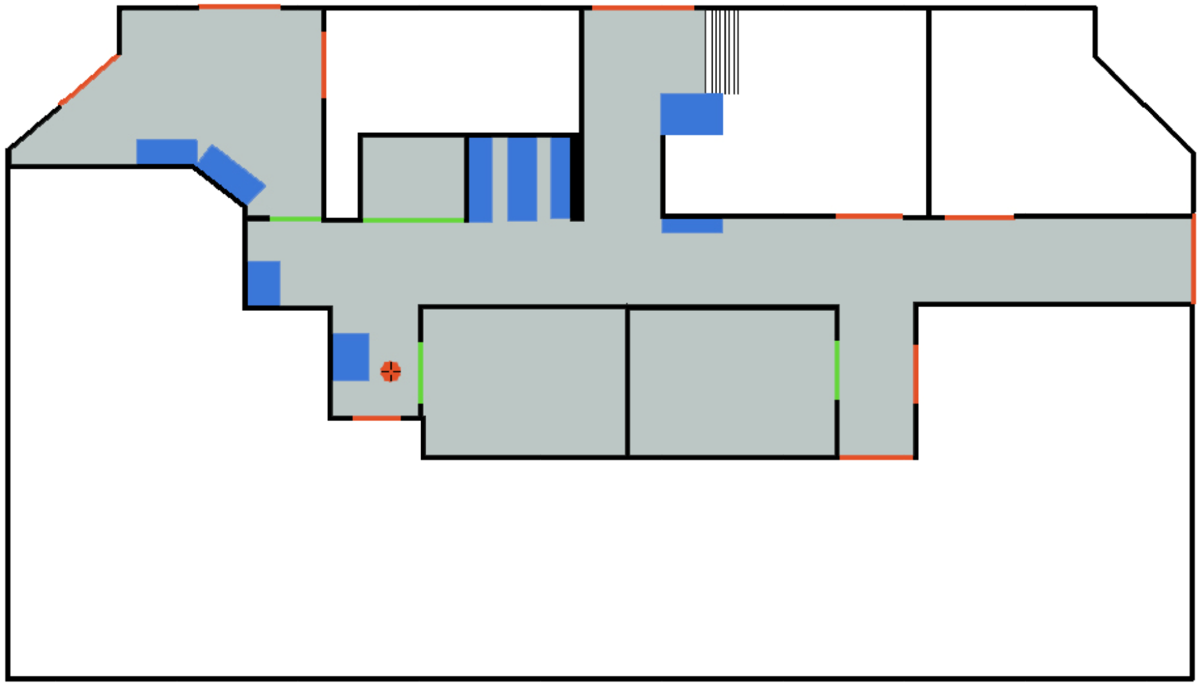

Figure 4.
Main building basement.

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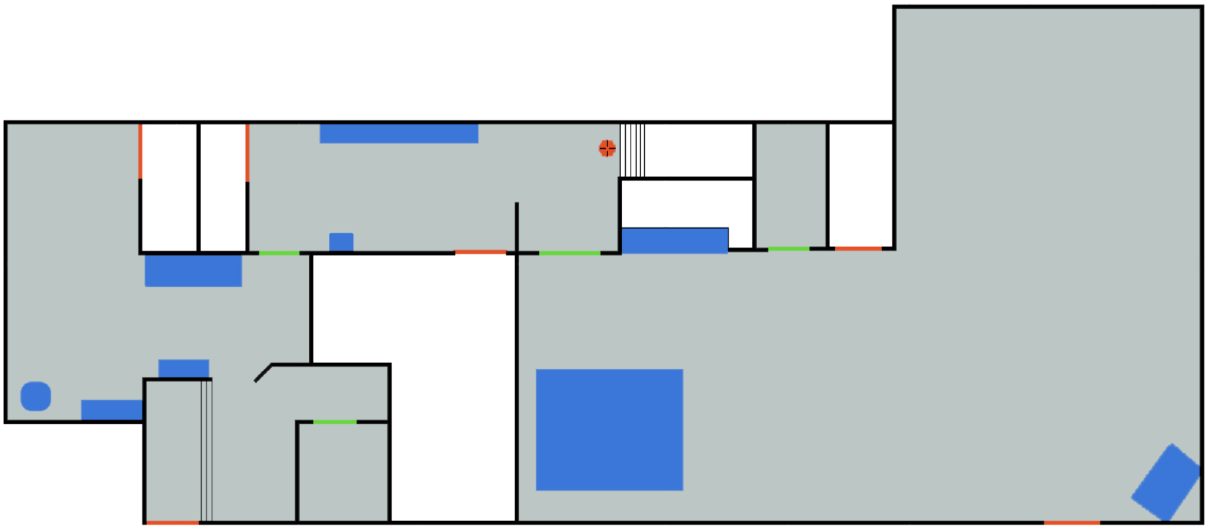

Figure 5.
Dormitory building basement.

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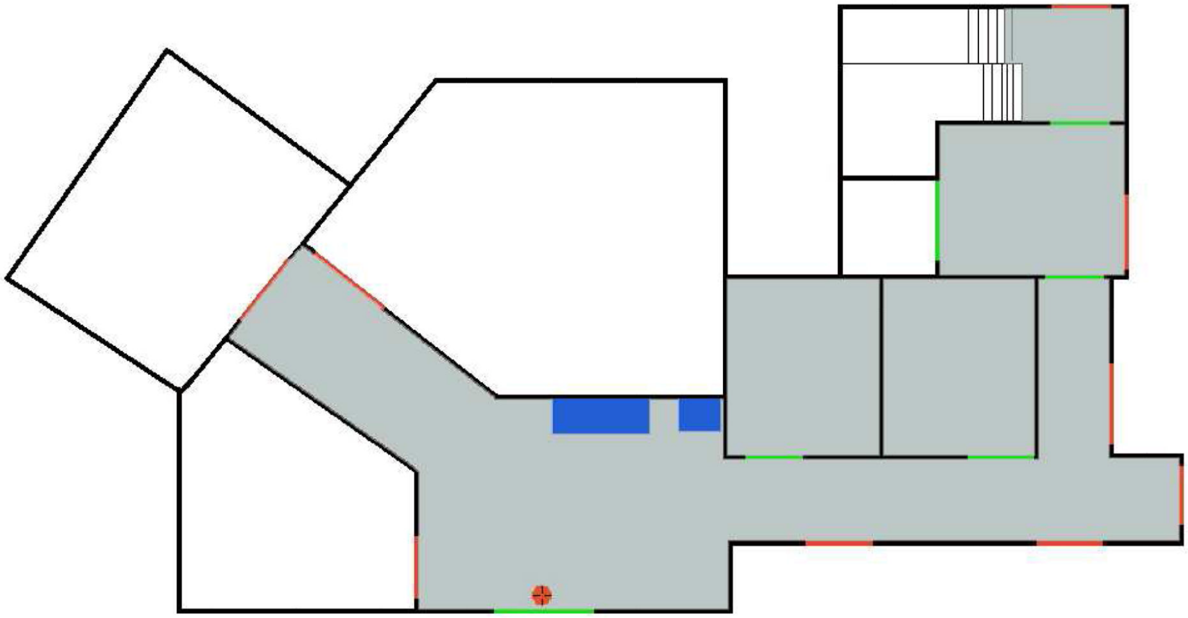

Figure 6.
St. Paul first floor.

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Table 1

Study participants

	Rehabilitation program	Age average	Gender		Age of vision loss		Use residual vision for O&M
			Female	Male	Congen-itally	Adventiti-ously	
Experimental (n=9)	Independent living program (*n*=6)	42 (22-66)	5	1	1	5	3
	Transition to college program (*n*=3)	18 (18-19)	2	1	2	1	3
Control (n=5)	Independent living program (*n*=4)	34 (24-48)	3	1	1	3	3
	Transition to college program (*n*=1)	18	1		1		

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Table 2
Variables measured by using data collecting tools

	Variables	Data collection tools		
		Verbal description	Observations	Computer logs
Strategies and process of the exploration task	Total duration			
	Spatial exploration strategies			
	Systematic exploration			
	Command actions			
	Technology and orientation problems			
	Self-motivated behavior			
	Researcher interventions			
Cognitive map	Structural components			
	Structural component location			
	Objects			
	Object location			
	Spatial strategy			
	Spatial model			
	Chronology			
Orientation task performance	Duration			
	Spatial strategies			
	Task completion			
	Type of path			
	Orientation problem-solving strategies			
	Command actions			
	Technology and orientation problems			
	Researcher interventions			
RS orientation task performance	Duration			
	Spatial strategy			
	Task completion			
	Type of path			
	Using second hand			
	Orientation problem-solving strategies			

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Table 3

Exploration time by strategies

VE	Session #	O&M teacher estimated duration	Duration	Spatial strategies	
				Changes	Average duration
M3 (*n*=9)	3	30:00	22:21	35	00:38
MB (*n*=9)	5	25:00	25:40	39	00:39
RHB (*n*=6)	10	25:00	19:47	34	00:35
St. Paul (*n*=9)	15	30:00	16:30	26	00:38

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Table 4

Participants' exploration process

VE	Session #	Spatial strategy				Systematic exploration		
		Perimeter	Grid	Exploring object area	Random	Excellent	Restless but systematic	Poor
M3 (*n*=9)	3	89%	8%	1%	1%	64%	30%	5%
MB (*n*=9)	5	88%	7%	1%	3%	54%	40%	6%
DB (*n*=6)	10	80%	7%	5%	8%	82%	13%	6%
St. Paul (*n*=9)	15	91%	5%	2%	0%	89%	10%	1%

Note: Duration is indicated in percentages of the overall time of exploration.

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Table 5

Participants' cognitive map

		Experimental group				Control group			
Space	**Participant**	**O&M teacher evaluation**	**Score (structure & objects)**	**Spatial strategy**	**Spatial model**	**O&M teacher evaluation**	**Score (structure & objects)**	**Spatial strategy**	**Spatial model**
M3	1	3	14%	0	0	4	7%	List	List
	2	3	11%	Perimeter	Route	4	27%	Perimeter	Route
	3	1	11%	Perimeter	Route	4	30%	Perimeter	Route
	4	1	57%	Starting Point	Route	2	11%	Perimeter	Route
	5	4	7%	List	List	4	5%	List	List
	6	1	14%	Perimeter	Route				
	7	3	0	0	0				
	8	5	0	0	0				
	9	1	9%	0	0				
MB	1	5	NA	NA	NA	1	5%	List	List
	2	2	11%	List/ Perimeter	List	2	45%	Perimeter	Route
	3	1	10%	List/ Perimeter	Cardinal/ List	2	48%	Perimeter	Route
	4	3	NA	NA	NA	2	19%	Perimeter	Route
	5	4	15%	List	Route	3	3%	List	List
	6	2	21%	List	Route				
	7	5	0	0	0				
	8	5	13%	List	Route				
	9	2	15%	List	List				
DB	1	4	35%	List	List	3	11%	List	List
	2	1	35%	Perimeter	Route	4	54%	Perimeter	Route
	3	1	96%	Perimeter	Route	4	67%	Perimeter	Route
	4	4	83%	Perimeter	Route/ Cardinal	2	74%	Perimeter	Route
	5	5	28%	List/ Perimeter	Route	3	NA		
	6	2	NA	NA	NA				
	7	3	22%	List/ Perimeter	Route				
	8	3	NA	NA	NA				
	9	1	NA	NA	NA				
St. Paul	1		39%	Perimeter	Route				
	2		83%	Perimeter	Route				
	3		86%	Perimeter	Route				
	4		64%	Perimeter	Route				
	5		53%	List	List				
	6		69%	Perimeter	Route				

		Experimental group				Control group			
Space	**Partic ipant**	**O&M teacher evaluation**	**Score (structure & objects)**	**Spatial strategy**	**Spatial model**	**O&M teacher evaluation**	**Score (structure & objects)**	**Spatial strategy**	**Spatial model**
	7		56%	Perimeter	Route				
	8		33%	List	List				
	9		28%	List	List				

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Table 6

Virtual environment orientation task performance

		Familiar space		Unfamiliar space	
		M3 (5 tasks)	MB (4 tasks)	DB (5 tasks)	St. Paul (5 tasks)
n		*n*=8	*n*=7	*n*=6	*n*=9
Task completion	Failed	7%	22%	10%	
	Arrived at target's zone with verbal assistance	8%	22%	13%	4%
	Arrived at target's zone	2%	11%		
	Successful	83%	47%	77%	96%
Spatial strategy	Perimeter	89%	87%	91%	80%
	Object-to-object	6%	10%	7%	15%
	Grid	6%	3%	2%	5%
Type of path	Wandering around	18%	25%	17%	4%
	Indirect	11%	11%	7%	4%
	Direct with limited walking around	32%	32%	17%	18%
	Direct	38%	32%	59%	74%
Orientation problem-solving strategies	Object landmark	7	1	2	2
	Stop and think		1	1	
	Cardinal direction		2		
	Reversing to starting point	3	7	7	4
Command action	Restart	9%	11%	3%	
	Additional auditory feedback (percentage of total duration)	72%	89%	83%	87%
Problem	Technology	6		1	1
	Orientation	3	4	3	1
Researcher intervention	Technology	13	5	5	5
	Orientation	10	7	5	3

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Table 7

Experimental group real space orientation task performance

			Successful completion	Direct path	Spatial strategy - Perimeter	Second Hand	Orientation problem-solving strategies			
							Landmark	Travel for more info	Going back to starting point	Stop and think
Familiar space	M3	Object-oriented	76%	69%	96%	48%	23%	6%	6%	12%
		Reverse	66%	60%	92%	44%	20%	7%	14%	14%
		Perspective-taking	65%	59%	96%	36%	29%	6%	29%	36%
		Reverse	100%	92%	88%	18%	9%	0	9%	0
		Pointing	81%							
	MB	Object-oriented	73%	73%	96%	48%	35%	0	21%	27%
		Reverse	88%	81%	96%	36%	7%	7%	7%	0
		Perspective-taking	52%	58%	97%	20%	34%	7%	33%	53%
		Reverse	100%	79%	100%	26%	36%	0	7%	0
		Pointing	76%							
	DB	Object-oriented	92%	92%	82%	18%	9%	0	0	9%
		Reverse	100%	92%	78%	10%	0	0	0	9%
		Perspective-taking	92%	92%	77%	17%	25%	0	17%	26%
		Reverse	100%	100%	63%	13%	17%	0	0	0
		Pointing	97%							
Unfamiliar space	St. Paul	Object-oriented	67%	56%	79%	21%	11%	6%	0	50%
		Reverse	89%	89%	53%	30%	0	0	0	11%
		Perspective-taking	73%	56%	86%	21%	17%	0	17%	33%
		Reverse	89%	83%	80%	16%	0	0	29%	7%
		Pointing	81%							

Note: Perimeter strategy and second hand are indicated in percentages of the overall time of exploration.

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Table 8

Control group real space orientation task performance

		Successful completion	Direct path	Spatial strategy - Perimeter	Second Hand	Orientation problem-solving strategies			
						Landmark	Travel for more info	Going back to starting point	Stop and think
M3	Object-oriented	50%	40%	92%	40%	10%			40%
	Reverse	70%	50%	99%	29%	10%		20%	30%
	Perspective-taking	40%	40%	100%	22%				10%
	Reverse	40%	40%	100%	36%				
	Pointing	56%							
MB	Object-oriented	80%	70%	99%	23%	30%			10%
	Reverse	60%	70%	100%	33%	10%			
	Perspective-taking	20%	20%	50%	7%				10%
	Reverse	30%	30%	50%	11%				
	Pointing	68%							
DB	Object-oriented	80%	70%	100%	28%	20%		10%	10%
	Reverse	90%	80%	99%	24%				
	Perspective-taking	60%	50%	82%	13%	10%			40%
	Reverse	60%	40%	88%	19%		10%		10%
	Pointing	79%							