Using Wii Technology to Explore Real Spaces Via Virtual Environments

for People Who Are Blind

Structured Abstract

Purpose - Virtual environments (VEs) that represent real spaces (RSs) give people who are blind the opportunity to build a cognitive map in advance that they will be able to use when arriving at the RS.

Design - In this research study Nintendo Wii based technology was used for exploring VEs via the Wiici application. The Wiimote allows the user to interact with VEs by simulating walking and scanning the space.

Finding - By getting haptic and auditory feedback the user learned to explore new spaces. We examined the participants' abilities to explore new simple and complex places, construct a cognitive map, and perform orientation tasks in the RS.

Originality – To our knowledge, this finding presents the first virtual environment for people who are blind that allow the participants to scan the environment and by this to construct map model spatial representations.

Keywords: Blind; Orientation and mobility; Cognitive map; Virtual environment; Wii

Article classification: Research paper

Introduction

Space plays an important role in everyday life. We live in it and move through it, and yet we find it extraordinarily difficult to come to grips with it (O'Keefe and Nadel, 1978), especially in new and unfamiliar places. Orientation and mobility (O&M) tasks in RSs that are obvious for sighted people are not obvious for people who are blind. The lack of sense of vision makes it difficult to identify locations and obstacles, or simply to find the way. By using internal sensory systems, such as olfactory, audio, and touch, people who are blind can collect information about their immediate environment and use it to orient themselves in space (Ungar et al., 1996).

Cognitive Map

General knowledge about a space can be learned from previous experience in the space or from seeing the space from a bird's eye view (Porathe, 2008). In both cases the representation is stored in the brain as a cognitive map – an external image-like representation that includes knowledge about a place, as well as knowledge consisting of spatial relationships within that space (Kitchin, 1994). Research on spatial models indicates that sighted people use two spatial models: the route model and map model. 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 (Fletcher, 1980; Kitchin and Jacobson, 1997). In his research, Fletcher (1980) shows that people who are blind mainly use the route model when exploring and navigating in spaces. The process for collecting spatial information has an effect on the cognitive map coding and later affects the decision-making processes that result in spatial behavior within a space (Lloyd, 1989). Past research (Lahav and Mioduser, 2004) reports that during their verbal descriptions people who are blind tend to give more details about the structural components and their location in the space as compared to description of objects in the space and their location. Their chronological approach in the descriptive process also tends to start with the structural components.

O&M Aids for People Who Are Blind

Over the years, secondary O&M aids have been developed to help people who are blind explore RSs. The existing inventory of O&M electronic aids encompasses more than 146 systems, products, and devices (Roentgen et al., 1993). These secondary aids are not a replacement for primary aids such as the long cane and the dog guide. The cane is a device used ‘to provide detection or preview by extending the tactile sense of the user’ (Farmer and Smith, 1997, p. 232). The dog guide responds ‘to a specific set of commands given by voice and hand signals… a dog guides the person who is visually impaired from the beginning to the end of each block. Once there…the dog waits for the next command’ (Whitstock, Frank and Haneline, 1997, p. 261). There are two major types of O&M aids: (i) preplanning aids that provide the user with information before arrival in an environment, for example verbal description, tactile maps, physical models, digital audio, and tactile screens; and (ii) in-situ aids that provide the user with information about the environment while in the space, for example obstacle detectors, tactile vision substitution system, embedded sensors in the environment, and Global Positioning Systems (GPS) based on satellite communication.

Virtual Environments for People Who Are Blind

The use of virtual reality in domains such as simulation-based training, gaming, and entertainment industries has 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) (Schultheis & Rizzo, 2001; Standen, Brown, & Cromby, 2001). Interaction in the VE by special needs populations presents both benefits and limitations. The benefits of the VE mainly include the user's independent interaction and activity in the VE. Users receive immediate feedback. The VE allows the user to practice without fear, time limitations, or the need for the participation of a professional. In addition, the VE technology allows the professional to manage the amount of information and sensorial stimuli that users receive during their interaction within the VE. These unique capabilities of the VE technology system fulfils the need to design a flexible and adaptive learning or rehabilitation program for each client according to his or her special needs and abilities. Moreover, the VE technology can assist professionals in gathering information about their clients' interactions. On the other hand, the VE has some limitations. The VE is not a replica or replacement for RS interactions and activities. Furthermore, most rehabilitation centers and schools cannot afford these expensive technologies. Additionally, some systems under development are still too heavy, bulky, or complicated for use outside the laboratory environment.

Technologically advanced virtual devices enable individuals who are blind to learn by using haptic and audio feedback to detect artificial representations of reality. The most recent generations of haptic devices transmit feeling through direct contact with the virtual object (e.g., SensAble Phantom Desktop, Immersion Corp.'s CyberForce, Novint Falacon, and Nintendo's Wii). Stemming from the development of these devices, applications have been researched and developed especially for people who are blind, including identification of texture and shape recognition (Semwal and Evans-Kamp, 2000; Sjotrom and Rassmus-Grohn, 1999), mathematical learning environments (Karshmer and Bledsoe, 2002; Van Scoy et al., 2000; Van Scoy et al., 2005; Yu et al., 2001), and acquisition of spatial information (Evett et al., 2009; Lahav and Mioduser, 2004; Sánchez and Sáenz, 2010). Researchers have shown that by exploring VEs that represent RSs, people who are blind can construct a useful cognitive map about previously inexperienced spaces.

Wii-based Virtual Environments

This research is part of collaborative research between research groups from Nottingham Trent University and Tel Aviv University, and continues and extends the research of Evett (Evett et al, 2008; 2009). In this research study we used the Nintendo Wiimote as a pre-planning aid for exploring VEs that represent RSs (see Figure 1). Using this technology has many advantages. It is widespread, cheap and popular, and easy to use with a standard PC (Battersby, 2008). Using the Wiimote's Bluetooth capability it is a simple task to interface the Wiimote with a standard PC. The Windows Wii application (Wiici) was created to handle the connection and pairing between the Wiimote and the target operating system. Wiici is a functional windows-based driver application written in C with Peek's Managed Library for Nintendo's Wii remote (Wiimote) as its heart (Peek, 2008). This driver provides facilities for keyboard, mouse and joystick mapping, for peripheral input data capture, and for a basic capacity for the replay and analysis of any captured data. Wiici not only provides the facility for the Wiimote to be mapped to the windows system, but also supports multiple extensions such as the Wii Classic Controller, the Wii Nunchuck, and the Wii Fit board. Interface panels have been created to support mapping functionality by enabling a user to configure each of the Wiimote's physical inputs to any desired keyboard or mouse input combination. In effect, this capability enables the Wiimote to be seen by the system as any of the highlighted devices, limited only by the volume of inputs available from the device. Customizable feedback is developed through the feedback-mapping panel, where flags may be set to operate any of the Wiimote's feedback mechanisms (Evett et al., 2008).

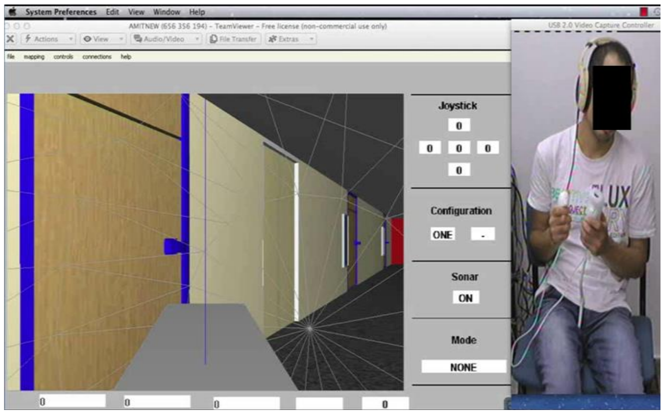

Figure 1. A participant using the Wii-based system and the VE display as seen on screen.

Figure 1 describes the research set up. On the left sit pde of the screen the VE scenario is shown, along with the Wiimote avatar in the foreground. On the right side a participant is sat next to the computer to which the Wii device was connected. The participant is holding the Wiimote in his left hand and the Nunchuck in his right hand, and receives auditory feedback via stereo headphones. The Wiimote can be used as a ‘virtual cane’ to scan the environment in front of the user and the Nunchuck to direct motion. As a result of this interaction the user receives auditory feedback via stereo headphones (the speaker on the Wiimote allows audio to be transmitted from the host and played back), and haptic feedback on the Wiimote device (rumble device, whose frequencies can be manipulated to provide the illusion of different lengths of rumble to indicate the proximity to an object).

Ten VEs were developed for this research. Two of the VEs are simulations of real indoor spaces, and the other eight are for use in training.

The main goal of this research was to obtain an understanding of whether people who are blind can construct a cognitive map by exploring a VE using the Nintendo Wiimote and the WiiCi mapping tool and later to apply it in the RS. The present study was designed to consider three main questions:

1. What exploration strategies and processes do people who are blind use when working with the VE Wii-based system?
2. Does walking in the VE contribute to the construction of an efficient cognitive map of the unknown space?
3. How does this cognitive map contribute to the blind person's O&M performance in the RS?

Method

Participants

The participants (N=10) were all adults, men and women aged between 25-40 years, and were totally blind (no residual vision), both congenitally blind and late blind. All volunteered to participate in this study. The participants were divided into two equal groups: experimental group and control group. In this article we will report about the experimental group only who worked on the Wii-based VEs (n=5).

Variables

One independent variable was defined in this research, the complexity of spaces explored by the participants: a simple environment and a complex environment.

Three sets of dependent variables were defined:

Exploration Process: Four variables were related to the exploration process: duration; exploration mode: walk-around mode (exploring the space by navigating the avatar in the space), or look-around mode (exploring the space by standing in one spot and getting information as requested about the object name, object distance, space structure name, or space structure distance); orientation strategies (perimeter, grid, object-to-object, exploring object area, and random); and systematic exploration of the environment to acquire spatial information.

Cognitive Map Construction: Eight variables were related to the cognitive map construction: structural component; structural components' location; object; objects' location; spatial strategy; estimated relationship between the spaces' components; spatial model; and chronology description.

Orientation Tasks Performance: Four variables were related to the orientation tasks performance: duration; success; type of path; and aids they were used (using second hand to support their orientation, object 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).

Instrumentation

The research included four implementation tools and three data collection tools. The four-implementation tools were the following.

Simulated Environments: This research included RSs located at the School of Education at Tel-Aviv University campus. To examine the effect of learning as a result of the exploration task in the Wii system two indoor spaces were chosen. These RSs differed in their level of complexity (size, structure and number of components). The simple environment (Figure 2) was a rectangular shape 44 square meters, with five doors (the light green lines represent private doors) and two windows and nine objects (dark green): a communication cabinet (item 1); a electric cabinet (item 2); two mail boxes (see figure 2 items 3 and 4); a chair (item 5); one bench (item 6); a recycle bin (item 7); and two boxes (item 8 and 9). The complex environment (Figure 3) was bigger, in a ladder formation (two long parallel corridors at each side, and two short corridors in between), had four areas, and 11 objects in it. The light green and red lines in the figure below represent public and private doors (see figure 3 items 10 and 11). The dark green represent structural and object components such as: two benches (items 1 and 7); stairs going down (item 2); a recycle bin (item 3); a snack machine (item 4); two round tables (items 5 and 6); a chair (item 8); a mail box (item 9); window (item 12); an electric cabinet (item 13); pole (item 14); and one box (item 15). Eight different VEs were built for training the participants on how to use the VE Wii-based system.

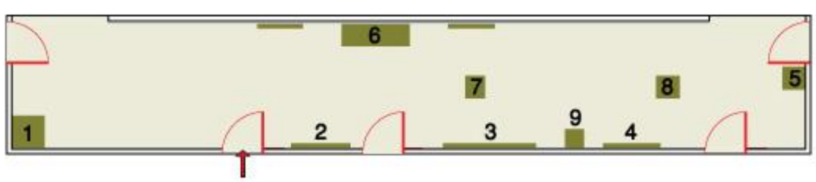

Figure 2. The simple environment.

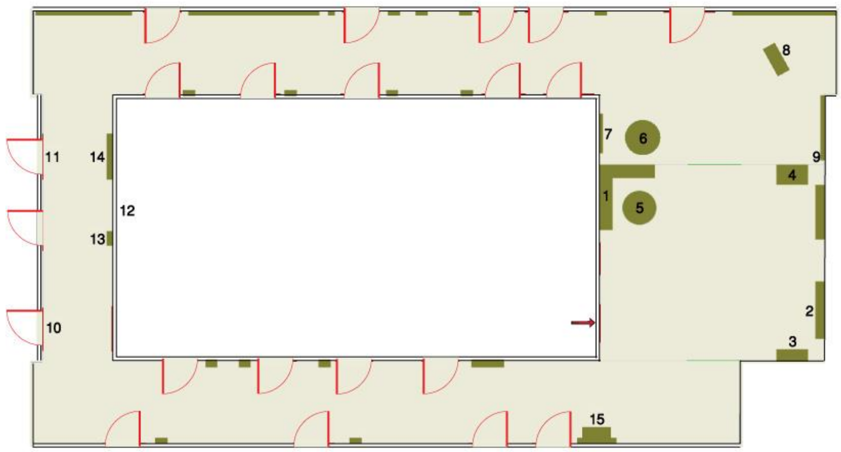

Figure 3. The complex environment.

Exploration Task: The experimental group were asked to explore each space via the VE Wii-based system. Participants were instructed to learn the space in their own way in a limited time that was recommended by O&M rehabilitation specialist (40 minutes for exploring the simple space and 60 minutes for exploring the complex space).

Description Task: After exploring the environment, participants were asked to describe the environment verbally. The verbal description was a tool for representing the cognitive map, which the participants constructed as a result of his or her exploration in the VE. Verbal description was chosen as opposed to a task of construction a physical model to prevent the participants from any learning they might do during the construction.

Orientation Tasks in the RS: All participants were asked to perform five orientation tasks in the RSs (simple and complex): (a) two Object-Oriented tasks (for example: to go to an object from the original exploration starting point); (b) two Perspective-Change tasks (for example: to go from a new starting point to an object); and (c) Point-to-the-Location tasks, in which the participants were asked to point to six different structural or object components from the exploration starting point.

In addition a set of three tools was developed for the collection of quantitative and qualitative data, as follows:

O&M Questionnaire: The aim of this questionnaire was to evaluate the participants' O&M experience, abilities, and self-evaluation of their O&M ability. The questionnaire included 50 questions about the participant's O&M ability indoors and outdoors as well as in familer and unfamiler spaces. The O&M questionnaire was taken from previous research (Lahav, 2003). This O&M questionnaire was itself evaluated by four O&M rehabilitation specialists.

Observations: Each participant was video-recorded during their VE Wii-based system exploration tasks and orientation tasks in the RS (see Figure 4).

Open Interview: After the exploration task, the participant verbally described the space. This open interview was video-recorded and transcribed.

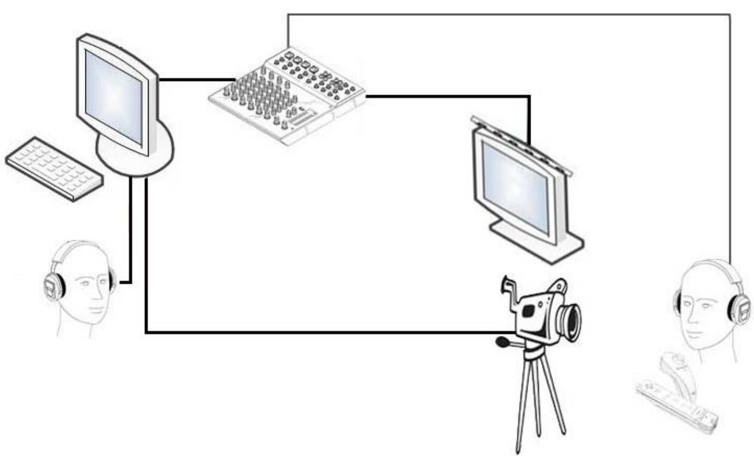

Figure 4. The Wii-based system and the research collecting data system.

Procedure

This research proceeded during the years 2012-2013. The procedure in this research was based on earlier work that examined the construction and use of cognitive maps after exploring VEs (Lahav, 2003). All participants worked and were observed individually. The participants had six meetings of two hours each. In the first session the participants completed the O&M questionnaire. Next, the participants learned to operate the VE Wii-based system for exploring the VEs and to gain confidence in using it (four sessions of 90 minutes each). The next two sessions were dedicated to exploring the simple and the complex environments by using the VE Wii-based system. After the exploration task the participants described the space and later performed orientation tasks in the RSs. All participants carried out the same orientation tasks in the RS and in the same order. All meetings were video-recorded.

Results

Research Question 1: What exploration strategies and processes do people who are blind use when working with the VE Wii-based system?

The participants explored the VE independently by using the Wii-based system. In both the simple and complex VEs, three of the participants used less time than the suggested time (that was suggested by the O&M specialist), and the other two participants asked for more time. The results showed that the look-around mode was the main exploration tool that was used to explore the VEs. The participants used the look-around mode on an average of 73% of their exploration time, 16% of their exploration time for pauses, and only 10% of their exploration time for walk-around mode. The total look-around mode data was coded and analyzed into four different variables: look-around mode-object-name, look-around mode-object-distance, look-around mode-space-name, and look-around mode-space-distance. This separation aimed to aid the researcher to understand the participants' exploration. The results showed that in 42% of the total look-around mode duration the participants used look-around mode-name (by scanning and eliciting the object name, auditory feedback was given), and 32% of the time they used look-around mode-distance (by scanning and eliciting distance information, audio feedback announced the number of steps between the object and the participants' location). In addition, when participants collided with a component they preferred more information about the distance of the component in front of them than its name; however, when they used the look-around mode they checked the component's name more often than its distance. Although the VE Wii-based system allows the look-around mode to indicate different heights, only one participant used this feature and then only for a few seconds. The spatial strategy that was most used was the object-to-object strategy (Table 1). During the exploration tasks the participants were consistent in their exploration processes.

Table 1: Exploration Process Experimental Group

	N	Duration (minutes)	Look-around mode		Spatial strategy		Pauses
			Name	Distance	Perimeter	Object to object	
Simple environment	1	29:24	37%	33%	2%	6%	23%
	2	49:39	28%	54%	5%	6%	7%
	3	38:32	41%	33%	0%	3%	22%
	4	58:45	45%	21%	4%	3%	28%
	5	32:18	50%	28%	6%	8%	7%
	Total average		74%		8%		17%
Complex environment	1	26:36	51%	22%	1%	7%	21%
	2	63:11	26%	49%	3%	13%	6%
	3	44:43	46%	32%	2%	2%	16%
	4	86:53	43%	23%	5%	6%	22%
	5	45:13	51%	20%	9%	11%	7%
	Total average		72%		12%		14%

Comparing behaviour within the two environments shows that the exploration time was divided almost equally between the same methods in the simple environment and in the complex environment. In the simple environment the participants used the look-around mode 74% of the time and in the complex environment they used it 72% of the time. Spatial strategies were used in the simple environment 8% of the total exploration time, and in the complex environment were used 12%. Pauses were used in the simple environment for 17% of the exploration time, and used for 14% of the exploration time in the complex environment. The use of different look-around modes was also divided in the same way: 40% look-around mode-name in the simple environment compared to 43% in the complex environment, 34% of look-around mode-distance in the simple environment and 29% in the complex environment.

Research Question 2: Does walking in the VE contribute to the construction of an efficient cognitive map of the unknown space?

We examined the descriptions of the simple and the complex spaces (Table 2). For the simple environment, the participants mentioned in their description an average of 61% of the total components that were located in the environment, and in the complex environment they mentioned 40% of the total components. The participants included in their verbal description more objects than structural components. Most of the participants used an object-to-object strategy to describe the space, and in a few descriptions they described the space by dividing it into areas. Nine descriptions were based on an estimated relationship description of at least four sentences that included such descriptions, for example: "on the same wall", "when I am behind door 214, the bench is on the left side". Six out of the ten descriptions were based on a map model, three on a route model, and one on a verbal list. All participants started their descriptions by mentioning a structural component.

The results show a difference between the simple environment and the complex environment. The simple environment was described in more detail than the complex environment. In describing the simple environment, four participants constructed a map model, however when describing the complex environment only two participants constructed a map model.

Table 2: Verbal Description Process

	N	Space components	Spatial strategy	Estimated relationship	Spatial representation	Chronology
Simple environment	1	66%	List	4	Map model	Structure
	2	75%	Starting point	11	Map model	Structure
	3	57%	Object to object	9	Route model	Structure
	4	59%	Object to object	15	Map model	Structure
	5	50%	Area & Object to object	16	Map model	Structure
Complex environment	1	19%	List	1	List	Structure
	2	44%	Area	12	Route model	Structure
	3	38%	Object to object	14	Route model	Structure
	4	53%	Area & Object to object	15	Map and route model	Structure
	5	46%	Area	15	Map model	Structure

Research Question 3: How does this cognitive map contribute to the blind person's O&M performance in the RS?

In answering the third question the participants' orientation tasks performances in the RS were examined. The orientation tasks included: two Object-Oriented tasks, two Perspective-Change tasks, and a Point-to-the-Location task. These tasks were evaluated by duration, their success in the task, the path that was chosen, and the aids they used (Table 3).

In the simple environment, the success average of the Object-Oriented tasks and Perspective-Change tasks was 73%, while in the complex environment the success was 50%. In 73% of all of the success cases the participants walked directly to the object.

In the exploration task of the complex environment, two of the participants stayed in the entrance lobby and did not explore the entire environment. These actions affected the results, as the participants could not know where the objects were located. In their first task they walked carefully in the VE, transforming their VE landmarks in the RS to base their spatial knowledge. After this process they became more confident, so the orientation task durations grew shorter even when an object was farther away or even in the Perspective-Change tasks. As they became more confident, the participants reduced the use of their second hand for obtaining more information. As the research took place in a RS and not in a lab, there were sounds that the participants used as landmarks, for example, the sound of a snack machine or students walking and talking in the lobby.

Table 3: Success in Orientation Tasks

	N	Object-oriented tasks			Perspective-change tasks			Pointing
		Duration (minutes)	Success	Direct path	Duration (minutes)	Success	Direct path	
Simple space	1	5:58	67%	33%	4:54	100%	100%	100%
	2	3:00	67%	67%	5:00	67%	67%	67%
	3	1:57	67%	67%	4:09	33%	0%	67%
	4	2:54	100%	100%	9:36	100%	67%	83%
	5	2:17	67%	67%	3:34	67%	67%	83%
	AVG	3:13	73%	67%	5:27	73%	60%	80%
Complex space	1	3:40	50%	0%	10:04	50%	50%	50%
	2	6:13	50%	50%	10:39	100%	50%	0%
	3	1:05	0%	0%	8:49	50%	0%	17%
	4	11:58	0%	0%	11:05	100%	100%	33%
	5	3:46	50%	50%	5:22	50%	50%	50%
	AVG	5:20	30%	20%	9:12	70%	50%	30%

The Point-to-the-Location tasks were evaluated using their success of pointing to the right directions.

After the RS tasks the participants were asked to describe their walk in the RS as a result of their exploration in the VE. Two participants: second participant (female, 40 years old congenitally blind) and fifth participant (male, 25 years old congenitally blind) described it very well. For example, the second participant said: “I felt like someone telling me a very detailed description of the area and then I found this things by myself…. Interestingly while working with the Wii sometimes I found myself in a position that I did not know where I was and where the things were located relative to each other, but then, when I transferred to the real environment then suddenly I realized things and suddenly I could remember: ‘that this is located before the door or after the door’ and things popped-up much more than during [the VE walking]…. I thought it was very confusing ‘right - left - left – right’, but now that I am walking here I remember the virtual walking... and I say: if I see a bench then I know that I expect to see a window', In other words, I knew what to expect later on and I didn't think that I would know it." Th fifth participant said: "It really reduced concerns, I knew more or less what was there and what to expect, even if I did not know exactly where everything was located…. Yes I managed to get something from it, even though I was exploring only part of it I managed to get something in terms of the familiarity with the area…It reduced my concerns just a bit, it gave me a picture, it gave me a picture but not an exact one so I could not be completely confident how the area looked like that I was entering in to.... in the second environment my concerns were reduced a little bit but still it was a new environment mainly because I knew it's bigger… During the tasks, I felt more familiar with the first area, with the second area I think I understood less the structure of the environment... I had a direction but very vague…"

Conclusions

The use of the VE Wii-based system supports the user in collecting information and constructing a cognitive map of the research spaces that later was applied in the RSs, similar to previous research studies (Lahav and Mioduser, 2004; Lahav et al., 2011; Sánchez and Sáenz, 2010). The participants used the VE Wii-based system to apply a new exploration strategy: the look-around mode - scanning the space. The option of using the look-around mode gave the participants the ability to stand in one place and to scan around without the need to walk. The VE Wii-based impacted the way the participants explored the VEs, in that they used mainly this look-around mode. For the short period of time that the participants chose to walk, object-to-object was the main spatial strategy and perimeter was secondary, whilst the findings of other research studies showed that participants walked mostly using a perimeter strategy, and walking was the main tool of exploration (Lahav and Mioduser, 2004; Lahav et al., 2011). The new exploration strategy methods afforded by the Wii-based system are probably the main reason that the participants constructed a map model as a spatial representation.

As the spaces became more complex the cognitive map was less detailed. Such changes in the spatial representation should be examined in future studies , also considering the use of outdoor environments. Although the cognitive map was less detailed as the spaces became more complex, the participants still managed to perform most of the tasks in the corresponding RS.

This study's results have important implications for the continuation of the research, and also for implementation. Further research studies should examine the participants' exploration of complex outdoor and indoor unfamiliar environments and apply this spatial knowledge in the corresponding RSs via orientation RS tasks. These new spaces need to include public areas such as museums, public transportation systems, government buildings, academic campuses, city centres area, and outdoor and indoor shopping areas. Examination of complex spaces of differing shapes (parallel corridors, lobbies, open areas, etc.). Other research studies might examine the participants' ability to construct cognitive maps as a result of exploration of several vertical levels in the VE. Finally, a comparison between the type of exploration (walk around mode versus look-around mode) on their exploration ability, construction of cognitive maps, and application of this knowledge in the RS should be considered. Other research studies might examine the type, and the amount of spatial information, that people who are blind need to construct a cognitive map from, and that can be applied and used by them in the RS.

Future development of the VE Wii-based system will need to focus on the user's training process. Walking in the VE Wii-based system required extensive training; the participants needed a long training time (eight hours) to develop the required exploration skills, as they had to develop new and different exploration skills and strategies to those used in a RS.

When travelling to unfamiliar spaces for pleasure or business, and there is demand for new spatial information, and the VE Wii-based could support people who are blind in exploring and collecting spatial information in advance in a safe environment. This spatial information could be available and accessible via the Internet, in much the same way as visual maps are accessible to sighted people (e.g., Google Map; Mapquest). It could also be made available to them in real time via mobile devices to augment and update their spatial information developed on PCs, and just such a system is currently in development in our research teams.

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