International Conference on Virtual Rehabilitation 2011
Rehab Week Zurich, ETH Zurich Science City, Switzerland, June 27 - 29, 2011

Virtual Environment Support Orientation Skills of Newly Blind

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***Abstract*— The newly blind face enormous emotional, cognitive and physical difficulties in the first stage of rehabilitation. During the traditional orientation and mobility rehabilitation program, the newly blind are trained in basic orientation and mobility skills. The virtual system BlindAid aimed to serve as a simulator for the subject to practice his or her new spatial knowledge and orientation and mobility strategies. The two main goals of this research were to examine: (1) the exploration strategies and process of the newly blind when using a virtual environment; (2) the contribution of the virtual environment exploration process to performance on orientation tasks in virtual environments and real spaces. The findings supply evidence that interaction with the BlindAid system by people who are newly blind provides the participants' development of comprehensive cognitive maps of actual known and unknown spaces during their rehabilitation program**.

Keywords- Blind; Cognitive processing; Cognitive map; Rehabilitation; Orientation; Mobility; Spatial; Virtual environment; Haptic devices

I. Introduction

In the process of losing sight, newly blind people face great mental and cognitive difficulties, and difficulty with basic daily skills. The traditional orientation and mobility (O&M) rehabilitation program supports the acquisition of spatial mapping and orientation skills by supplying perceptual and conceptual information. The shortage in visual information is compensated by perceptual information such as the haptic, auditory and olfactory senses.

A. Orientation and Mobility Technology Devices

Over the years, O&M aids have been developed as secondary aids to help people who are blind to build cognitive maps and explore real spaces. These secondary aids are not a replacement for primary aids like the cane and the dog guide. The inventory of O&M electronic aids encompasses more than 146 systems, products, and devices [1]. There are two types of O&M aids: (i) pre-planning aids that provide the user with information before a person arrives in an environment such as, a verbal description of the space, tactile maps, strip maps, physical models, sound-based VE systems [2], and digital audio and tactile screens. (ii) in-situ aids that provide the user with information about the environment in-situ, such as obstacle detection and embedded information and navigation systems. The obstacle detection devices include the Sonicguide [3], Kaspa [4], Miniguide [5] or Palmsonar [6], and the Tactile Vision Substitution System (TVSS). For the embedded information devices environmental adaptation is needed, such as Talking Signs, which place sensors in the environment [7], or audio beacon activated by using cell phone technology [8]. The navigation systems that use personal guidance systems (GPS) are based on satellite communication and include VoiveNoteGPS, Trekker, Wayfinder Access, and others [9, 10].

The BlindAid system has no limitations with regard to workspace size, shape, or number of components of the real space. A semi-automated editor reads a blueprint file and transfers it to a virtual environment (VE) that can be available and accessible to all in the future via the web, resembling spatial information that is accessible to sighted people.

B. Virtual Environment as a Learning and Rehabilitation Tool

The uses of virtual reality in domains such as simulation-based training, gaming, and the entertainment industries have been on the rise in recent years. In particular, this technology is used for learning and rehabilitation environments for people with disabilities (e.g., physical, mental, and learning) [11, 12]. Research on the implementation of haptic technologies within VEs and their potential for supporting rehabilitation training has been reported for sighted people [13, 14]. Technological advances, particularly in haptic interface technology, enable blind individuals to expand their spatial knowledge by using artificially made reality maps through haptic and audio feedback [15] and construction of cognitive maps [16-18].

C. Carroll Center Traditional Orientation and Mobility Rehabilitation Program

The Carroll Center for the Blind (CCB) practitioners followed Amendolas' methodology, which is based on systematically collecting information through haptic, auditory, olfactory senses, and kinesthesia. The CCB O&M rehabilitation program is an intensive and comprehensive rehabilitation course, a 16-week campus-based program. The O&M program includes three parts: orientation, mobility, and cane technique. The orientation part has five components: (a) the use of sensorial landmarks and clues; (b) the use of visual scanning and audible signals to cross a street; (c) the use of cardinal directions for travel; (d) ability to recover when

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978-1-61284-474-9/11/$26.00 ©2011 IEEE

disoriented (problem solving); and (e) the construction of mental map for a route. The mobility part has three components: (a) the use of a human guide (b) indoors travel; and (c) community travel. The third part of the O&M program focuses on cane technique. During the 14 weeks of the campus-based program every client has three-to-four O&M sessions each week for 50 minutes each.

The study described in this paper is part of a larger research effort that included design and development of the BlindAid system, which was a usability study on the system components and studies on the contribution of the BlindAid system to users who are blind in exploring virtual maps in order to familiarize themselves with new and unfamiliar real spaces. In this paper we will describe the use of the BlindAid system as a simulated space to train, develop, and apply spatial, orientation, problem solving, and systematic strategies. In addition, this system provides tools for O&M instructors to evaluate the progress of their clients, while in-situ, during their rehabilitation program.

The main research questions of this study were:

1. What exploration strategies and processes do people who are newly blind use working with the VE?
2. How does the exploration in the VE contribute to the newly blind person's performance in orientation tasks in the real space?

In the next section, we will briefly describe the BlindAid system. Next, we will present the general research method. We will then present the research results, and we will conclude with a discussion on the merits of using the BlindAid system embedded in a traditional O&M rehabilitation program.

II. The BlindAid System

The BlindAid system was designed through active collaboration among engineers and learning scientists at the MIT Touch Lab, an expert on three-dimensional (3D) audio in VEs, and an O&M instructor from the CCB. The system provides virtual maps for users who are blind via haptic and audio feedback. The haptic device, a Desktop Phantom (SensAble Technologies), allows users who are blind to interact manually with the VE and has two primary functions: (1) it controls the position of the user avatar within the VE and (2) it provides haptic feedback and cues about the space from the tip of the Phantom. The headphones present sounds to the users as if they were standing in the VE (Figure 1). Each structure and object component has haptic and audio representation; for example, doors in the VE are represented by haptic feedback and a variety of icons (public, private or elevator door). The virtual workspace is a rectangular box that corresponds to the usable physical workspace of the Phantom, and the user avatar is always contained within the workspace. For moving the virtual workspace in order to explore beyond the confines of the workspace the user presses a button on the Phantom stylus causing the user avatar position to be fixed in the VE. Six command actions on the computer's numeric keyboard permit the user to control other aspects of the system while interacting with the VE. The command actions include restart, pause, start, install and recall landmark, detail audio information, zoom-in, and zoom-out. In addition to the user mode described above, the system also has two additional modes: (i) *The editor mode*: this mode in this stage of research and development is a semi-automated editor that can read a blueprint file and create a VE; (ii) *The evaluation mode:* this mode allows researchers to record and review the avatar's position and orientation within the VE during an experiment session.

The integration of the BlindAid system into the CCB traditional O&M rehabilitation program happened in two stages. The first stage included planning and design of VEs with O&M rehabilitation specialists, and the second stage included the participant trainee sessions in the BlindAid system in parallel with the orientation rehabilitation program.

Figure 1. The BlindAid system.

III. Method

A. Participants

The research included one participant who was selected on the basis of four criteria: newly blind enrolled in the CCB rehabilitation program, not multi-handicapped, English speaking, and comfortable with the use of computers. The subject, A. is female, adult, and late blind. A. uses residual vision for mobility. A. started to work with the BlindAid system in her third week and had a total of 17 sessions. A. was trained wearing a blindfold during her O&M rehabilitation training as well as during the VE sessions.

B. Variables

Four groups of dependent variables were defined: prior spatial knowledge, process of the exploration task, VE orientation tasks performance, and real space orientation tasks performance. Most of these variables were defined in our previous research [19, 20].

C. Instrumentation

The research included four implementation tools and five data collection tools. The three-implementation tools were:

1) Simulated environments

Nine spaces in the Main building, the Dormitory building, and the CCB campus were chosen by the CCB O&M instructors and the researcher to be modeled as learning VEs; eight VEs included the four floors of the two buildings, and the ninth was a model of the CCB campus and it surroundings.

2) Exploration task

The subject was asked to explore each VE individually and with time limitations. An O&M rehabilitation specialist defined the exploration time limitation for each VE, according to their estimation of the time required for exploring the equivalent physical space.

3) Physical space orientation task

After the orientation tasks performance in each VE, the participant was asked to perform nine orientation tasks in the real target space: (a) two Object-Oriented tasks. The subject was asked to perform and then reverse the tasks; (b) two Perspective-Taking tasks. The subject was asked to go from location A to location B and then asked to return to location A; and (c) a Point-to-the-Location task in which the subject was asked to stand at the starting point and to point with her finger to the location of five to six different objects.

In addition to the above three implementation tools, a set of five tools was developed for the collection of quantitative and qualitative data:

1) O&M questionnaire

The aim of this questionnaire was to evaluate the participants' O&M experience, abilities, and self-evaluation of her O&M ability. The questionnaire had 50 questions about the participants' O&M ability indoors and outdoors as well as in known and unknown environments. The O&M questionnaire was taken from our previous research [19].

2) O&M rehabilitation instructor evaluation

Before integrating the BlindAid system in the traditional O&M program, the O&M instructor was asked to evaluate her clients' behavior. Next, during the BlindAid activity the O&M rehabilitation instructor was asked to recommend O&M methods for the participant to use in the VE training.

3) Observations

The participant was video-recorded during her exploration and orientation tasks. These video-recordings were transcribed.

4) Open interview

Before the exploration task, the participant verbally described the space. This open interview was video-recorded and transcribed.

5) Computer log

The computer data enabled the researchers to track the users' exploration activities in the VE in two ways: as a text file and as a video recording file.

D. Procedure

The participant worked and was observed individually. In the first session an O&M questionnaire was obtained. Prior to this time the O&M rehabilitation specialist that worked with this participant answered the O&M rehabilitation specialist questionnaire. In sessions two and three, the participant learned how to operate and to gather spatial information by using the BlindAid system. Afterwards, each session was dedicated to different simulated environments from simple spaces to complex spaces and included orientation tasks in the VE and in the real physical space. Starting with Main building-Basement and ending with the ninth simulated environment – the CCB campus (sessions 4-16). Every session started with a verbal description of the target space, followed by the VE exploration task. After each exploration task, A. asked to perform six Object-Oriented tasks in the VE. In each, she was asked to find a different object in the explored VE. After performing the orientation tasks in the VE, A. was asked to perform nine new orientation tasks in the physical space. First, she performed two two-part Object-Oriented tasks; in each, she stood at the same location and faced the same direction as the VE's starting point. She was asked first to find an object and then to return to the starting point ("reverse"). Second, she performed two two-part Perspective-Taking tasks. In one, she was asked to go from location A to location B and then to reverse to location A; in the second, she was asked to go from location A to location C and then to reverse to location A. Third, A. performed a Point-to-the-Location task, in which she was asked to stand at the same location as the VE's starting point, and then point with her finger towards the location of five to six different objects. Each session lasted 50-90 minutes, with two to three sessions every week. All the sessions were video-recorded and transcribed. Once in ten days the researcher met individually with the O&M instructors. The main rationale behind these meetings were to assess, share and exchange thoughts about the participants' orientation skills and behavior and whether a special orientation method was needed for the BlindAid system. Processing and analysis of the collected data using the video recording, the transcription, and computer log data.

E. Data Analysis

To evaluate the participants' O&M exploration and performance we applied previously developed coding schemes [19, 20]. Four O&M rehabilitation specialists who have been working for more than 15 years in a rehabilitation center for people who are blind defined these coding scheme instruments. They took part in the design and construction of each coding scheme based on the observation of video data and computer logs; the identification and classification of exploration strategies; the consolidation of evaluation instruments based on previous analyses and on the O&M literature [21-23], and the implementation of the coding schemes for analyzing the participants' exploration, performance, and acquaintance with the new space. The participants' video records were transcribed and then coded simultaneously with the participants' computer logs using Interact, a qualitative statistical software package. The computer log data was parsed and analyzed using quantitative statistical software.

IV. RESULTS

Research Question One: What exploration strategies and processes do people who are newly blind use working with the VE?

The O&M rehabilitation specialist suggested an average time to explore each of the spaces. The average time that was suggested to explore the CCB campus was 90 minutes, divided to three separate sessions to allow exploration and orientation tasks in 50 minute increments (the length of each session). In 75% of the tasks, the duration of exploration time was lower than the average exploration time suggested by the O&M rehabilitation specialist (Figure 2).

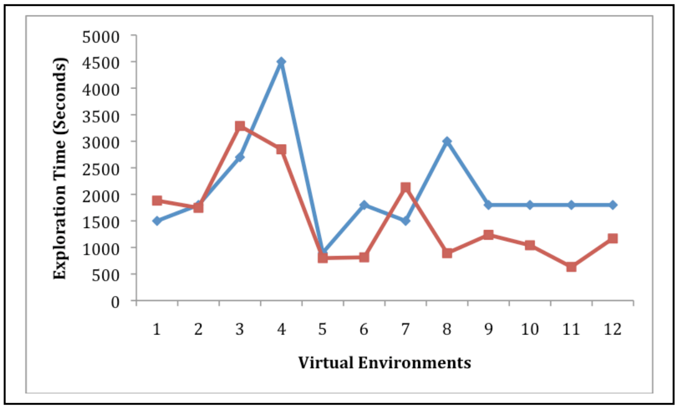

Figure 2. Time suggested by O&M rehabilitation specialist and A's exploration time duration

The perimeter strategy was the most used strategy during all the exploration tasks. In all the exploration tasks beside one, the participant started with the perimeter strategy. In 66% of the exploration tasks A. exchanged strategies very frequently, in the last half or last quarter of the exploration task. She used the following strategies: grid, object-to-object, and exploring object area with the perimeter strategy. For example, in the Dormitory building 1st floor exploration task, the total duration time was 14:52 minutes, and the perimeter strategy was used for 12:36 minutes. In the last quarter A. exchanged 22 times strategies: perimeter, grid, object-to-object, and exploring object area.

In the first task (Main Basement) A. explored the environment in a restless way. In the second exploration task (Main 3rd floor) she started to explore the space systematically and then after six minutes became restless. In the third (Main 2nd floor), fourth (Main 1st floor), and seventh (Dorm basement) exploration tasks A. started to explore the spaces with a restless or poor exploration method and then changed to a more systematic method. After a while she explored without any method for a short time (1:30 seconds) and then returned to exploring the space systematically. These shifts occurred three to four times in one exploration task performance. In the last seven exploration tasks A. explored the spaces systematically. The time spent in restless or poor exploration methods decreased until it disappeared completely in the last four sessions.

The command action most used was the additional audio feedback that gives detailed descriptions of the object the user interacts with. A. used this command action in two ways - either she pressed the key (number nine) along with her exploration, or she pressed the key only after her interaction with an object when she wanted additional information about it. Another command action that was used is the Zoom-out, which allows the user to eliminate all the objects in the environment and to explore only its structure. In the first three environments the user used this zoom-out tool in the beginning of the exploration process and it was used for 29%-62% exploration duration time. Over time A. used this tool less. Similarly, the restart command action that allows the user to return to the starting point was used mainly in the first four environments, and with time the use of this command action decreased.

During the exploration process technology and orientation problems arose (see Table 1 and Table 2). The technology and orientation problems appeared mainly in the first four environments, and decreased and almost vanished in the other explored environments. In the first sessions A. had difficulty moving the VE workspace, differentiating between the audio feedback of public and private doors, "opening" a public door (i.e. figuring out how much force she had to apply via the stylus to "open" the virtual door), and finding a key on the numeric keyboard. For example, during her exploration of the Main building 3rd floor A. had 16 technology problems and 10 orientation problems. In the last environment she explored (the CCB campus) she had two technology problems and no orientation problems.

Table 1: Technology Problems During the Exploration

VR	**Technology**				**Sum**
	Moving Workspace	Door	Find Key	Other	
Main Basement	0	5	1	2	8
Main 3rd Floor	8	6	0	2	16
Main 2nd Floor	4	2	3	4	13
Main 1st Floor	3	0	3	1	7
Dorm 3rd Floor	1	1	1	2	5
Dorm 2nd Floor	1	2	0	0	3
Dorm Basement	0	4	0	0	4
Dorm 1st Floor	0	1	0	1	2
CCB Campus 1	1	0	0	1	2
CCB Campus 2	3	0	0	1	4
CCB Campus 3	0	0	0	2	2
Sum	21	23	9	16	140

Table 2: Orientation Problems During the Exploration

VR	Orientation Disorient				Sum
	In Space	Starting Point	Confront Spatial Information	Construct Cognitive Map	
Main Basement	4	3	0	2	9
Main 3rd Floor	6	1	3	0	10
Main 2nd Floor	7	1	0	0	8
Main 1st Floor	6	3	4	0	13
Dorm 3rd Floor	0	0	4	0	4
Dorm 2nd Floor	1	0	0	0	1
Dorm Basement	7	0	4	1	12
Dorm 1st Floor	3	0	3	0	6
CCB Campus 1	0	0	2	1	3
CCB Campus 2	1	0	0	0	1
CCB Campus 3	0	0	0	0	0
Sum	35	8	20	4	67

Starting with the second exploration task, A. became aware of her exploration behavior and started to be more participatory. Her activities during the exploration tasks demonstrate these behavior changes, for example, she sets a target to find in the VE simulation, decides in advance what spatial strategy to use, uses orientation problem solving techniques that she learned during the traditional or VE O&M sessions, or (by the 4th environment) asks the researcher for an orientation task. This suggests changes in her motivation, attitude, and her exploration behavior in the VE during the exploration tasks. The participants' awareness and involvements happened throughout all the exploration tasks.

Throughout the participants' exploration process the researcher made some interventions when problems arose for A. in spatial strategy, orientation and technology. There were three types of interventions: technology, orientation and motivation. The orientation interventions were based on collaborative conversations with her O&M rehabilitation teacher. In the first exploration task (Main Building-Basement) A. mainly gathered spatial information through her visual channel. When blindfolded she had difficulties collecting the spatial information through other senses (e.g. the auditory and haptic) After three exploration tasks (Main building-basement, 3rd and 2nd floor) the O&M rehabilitation instructor observed and evaluated the participants' exploration behavior in the VE and the physical space orientation tasks. Her recommendations to A. were to collect spatial information through the audio and haptic channel, to explore the VE first without objects and then to add them, to explore the environment systematically, to be aware of the staircase, and to be aware of her own anxiety about new spatial information. The researcher instructed A. based mainly on the above O&M rehabilitation instructor's recommendations. These interventions were reduced during the environment exploration process. For example, in the fourth environment - Main-building 1st floor, the researcher instructed the participant 11 times on technology issues, 21 times on orientation issues and 8 times on motivation issues that arose during the exploration process.

Research Question Two: How does the exploration in the VE contribute to the newly blind person's performance in orientation tasks in the real space?

After the exploration in the VE system, the participant was asked to perform nine orientation tasks in the real space: two Object-Oriented tasks, two reverse tasks, two Perspective-Taking tasks, two reverse tasks, and a Point-to-the-Location task. As a result of schedule limitation, A. performed 19 Object-Oriented tasks, 17 Object-Oriented reverse tasks, 20 Perspective-Taking tasks, 17 Perspective-Taking reverse tasks, and 8 Point-to-the-Location tasks. In the orientation tasks in the CCB Campus A. performed one Object-Oriented task follow by two Perspective-Taking tasks. A. succeeded in performing the tasks very well (95% success). Similarly to her performance in the VE tasks, A. used mainly (74%) the perimeter strategy in the first session and then started to integrate the perimeter strategy with the object-to-object strategy (12%) and the object-to-object strategy only (12%). When A. arrived to the CCB campus she used only the perimeter spatial strategy. A. used the direct path in 75% of the tasks and a direct path with limited walking around in 16% of the tasks, and only in 4% of the tasks she wandered around the space looking for the target object. Throughout her navigation in the real space A. used orientation problem solving strategies. In 26% of the tasks A. used one or more landmarks (object landmark, ground landmark such as texture and elevation, audio landmark, or cardinal direction). She went back to the original starting point twice, and in two tasks only she used her second hand to explore the space and to search for landmarks. After the orientation tasks, the participant performed the Point-to-the-Location task. In this task the participant was asked to stand at the starting point facing in the same direction as in the VE and to point with her finger to the location of five or six different objects (a total of 48 tasks). A. performed successfully in 96% of the tasks. In the physical space orientation tasks the researcher didn't make any interventions.

V. Discussion

The study reported here is part of a research effort aimed to understand if and how work with a VE enhances and supports the establishment of exploration methods by people who are blind and newly blind. The BlindAid system was used as simulator aid to train, develop and apply O&M methods, and to develop and practice orientation problem solving. The system acts as pre-planning aid to help newly blind people to develop awareness about the environment in which they are traveling, in a safe and relaxed manner. In addition this system provide information for O&M rehabilitation instructors to evaluate the progress of their clients, while in-situ, during their rehabilitation program. The results of this study helped us to elucidate several issues concerning the contribution of the VE to the exploration strategies and learning process of spaces by people who are newly blind.

We found much evidence of the constructed map and its contribution to the participants' performance in the real space. Walking in an unknown environment for the first time is usually slow and hesitant. Unexpectedly, the exploration time of the unknown space was shorter than the duration time predicted by the O&M specialist. The VE has no limitation with regards to the size and shape of the real space, or the amount of spatial information included. In addition, this technology has unique features that can exist only in the VE and contributes to the users' spatial abilities. Such tools enhance the participants' ability to gather spatial information and to improve spatial activities within the simulated environment early in the exploration learning process. These command actions were used mostly as a support tools in the first exploration tasks. The BlindAid system allowed the participant to transfer her spatial knowledge and abilities from the real space to VE and back to the real space by using the same spatial strategies and variety of landmarks (e.g. object location, audio, ground, or cardinal landmarks). The VE as a pre-planning aid allowed the participant to explore the VE in advance and to perform orientation tasks in the real space. The participants' level of success in performing Object-Oriented tasks and Perspective-Taking tasks contrasted with previous reports on (blind and sighted) people's difficulties and unsuccessful performance in those tasks [24, 25]. Our previous research shows results similar to this research [20] unveiling the complex ability developed by the participant to manipulate the cognitively mapped spatial information and to proceed confidently and successfully to the target.

Previous research found that the visual deficit affects navigational capability negatively in that many people who are blind become passive, depending on others for continuous aid [26]. In light of the encouraging results of this study, we can conclude that the richness and strength of the VE as a training and simulation learning and rehabilitation aid can provide a strong foundation for the participants' development of comprehensive exploration methods of the space and application of these methods in the real space. An important byproduct of the study is related to the VEs potential to become powerful tools for people who are blind and newly blind in the learning and rehabilitation 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. One possible application is for supporting the acquisition of O&M skills and strategies by late blind as part of their rehabilitation process. At another level, the development of more automated editing tools for the VE will support the creation of a variety of spaces (e.g., public buildings, shopping areas, airports, public transportation areas) enabling pre-visit exploration and recall of unknown spaces by people who are blind. The Internet will then make it possible to distribute this spatial information on a large scale.

This study's results have important implications for the continuation of research as well. Further studies should examine a large group of people who are newly blind training in the VE during their rehabilitation program and a control group that will be trained only by the traditional O&M rehabilitation program. Additional variables to be studied should relate to properties of the environment - e.g., complex public spaces, such as campuses and transportation areas. Finally, a comparison with other O&M aids used by people who are blind to learn about unknown environments (for example, tactile maps, verbal descriptions, GPS) may serve for comprehensive evaluation of the contribution of the virtual tools to people's spatial performance.

ACKNOWLEDGMENT

This research was partially supported by a grant from The National Institutes of Health - National Eye Institute (Grant No. 5R21EY16601-2), and partially supported by The European Commission, Marie Curie International Reintegration Grants (Grant No. FP7-PEOPLE-2007-4-3-IRG). We acknowledge the Carroll Center for the Blind, Newton, MA for the collaboration and the support during the BlindAid system design and research. We thank our anonymous participant for her time, efforts, and ideas.

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