Usability of a Multimodal Video Game to Improve Navigation Skills for Blind Children

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This work presents an evaluative study on the usability of a haptic device together with a sound-based video game for the development and use of orientation and mobility (O&M) skills in closed, unfamiliar spaces by blind, school-aged children. A usability evaluation was implemented for a haptic device especially designed for this study (Digital Clock Carpet) and a 3D video game (MOVA3D) in order to determine the degree to which the user accepted the device, and the level of the user's satisfaction regarding her interaction with these products for O&M purposes. In addition, a cognitive evaluation was administered. The results show that both the haptic device and the video game are usable, accepted and considered to be pleasant for use by blind children. The results also show that they are ready to be used for cognitive learning purposes. Results from a cognitive study demonstrated significant gains in tempo-spatial orientation skills of blind children when navigating in unfamiliar spaces.

Categories and Subject Descriptors: K.4.2 [**Computers and Society**]: Social Issues—*Assistive technologies for persons with disabilities*

General Terms: Human Factors

Additional Key Words and Phrases: Blind children, virtual environments, navigation, haptic and audio interfaces

ACM Reference Format:
Sánchez, J., Saenz, M., and Garrido, J. M. 2010. Usability of a multimodal video game to improve navigation skills for blind children. ACM Trans. Access. Comput. 3, 2, Article 7 (November 2010), 29 pages. DOI = 10.1145/1857920.1857924. http://doi.acm.org/10.1145/1857920.1857924.

This article was funded by the Chilean National Fund of Science and Technology, Fondecyt #1090352 and Project CIE-05 Program Center Education PBCT-Conicyt.
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1. INTRODUCTION

It is known that the first sensory-motor activities of a child such as play, movements while playing and observation of the effects of such movements, later affect the development of the child's cognitive functions and comprehension [Piaget 1962]. When a child experiences movements he or she also experiences notions of time, space and the logic of events, thus learning to make sense of the entire surrounding environment and achieving an understanding of reality [Piaget 1962]. For this reason, when children do not develop sensory-motor coordination correctly, they can experience problems in the future with regard to navigation through their surrounding environment.

In particular, one of the problems for blind people when moving about is determining their location in the environment and knowing which way they are facing and the direction in which their body is moving. The lack of information on important objects in the environment that may serve as anchors and points of reference for their own position is also important [Hub et al. 2004]. Thus, any information on the characteristics of the objects in such a context could be important and relevant for a blind person [Kulyukin et al. 2004].

Our research consisted of providing a technological tool especially designed and developed for blind people in such a way that they could interact and develop navigation skills. As such, they would be able to know where they are and make decisions regarding what route to follow in order to get to certain destinations.

To avoid any potential risks and to move about safely, some blind people prefer to navigate by using the room's perimeter (shorelining) rather than crossing through the center of a room. It is simpler for them to continue their route by touching the wall and thus more easily locating the access points and obtaining a specific route, than it is for them to move about in open space [Sánchez and Zuñiga 2006]. This way of exploring the environment can lead users to find inefficient solutions to mobility problems [Kulyukin et al. 2004]. Knowing the size of a room is not easy, and this is useful information that would help them to situate themselves. In general, blind individuals can detect the level of echo produced in a room (either by talking, clapping or tapping their cane) in order to determine its size.[1] When a blind individual has more time to walk around and dedicates time to getting to know and moving about in a closed environment, he is willing to listen to descriptions and is able to identify details that allow for a more accurate level of navigation [Sánchez and Zuñiga 2006].

The majority of meaningful, learning-based, spatial experiences are related to the use of the body as the central axis of learning, and in this way the development of psychomotor functions in each individual acquires a fundamental role [Berruezo 2000]. The term "psychomotor functions" refers to the cognitive, emotional, symbolic and sensory-motor interactions inherent in the ability to be and express oneself in a psychosocial context. Through the practice of psychomotor functions, a child experiences space, objects, and people.

[1]Focus Group 2005 Universidad de Chile.

The possibility of discovering and being discovered provides a child with a better opportunity to acquire and integrate knowledge of his own body, space and time into her mental schemes [Berruezo 2000]. Thus, psychomotor functions allow for the integral development of a child through the interaction of the body with the external environment; in this way, movement and the person are related and activated in order to lead the child towards a total form of development and balance in all the dimensions involved: motor, affective, cognitive and social.

Since the womb, the first form of contact with the world around us is through movement. Learning occurs when a child explores and makes physical contact with the world around him. This principle was widely studied by Piaget [1954, 1956], who in his studies describes that in the first stages of life, movement is one of the initial forms of contact with the environment and the surrounding reality.

Unlike a sighted child, for whom movement emerges from visual curiosity, a blind child lacks visual experience, such as seeing oneself in the mirror, or other people, and relating to or feeling a visual attraction to an object. As this visual possibility for a blind child to be "attracted" to things is absent, her mobility is diminished, as at first sound is not able to transmit the idea that there are things that can be touched. With time, however, the development of a fine-tuned sense of hearing can change this [Nielsen 1989].

In this way, despite the fact that the lack of a visual channel obviously has repercussions on the ability to obtain information from one's surroundings, and on the development of spatial perceptions, it has been shown that a blind or low-vision child is able to develop the aspects related to spatial orientation just as well as a sighted child [Sánchez 2008]. The difference lies in the use of the other sensory channels and in the need to know the surrounding environment in a structured way, thus being able to generate mental schemes that make it possible to move about in the environment through the implementation of various strategies that they generate themselves as their spatial abilities increase and their needs and interests continue to determine their need to situate themselves in space [Arnáiz 1994].

2. RELATED WORK

There are several different solutions to help blind users with their orientation and mobility. One way to help them become more autonomous could be to provide them with virtual training, so that they are then able to transfer this learning to the real world. There are several studies in which blind users use an unknown virtual environment simulator with which they can interact through both audio [Amandine et al. 2005; Kehoe et al. 2007; Sánchez and Lumbreras 1998; Tzovarus et al. 2002] and tactile cues [Crommentuijn and Winberg 2006; Crossan and Brewster 2006; Lahav and Mioduser 2008b; Murai et al. 2006; Pascale et al. 2008].

Having a mental map of space is fundamental for the efficient development of orientation and mobility techniques. As it is well known, most of the information required for such a mental representation is collected through visual channels [Lahav and Mioduser 2008b; Rodrigues 2006; Sánchez and Zuñiga 2006]. It is not feasible for blind users to access this information as fast as it can be done through the use of vision, and they are obligated to use other sensory channels for exploration (audio and haptic as well as other modes) in order to compensate [Carter and Corona 2008; Lahav and Mioduser 2008b]. Lahav and Mioduser [2008a, 2008b] have researched the existing relation between mental representations of space produced by the blind when using virtual environments with audio and haptic interfaces and their subsequent transfer of spatial information to the real world. To these ends, they used a virtual environment modeled on a real one, which the blind user explores in order to train and improve his real-life navigation skills. The results obtained by these authors were encouraging, for which reason this study can be used as a base for researchers regarding the use of virtual environments to develop varying skills.

One possibility for assisting the blind in their navigation is through the use of audio-based video games. A variety of studies highlight the importance of the use of video games for learning [Squire 2003; Steinkuehler 2008]. In particular, emphasis is placed on the fact that video games have a constructive impact on the development of problem-solving skills, showing that, after gaming, learners improve their strategies for understanding, designing, carrying out and evaluating a problem [Klopfer and Yoon 2005; Westin 2004]. Video games can also allow for the development of specific skills [Sánchez 2008], promote high-order learning [Steinkuehler 2008], increase students' interactions [McDonald and Hannafin 2003], as well as improve social [Pellegrini et al. 2004] and cultural [Cipolla-Ficarra 2007] skills. In addition, such games produce a high level of motivation and commitment for learning which are fundamental aspects that help to improve the learning activity [Klopfer and Yoon 2005; Sánchez 2008].

In the work done by Kelly et al. [2007] a shooter-style educational game for science learning is presented. The authors point to three key aspects in the design process for this type of game. These are: (a) the design of the game, in which the strategy and the contents of the game must be clear; (b) the integration of the video game, which corresponds to the way of presenting the contents and the interaction between the many elements of the game; and (c) the provision of multiple levels to construct the simulations and visualizations of the processes present in the game. The authors emphasize that the success of the work requires careful coordination between video game designers and those who review the content, and this is not easy to achieve. On the other hand, such coordination is essential for the success of an educational video game.

The possibility of using educational video games opens enormous possibilities for working with learners who are blind. It provides the opportunity to develop more complex skills such as navigation and to do so in a motivating and challenging way. As digital natives[2] [Prensky 2001] they find this method closer to their usual ways of associating with technology [Go and Lee 2007]. For this reason, several authors believe that video games represent a tool that

[2]A digital native is a person that has grown up with digital technology such as computers, video games, Internet, mobile phones and MP4s.

allows for a closer approximation to 21st century learners' ways of learning and interacting [McMichael 2007; Proserpio and Viola 2007].

Sánchez and Flores [2008] introduce AudioNature, an audio-based virtual simulator for science learning implemented through a mobile device platform. In order to adjust the software to the mental model of users with visual disabilities, a user-centered design methodology is employed. The game presents an ecosystem that has been altered and challenges learners to return it to normality through interactive tasks and problem solving. The evaluation of the software provided evidence that points towards gains in problem solving skills and showed that mobile learning activities facilitate the user's interaction with the software.

Trewin et al. [2008] present PowerUp, a virtual, multiplayer, educational video game that provides users with a great degree of access. In their paper, the authors discuss the characteristics necessary for virtual worlds to be usable by and accessible to users with some kind of disability. In particular, the game is accessible to people who are blind due to the configuration of the size of the letters, text-to-speech feedback, and navigation through the use of the keyboard. The usability evaluation performed shows the interest that blind users have in immersing themselves in the world of the video games and the virtual environments, being able to interact without any major difficulties.

Soute and Markopoulos [2007] ventured to develop "Camelot," a video game that uses pervasive computing (embedded technology and connectivity as computing devices) in which children construct a castle collaboratively. This kind of game allows children to interact freely without necessarily realizing that they are using technology, which produces a high degree of social interaction spontaneously and transparently.

AudioGene [Sánchez and Aguayo 2008] is a game that uses mobile technology so that blind and sighted children can interact, become socially integrated and learn science. AudioGene was designed by taking the mental models of both blind and sighted users into consideration. The goals of AudioGene were to integrate blind and sighted classmates, teach them science content focusing on genetics, create participative methods for collaboration between blind and sighted users, and use mobile devices to achieve these goals. The results showed that there was a real possibility for integrating sighted and blind users and that the technology, methodology and tools used in this study can help achieve such a goal.

AudioLink [Sánchez and Elías 2007] is an audio-based video game that reinforces science concepts in a playful environment for legally blind children. In the game, the players interact with characters and objects in order to complete the game's central mission. As the child interacts with the game in order to complete the mission, he develops problem-solving skills, learns science content and develops orientation and mobility (O&M) skills. AudioChile and AudioVida [Sánchez 2008] are sound-based games for blind children that are oriented toward developing problem solving and O&M abilities. In AudioVida, the halls have a specific mono sound associated with the two intersecting. Thus, the user is able to know her location when she recognizes an intersection of the hallways by hearing both specific sounds for each hallway at the same time.

In AudioChile, on the other hand, the user's location is provided by varying the intensity of the sound through spatialized sound effects. The evaluation of the three video games provided evidence that they generate gains in problem solving skills in children who are blind.

Tim's Journey [Friberg and Gärdenfors 2004] is a video game that allows a blind user to navigate through virtual spaces that are defined through the use of specific sounds, thus allowing users to be able to generate a mental representation of the space traveled. The results show that users who are blind are able to navigate through virtual environments when guided by sound. Finger Dance [Miller et al. 2007] is an audio-based video game that allows a blind user to develop temporal skills through sound sequences that he must synchronize with other audible bases in order to achieve the highest possible score. The results of this work also demonstrate audio perception training for blind users. It is not enough to merely generate these audio-based video games; rather one must adopt a new (or ad-hoc) pedagogical methodology based on the lessons or skills to be taught or practiced [Kickmeier-Rust et al. 2007; Squire 2003].

A user who is blind can enjoy a conventional degree of navigation in a familiar environment because he knows the surroundings or because he has adequate aids for navigation. In a closed and unfamiliar environment, the experience of navigation can be complex and completely nondeterministic [Kulyukin et al. 2004]. Examples of this are navigating in an airport, hotel, government building, or a new school, all of which may represent unfamiliar environments. Having access to some assistance or some training is ideal to be able to achieve an adequate degree of autonomous and independent movement. Although there are some forms of assistance, both technological (such as using GPS or Wi-Fi technology) and nontechnological (such as using guide dogs or a white cane), for improved orientation and mobility, their benefits are limited in the context of complex environments. For example, no information is provided on topological factors or place distribution. Information is only obtained for the specific location (without references) which does not allow the user to form a mental map of the entire place. As a result, they cannot guide the user to choose the best possible route to a certain destination [Rodrigues 2006].

Perhaps a less studied niche is the use of interactive, digital technologies for the development of skills that are not all stimulated in the context of a classroom or in the school itself; these are orientation and mobility skills having to do with sensory-motor coordination and tempo-spatial orientation. An adequate degree of control over these abilities is key for school-aged children in that, without such skills, their communication, interaction, and movement skills, as well as their autonomy and independence, can be altered. All of these factors are key for appropriate school integration and social inclusion.

Of all the existing work, we highlight the use of video games for the development of skills. Together with this, it is important to consider the use of different sensory channels, such as audio and touch, by blind users. The focus of this investigation was to utilize a video game that would provide for a digital interaction by means of audio and touch in such a way that blind children could develop orientation and mobility skills.

In this article, we present the results of a usability evaluation study that were previously presented at ASSETS 2009 [Sánchez et al. 2009]. This updated and extended version expands on that initial study and adds new data, results and analyses of an orientation and mobility evaluation study implemented with regard to the use of a haptic-based device (Digital Clock Carpet) and a 3D sound video game (MOVA3D) for the development and use of orientation and mobility skills in unfamiliar, closed spaces by school-aged, blind children.

3. HARDWARE AND SOFTWARE

Our research was carried out in three main stages. The first stage consisted of the design and development of the Digital Clock Carpet (DCC) and an audio-based, 3D video game (MOVA3D). The second stage consisted of the usability evaluation of both products with the participation of blind end users. All users were legally blind, although some had low vision while others were totally Blind. Finally, the third stage consisted of a cognitive evaluation of the use of the video game (MOVA3D) and the Digital Clock Carpet with blind children.

3.1 Digital Clock Carpet

An hour system for directions was used to tell the user how to get to the destination point. The hour system is a metaphor used for indicating a certain direction and basically consists of situating the user at the center of an analog watch. In this system the user is always facing 12 o'clock, so if we want him to move right we say, "go to 3 o'clock"; to go to the left we say, "go to 9 o'clock"; and to go backwards we say, "go to 6 o'clock." This application has the advantage of having intermediate points that are easy to interpolate; for instance, if we say the direction is 1 o'clock, the user understands that it corresponds slightly to the right of his or her current direction. To move forward the user advances one step in the direction of 12 o'clock. The user controls the speed of his movement through the force of his body.

For the children to be able to understand and learn the hour system and in order to provide them with instructions for navigation, a low-cost, haptic device was designed and built that we called the Digital Clock Carpet (DCC). According to school curriculum, the children learn the hour system between 10 and 12 years of age. In order to learn and be able to use the DCC, children do not need to understand or have learned the hour system previously. This device allows the users to interact directly with their body, performing the movements naturally. The idea is that users have an alternative and complete input tool device that goes beyond the mere use of their hands through a keyboard or some other input device. In fact, the interaction is carried out in the same way as if he were moving in the real world. Basically, the user performs the turns that the video game indicates naturally, being able to adjust to the hour system proposed (1 hour = 1 turn) in the clock location system.

The DCC consists of a wooden base with 12 tactile cells with sensors that identify the hours of the clock. Each cell corresponds to a large key that the user can press. These keys close the electric circuit that is sent to the computer as a logic signal which is interpreted as a conventional keyboard letter. In

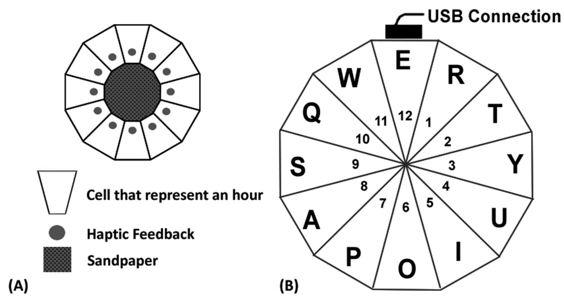

Fig. 1. Design of the digital clock carpet.

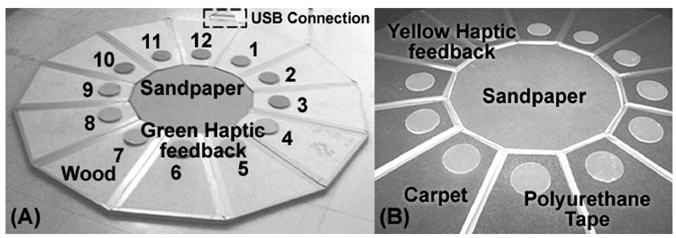

Fig. 2. Concrete digital clock carpet.

Figure 1 we can see how the carpet communicates with the computer, just like any other input device such as a keyboard, for which reason it is very simple and provides the freedom to program the interaction. Each hour is associated with a letter on the QWERTY keyboard. With this, feedback can be generated for the user after having captured the events that occur. All communication is carried out by means of the USB port of any personal laptop or computer allowing the program to function without any problems; the DCC is thus a plug-and-play device.

The user interacts with the device by using her body, pressing the different keys with her feet. In the first version of the DCC, a cylinder that juts out just 1 centimeter above the cell was placed in each cell so that it would be easy for the users to be able to locate the different keys. In the middle a sandpaper-like texture was placed, which is a material that the blind are accustomed to working with (Figure 2). For this texture to be useful for the users, they interacted with the carpet barefoot (Figure 3). The dimensions of the carpet included an 80cm radius, and it was 5cm high.

The software for testing the DCC informs the user which direction she should turn, at which point the child presses the direction (time) that she believes to be correct with her foot. For each action that the child performs with the device, there is an associated audio feedback. If the action is correct, a success sound is reproduced, and if the user is wrong, an error sound is reproduced. In addition, when wrong the user is told what time he is really pressing.

After the usability tests, described in detail in Section 4.2, Initial Usability Evaluation, iterative redesigns were made to the DCC, with which a second and final version was obtained. This final version incorporated a blue floor covering

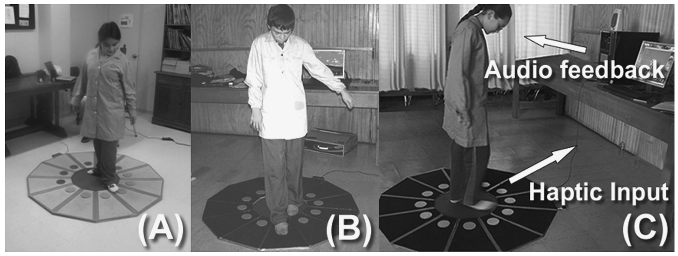

Fig. 3. Children interacting with the first (A) and second (B) version of the digital clock carpet (dcc). (C) The child plays with the video game MOVA3D through interaction with the DCC.

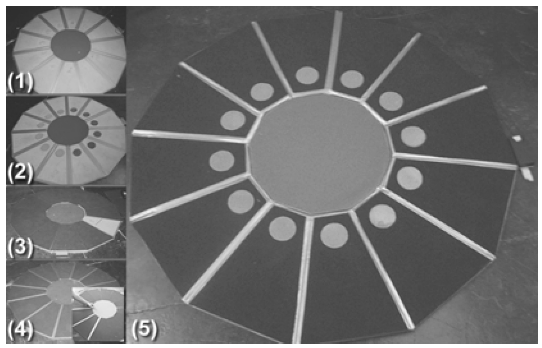

Fig. 4. Evolution of the design and development of DCC (1) The DCC has only the sandpaper in the middle, (2) First design of the DCC with green haptic feedback, (3) Carpet is added to each key, (4) The keys are secured with polyurethane tape, and (5) The second and final version of the DCC, with each key carpeted, sandpaper in the middle, all sealed with polyurethane tape and with the yellow-colored haptic feedback.

and the haptic feedback was painted yellow, achieving a high degree of contrast and improving the texture of the carpet for correct use by the users (Figure 4). The rest of the interaction remained the same. With this new version of the DCC, a new evaluation was made which is described later in Section 4.3, End-User Usability.

3.2 MOVA3D

The 3D video game MOVA3D uses 3D graphics and spatial sound which allows users to navigate freely through the virtual environment. Thanks to spatial sound, the users achieve a higher degree of immersion in the video game. This video game was developed following a user-centered methodology, incorporating children from primary school and aged 6 to 12, from the very beginning of the design process.

The metaphor that is used in the video game consisted of finding objects in a virtual environment. To find an object the user has to navigate through the entire space searching for it, and when he is close, a spatial alarm begins to sound allowing him to locate the object in space. Once the user picks up the object, she must bring it to a special area in the virtual environment. On the

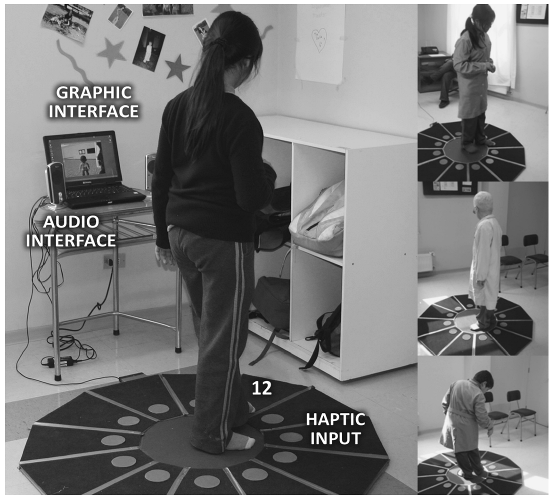

Fig. 5. Children interacting with the carpet and the video game. In playing with the carpet, the child is always facing 12 o'clock, which shifts according to his movements.

way to this special area, the user must make sure that the aliens that inhabit the surrounding area do not steal the object that she has found. The main idea is that the children navigate the space in the most complete and precise way possible. We could simply ask them to do this without any additional problems to solve, but in this way they perform an additional task beyond what they already have to do. Thus the excuse that we concocted to stimulate them to carry out the task is a metaphor. With it they are motivated to complete a fun task that challenges them and forces them to actively interact with the game that we designed. In this way, as they are carrying out the mission in the game, they are obliged to navigate, get to know and recognize the environment in which the game is immersed, which is also a representation of a real space.

Although the video game was conceived for use through the DCC, it is also possible to interact by using the keyboard, and thus its use is not only restricted to when the DCC is available. When the children play the video game through the use of the DCC, they make movements naturally and guide themselves through the environment by way of sound and the haptic device (see Figure 5).

When the user interacts with the video game through the keyboard, the arrow keys are used. Specifically, the up arrow key is for going straight, and the right or left arrow keys are for turning in the corresponding directions. If the user pushes the right arrow key, the turn will be clockwise, while if the left arrow key is used the turn will be counter clockwise.

3.2.1 *Audio Interface.* The spatial sound is relative to the user's orientation and thus accompanies the user throughout her navigation. For this reason, the audible cues that the user receives while navigating the virtual environment are always correct and are relative to how the user happens to be situated in the virtual space. These sounds were provided by a set of speakers placed in front of the DCC, simulating the spatial sound [Lumbreras and Sánchez 1999].

The system understands the user's orientation given that she always moves by using the clock system, so the turns that the user takes are all controlled (knowing that she starts off from a certain position). In the video game, it is impossible for the user to be oriented differently from what the system registers due to the way in which the player's interaction is designed.

The user can navigate several floors of a building by using stairs, in which he/she always obtains audio feedback from the place that is being navigated as well as from the actions that are performed. The audio feedback that is used corresponds to the following:

—reproduction of a specific sound when pressing the navigation buttons in the environment (forward, turn, go up/down stairs);
—reproduction of a specific sound for bumping into an object in the environment (walls, doors, objects);
—reproduction of a specific spatial sound when the user is close to a stairway or door;
—reproduction of a specific spatial sound when the user is in the presence of a watch (an object that must be found within the map);
—reproduction of a specific spatial sound when the user is in the presence of an enemy when the player has possession of a watch;
—reproduction of information through the use of prerecorded TTS in order to provide the user with information on his surroundings.

3.2.2 *Graphic Interface.* The spaces through which the user navigates can be fictitious representations of an environment or representations of a real environment. This is thanks to the fact that, in order to generate the virtual environments, all that is needed are the coordinates of the corners of the walls. In the video game, real spaces can be represented on their corresponding scale of representation, as can the objects that are found in the virtual environment.

The video game has textured graphics and characters that make it possible for students with low vision to take advantage of such visual resources. In addition, this feature makes the video game attractive for eventual use by sighted users together with their blind classmates. The main character is a child who represents the player (Figure 6(a)), and in addition there is a thief (Figure 6(b)), who tries to take the watch (Figure 6(c)) from the child.

Three environments for navigation were created, each of which represents an unfamiliar area of buildings in three different Chilean cities where the research was carried out. In the city of Santiago, the National Electronics and Telecommunications Center (CENET, for its Spanish acronym) was represented (Figure 7(a)); in the city of Viña del Mar, the Republic of Ecuador building was represented (Figure 7(b)), and for the city of Concepción, the Help for the People Who are Blind Corporation (COALIVI, for its Spanish acronym) building was represented (Figure 7(c)).

3.2.3 *Development.* The video game was developed using visual studio.net and c# programming language, to be used with a Windows XP operating system

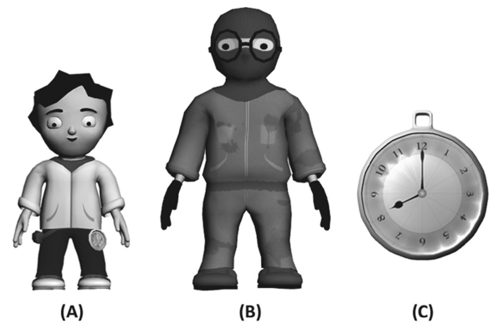

Fig. 6. (a) Representation of the child who has a compass hanging from his belt; (b) Representation of the thief; (c) The object that must be taken from the environment is a watch.

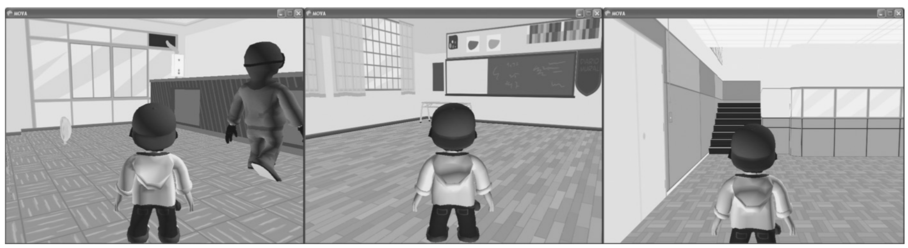

Fig. 7. (a) A room in the CENET building in the city of Santiago. In this room there is a watch and a thief who is looking for it. (b) A room in the Republic of Ecuador building in the city of Viña del Mar. (c) Access hall to the second floor of the COALIVI building in the city of Concepción.

or newer. This application uses the advantages of programming virtual environments provided by the Microsoft SDK development tools for XNA. For this reason, for its execution it is necessary to have Visual Studio Frameworks.NET 3.0 and XNA 2.0.

4. USABILITY EVALUATION

Three usability evaluations were implemented. The first consisted of a Heuristic Evaluation of the Video game (HEV). The second consisted of an Initial Usability Evaluation (IUE) of the DCC and the MOVA3D video game. Finally, once iterative redesigns were made to the haptic interface and the video game according to the results of the IUE, a third evaluation was implemented consisting of an End-User Usability Evaluation (EUE).

4.1 Heuristic Evaluation

4.1.1 *Sample.* The group of evaluators was made up of 5 experts in usability and interaction, aged between 25 and 35 years old. Four of them were computer science engineers and one of them was a computer scientist. All of them had experience and training in human-computer interaction and usability evaluation. Three of the experts habitually work with software for blind people several days out of every week.

4.1.2 *Instruments.* The heuristic evaluation was based on systematic inspections of the interface. We administered a heuristic evaluation questionnaire (HEQ) based on Shneiderman's golden rules [Shneiderman and Plaisant 2004] and Nielsen's usability heuristics [Murai et al. 2006]. This instrument has been used in other research projects related to interactive systems for users who are blind [Sánchez 2008]. The resulting instrument includes 10 dimensions, covering a total of 25 items in the form of statements about which the experts are asked to indicate their appreciation on a scale of response with the following values: strongly agree (5), agree (4), neutral (3), disagree (2) and strongly disagree (1). The dimensions evaluated were: (I) Visibility of system status, (II) Match between the system and the real world, (III) User control and freedom, (IV) Consistency and standards, (V) Error prevention, (VI) Recognition rather than recall, (VII) Flexibility and efficiency of use, (VIII) Aesthetic and minimalist design, (IX) Content design and (X) Velocity and media.

For example, the visibility of the system status was evaluated with statements such as, "The software clearly shows where the blind user is" and, "All possible controls are clearly marked for the blind user." In the case of Error prevention, one statement was, "There are messages that prevent possible errors." Finally, for Content design one statement was, "The content is adequate to the user's physical, social and cultural reality."

4.1.3 *Procedure.* The heuristic evaluation consisted of the free use of an advanced and operational prototype of the video game. It began with an introduction to the video game, explaining the objective and the degree of its development at the time of the evaluation. Then each evaluator proceeded to interact with the video game, selecting the different options on the menus and navigating independently through the virtual environment, using the functions that were available during the evaluation and solving a previously determined task consistent with finding an object within the virtual environment. To do this, all they had to do was follow the instructions provided by the software, and they could take as much time as they needed. After the interaction, each evaluator proceeded to respond to the evaluation instruments. Finally, a brief session of analysis and discussion with each evaluator was held in order to collect opinions and comments from the experts on the software, as well as new ideas and focuses to consider.

4.1.4 *Results.* With a maximum of five points for each of the heuristics studied, the results of the HEV came out to an average value of 3.80 points. This is a significant result considering that the evaluation was made by usability experts with a great deal of experience in the development of software for blind users, and that they were quite critical and rigorous when evaluating the heuristics (Figure 8). The strengths detected in this evaluation are related to content design (4.50 points), velocity and media (4.50 points) and recognition rather than recall (4.50 points). The heuristics with the lowest scores were visibility of system status (3.00 points) and error prevention (3.00 points). The main problem was with the use of unrestricted spatial sound, which caused confusion as at times it generated erroneous feedback. After the HEV, the sound

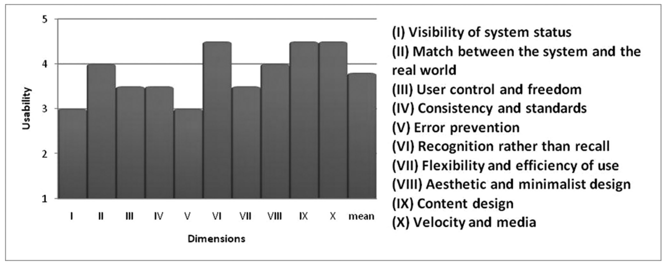

Fig. 8. Results of the heuristic evaluation of the video game (HRV).

was restricted to the rooms in which an object could be found, in addition to providing the user with feedback on specific locations in the virtual space.

4.2 Initial Usability Evaluation

4.2.1 *Sample.* The Initial Usability Evaluation (IUE) was performed with 20 students from the Hellen Keller and Santa Lucia schools for the blind in the city of Santiago, Chile. Of the 20 users, there were 11 boys and 9 girls; 15 had low vision and 5 were totally blind; all had different ophthalmologic diagnoses. The age of the users was between 6 and 12 years old. A usability expert and a teacher specializing in blind children worked alongside the students.

4.2.2 *Instruments.* The instrument used for this evaluation consisted of a scale of appreciation for the user, a scale of appreciation for the evaluators, and a set of open-ended questions, all regarding the DCC and the MOVA3D video game. These instruments have already been used in other, similar projects [Sánchez and Flores 2008]. The aspects evaluated by the users, through the use of the scales, were: the voice and sounds are agreeable, clear and easy to understand and distinguish; the separation and/or central space is big enough and well delineated; the circular marks are big enough, well marked and delineated; and how much they like this activity. For a higher degree of understanding and to facilitate the evaluation by the children, the scale of appreciation had a numeric scale from 1 (little) to 10 (a lot).

4.2.3 *Procedure.* A 20-minute work session per child was established, time in which they performed movement activities designed for using the carpet (10 minutes), responded to the scale of appreciation (5 minutes) and answered the open questions posited by the evaluators (5 minutes).

Initially each child was informed of the activity to be performed. Given that they had to get to know the DCC, the children were provided with 10 minutes to explore it however they wanted. During this time, they were asked about the perceptions or sensations they were feeling, and text area for their comments and criticisms was provided.

Once the participant felt confident enough with the DCC, she was asked to take a position in the central part (where the sandpaper is) as a way of providing the necessary position to initiate the activity. At that same time, without

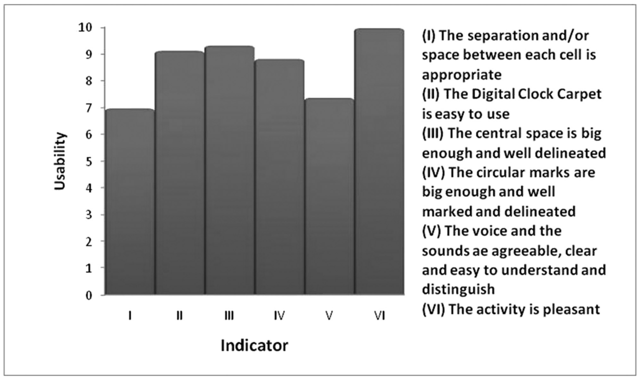

Fig. 9. Results of the initial usability evaluation (IUE).

giving them any instructions on the clock system, the participants were asked to situate themselves facing 12 o'clock. Here it is worth reiterating the fact that the clock system always changes together with the user's position, so that he is always facing 12 o'clock no matter which way he is actually facing on the clock.

4.2.4 *Results.*

4.2.4.1 *DCC.* In general terms, the carpet was perceived as easy to use (9.10 points of a total of 10) (Figure 9). This is supported to a certain degree by the fact that it is an external device that captures the attention of the participants, as it differs from the use of other devices that are habitually used to play games such as the mouse and keyboard on the computer.

As for the size and delineation of the central area of the carpet, this area was perceived quite favorably (9.30 points of a total of 10). This was identified immediately thanks to the differentiation in texture; it was even possible to perceive it through indirect touch with the users' shoes. The circular marks that operate as graphic/tactile signals in each of the keys on the carpet were also positively evaluated by the participants as good references for where each key is located (9.75 points of a total of 10). The existing distance or separation between each of the keys caused a less positive perception among the participants, as it made their ability to perform well on the activity more difficult (6.95 points of a total of 10) (Figure 9). The reason for this is that if the keys are too close together, there could be confusion when locating the desired key. The delineation of the spaces through the use of graphic/tactile signals was one of the characteristics of the carpet that the participants liked most (9.30 points of a total of 10) (Figure 9). This is explained by the fact that, thanks to partial vision or indirect touch (through the shoes) the users were able to not only know on what part of the carpet they were positioned but to establish a point of reference when changing directions as well. The graphic/tactile signs served as a reference for the participants to be able to know where each key that they had to push in order to execute an action was located, which in some cases facilitated the task (8.80 points of a total of 10) (Figure 9).

In comparing the results according to the degree of the user's vision (low vision or blind), it was observed that those with low vision presented slightly higher averages in the aspects evaluated, which is in line with both the physical and audio feedback that the haptic device (DCC) provides. However, after applying the Student's t-test, these differences were not found to be statically significant (Audio Feedback: $T(18)=0.296$; $p>0.05$; Haptic Feedback: $T(18)=0.440$; $p>0.05$).

4.2.4.2 *MOVA 3D.* Regarding the sounds and voices used in the video game, the level of appreciation by the children obtained scores higher than 5 for all indicators, with an average of 7.35 points out of a total of 10 (Figure 9). It is worth highlighting that in this item, no participant pointed out any problems or changes that should take place as far as the generation of the voice and the sounds of the video game.

From the very beginning the video game captured the participants' interest; each part of the game, in most cases, elicited immediate acceptance and desire to be part of the experience (9.95 points of a total of 10) (Figure 9). Of the total number of participants, not one expressed that the video game was boring or tedious; to the contrary, all the participants found it to be very fun and relaxing (9.90 points of a total of 10).

4.3 End-User Usability Evaluation

4.3.1 *Sample.* The End-User Usability Evaluation (EUE) was performed with 19 students (10 boys and 9 girls) from the Hellen Keller and Santa Lucia schools for the blind in Santiago, Chile. The ages of the students were between 6 and 12 years old. The users possessed varying ophthalmologic diagnoses, in that 15 had low vision and 4 were totally blind. The evaluation was focused solely and exclusively on the modes of interaction and the design of the interfaces. These students were different from those who participated in the Initial Usability Evaluation.

4.3.2 *Instruments.* For the EUE, the validated Software Usability Questionnaire for Blind Children was administered. This instrument has been used in several projects related to sound-based software and blind users [Sánchez 2008]. The questionnaire consists of 18 sentences for which the users had to define to what degree each of them was fulfilled, on a scale from a little to a lot, with quantitative values from 1 (a little) to 10 (a lot). The sentences were: "I like the software," "The software is useful," "The software is challenging," "The software makes me active," "I would use the software again," "I would recommend this software to other children/young people," "I learned through this software," "The software has different levels of difficulty," "I felt I could control the software's situations," "The software is interactive," "The software is easy to use," "The software is motivating," "The software adapts to my rhythm," "The software allowed me to understand new things," "I like the sounds in the software," "The sounds in the software are clearly identifiable," and "The sounds in the software provide me with information." Note that all sentences are positive,

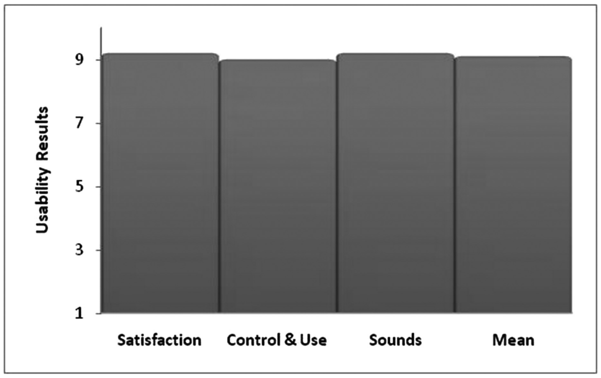

Fig. 10. Results obtained in the End-User Usability Evaluation (EUE).

as it is easier for a child to make an evaluation based on a positive statement than on a negative one. For example, in the case of a negative statement, a score of 10 (a lot) would imply a poor score, which is the opposite of an evaluation with a positive sentence. Such a situation could lead to confusion for the participating children, and it is for this reason that we rely on positive statements alone.

4.3.3 *Procedure.* The EUE was performed with the final version of the DCC, which was redesigned and improved based on the results obtained from the Initial Usability Evaluation. (In subsection 3.1, Digital Carpet Clock, we showed the evolution of the device design).

The application of the MOVA3D video game associated with the DCC device was also improved, obtaining better audio feedback. In particular, we improved the voice of the assistant and the sound feedback was made more real. The evaluation was performed during two sessions with two groups of users: one from the Hellen Keller School and the other from the Santa Lucia School for the blind in Santiago, Chile. Each student interacted with the device for ten minutes in order to complete the orientation-based tasks that the virtual environment proposed.

4.3.4 *Results.* The EUE of the software shows a high degree of evaluation in the 3 dimensions considered, obtaining scores higher than 9.00 points for all areas (on a scale of 1.00 to 10.00 points, in which 10.00 is the maximum score). The most highly evaluated scales were Satisfaction and Sounds, with 9.20 points each. The Control & Use dimension obtained a score of 9.00 points, while the average evaluation for the three dimensions was 9.10 points (Figure 10).

In analyzing the opinions provided by the users on usability and differentiating by the kind of user involved (low vision or totally blind), no significant differences were found. In the Control & Use dimension, the users with low vision (9.20 points) presented higher scores than the totally blind users (8.50 points). In the Sounds dimension, the users with low vision (9.50 points) presented

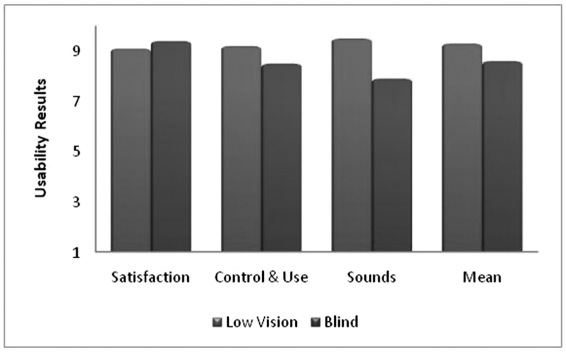

Fig. 11. Results according to type of vision in the dimensions evaluated in the End-User Usability Evaluation (EUE). None of the differences were statistically significant.

higher scores than the totally blind users (7.90 points). The differences presented between both kinds of users were determined to be not statistically significant after having applied the Student's t-test (Control & Use, $T(17)=0.724$, $p>0.05$; Sounds, $T(17)=2.439$, $p>0.05$) (Figure 11).

In the Satisfaction dimension, the totally blind users presented 9.40 points, compared to the 9.10 points presented by those with low vision (Satisfaction, $T(17)=-0.320$, $p>0.05$) (Figure 11).

In the case of the general average, it was observed that low vision users presented a higher average than the totally blind users, with scores of 9.30 and 8.60, respectively (Mean, $T(17)=0.977$, $p>0.05$) (Figure 11).

5. ORIENTATION & MOBILITY EVALUATION

5.1 Sample

For the orientation & mobility impact evaluation, researchers worked with 24 blind children between the ages of 7 and 14 years old. Of these, only 7 were totally blind and the other 17 had partial vision. All the children had a variety of ophthalmologic diagnoses and had no other kind of disability. Of the participating children, 11 were male and 13 were female. They attend different schools for the blind from three Chilean cities in particular: Santiago, Viña del Mar and Concepción. In the city of Santiago, we worked with the Santa Lucia Educational Center and the Hellen Keller School; in Viña del Mar, the work was carried out with the Antonio Vicente Mosquete Institute; and in the city of Concepción, we worked with the Help for the People Who are Blind Corporation (COALIVI).

5.2 Instruments

In this study, we measured the learning of O&M skills. An initial measurement was taken in order to get to know the level of O&M skills that the students had at the beginning of the intervention (without having used the technology). Afterwards, a final measurement of O&M skills was taken at the end of the intervention, measuring the skills that they had gained once they had used and interacted with the technology (the video game and haptic device).

To these ends, an O&M test was used [González et al. 2003] that contains common and specific indicators that measure different aspects of the degree of progress that the children have made after having worked on the different activities. In total, three dimensions are evaluated: Orientation and Mobility Techniques (36 indicators), Sensory-Motor Coordination (29 indicators) and Sensory-Spatial Orientation (38 indicators). Some of the indicators used to identify the achievement of Orientation and Mobility are “Safety and confidence in walking,” “Going up and down stairs,” and “Opening and closing doors.” For Sensory-Motor Coordination, some examples of the indicators are “Goes up stairs changing feet without help or support,” “Runs in a straight line,” and “Marches” (goes to the closest wall, touches it, and comes back). Finally, for Sensory-Spatial Orientation some indicators correspond to “In front,” “Behind,” “Diagonal or sideways,” “Recognizes and locates 12 o’clock regarding her position,” and “Recognizes and locates 9 o’clock regarding his position.” To measure the results, a scale was used with the following values: Achieved (expresses the expected behavior in its entirety), In process (expresses some aspects of the expected behavior), and Not achieved (no evidence at all of the expected behavior). For the purposes of this study, we have included only the parts of the test that we consider to be pertinent to our research.

This test was organized by age, so that the proposed indicators to be evaluated for each of the instrument’s dimensions would be in line with the respective stages of development for the participating children. As such, some indicators vary or are added based on whether they are applied to children between 7 and 9 years old, or to children between 10 and 14 years old. For the navigated areas, the educators used observation guidelines in order to collect the necessary information on the students’ progress and achievements.

5.3 Procedure

All of the activities with the children were carried out during a period of three months, in eight sessions that lasted 3 hours and 15 minutes each. For the preparatory stage, the students worked during one session. The interaction with the video game was carried out during five sessions, including one session of real-life navigation in their school, and one session of navigation through the real space. In one of the sessions the children worked with the concrete material that represents the real environment on a scale of 1:20. In the rest of the sessions they played with MOVA3D, using the keyboard and the DCC device. Two major stages were carried out, Preparation and Navigation Tasks, in which the children participated by interacting with the MOVA3D video game.

All of the working sessions scheduled in the respective cities were developed individually with each of the participants in order to best evaluate each child. The use of an appropriate physical space that would provide for the comfort and relaxation of the participants and evaluators was taken into account. This protected the emotional state of the participants and thus avoided the

Fig. 12. Girl participating in the preparatory task.

interference of external variables that could affect the results obtained in the evaluation.

The tests were administered by an educator who specializes in visual disorders. In order to avoid bias, the pre and posttests were administered by different educators. All of the sentences in the test used an objective item format, for which reason it was simple to evaluate the fulfillment of each item, as the evaluation consisted of determining whether the user had fulfilled the specific task or not.

The educators observed the students as they interacted with the technology. In the same way, the educators were also present when the students performed the task in the real environment to then be able to interpret and analyze the data.

5.3.1 *Preparation.* The Preparatory stage was centered on the development of the hour system through a chronological series of unique movement sequences with the provision of specific instructions, in which the starting point was established by positioning the user in the center of the DCC facing 12 o'clock. For a higher level of understanding of this idea, the position of the user's nose was associated with 12 o'clock, which allowed the users to understand that 12 o'clock on the clock system changes according to the body's position in space, which makes it so that the rest of the times are not static, such as in the use of a conventional watch. Based on this information (the location of 12 o'clock), it was possible to guide the users in their search for the other requested times, relating them to a certain position within the virtual scene (Figure 12).

5.3.2 *Navigation Tasks.* These were working sessions in which the children interacted with the video game by performing movement tasks regarding

Fig. 13. Children using the video game and navigating the space in the concrete model, (A) Boy with the model of the Hellen Keller School, and (B) Boy from the Santa Lucia School for the Blind.

knowledge and recognition of the virtual environment, establishing distances, location and the delimitation of rooms and halls through the use of sound cues and graphic information (in the case of users with low vision). At the same time users performed actions connected to the dynamic nature of these tasks, which were very useful for strengthening the blind and low-vision users' familiarization with the video game and the associated external devices. As a result, the users were able to execute the actions in the video game, using both the keyboard and the DCC. The following four tasks were performed.

(1) *Seeking watches in the virtual surroundings and in the school.* The idea behind this navigational task was for the children to strengthen their knowledge of the environment, the virtual surroundings and the elements available within them, in addition to the watches that they had to locate. With this, it was sought that the participants generate a mental image of the space from their navigation through the video game.
(2) *Work with the video game and with the support of a model made of concrete material.* With this task it was sought to develop learning of the different areas and elements that make up an unknown environment, in order to generate a mental image that allows the user to navigate and orient himself, and in this way to locate the objects situated in the different rooms of the virtual environment (Figure 13).
(3) *Route within the school.* The idea of this task was to get to know the children's abilities for orientation and mobility within a familiar environment, through the mental images that they already have of that environment. This task is carried out in their real-life school.
(4) *Navigation in the real-world space previously navigated in the virtual world.* Finally, when it was believed that the children had formed a

Fig. 14. Children navigating through the real space, represented virtually in the MOVA3D video game.

mental image of the environment, they were taken to navigate the space that they had been navigating virtually through the video game in real life. It is through this task that the level of transfer that is achieved by the students is determined, as only this will allow them to be able to successfully find the watch and complete the same objective as in the video game, but in the real world (Figure 14).

5.4 Results

5.4.1 *Navigation Tasks.* The 91.60% (22) of the participants successfully completed Task 1, being able to locate the watches. No task outcomes were measured for Task 2. In Task 3, 87.50% (21) of the participants successfully navigated the route within the school, though 3 of the 21 required assistance in doing so. In Task 4, 83.30% (20) of the participants successfully followed the real world route that they had practiced in the virtual world.

As the participants navigated the virtual space, they were able to consolidate the knowledge that they had of this space. In the beginning, most of the participants could not remember the exact number of rooms in the video game or the spatial location of these rooms. Little by little, as they gained more experience with navigation, they began to pay more attention to the details of the environment. For example, they were able to recognize if they were on the first or the second floor and in which specific room they were located. This was shown in their navigation through the routes that the students took in the real-life scenario.

In the task of navigation in the real world, all of the students navigated to find the treasures located in the real-life building based on what they had done in the virtual scenario which modeled the same rooms. The planning of the route depended directly on the strategy that each of the participants devised when positioning themselves in the space and beginning their navigation. In this way, it was possible for the students to position themselves based on the references they had learned in the video game and by using the mental image of the environment that they had constructed during the working sessions.

When faced with the real environment, it was observed that the students displayed a certain degree of uncertainty regarding this new scenario. Although it is safe to assume that they were familiar with the environment virtually, they had never actually been in this building before.

5.4.2 *Pretest/Posttest Comparison.* The results obtained are presented for each group of students separately, given that the tests administered are not exactly the same for each group, in that they vary according to the age range.

In comparing the means obtained by the 7 to 9 year old users within the Orientation and Mobility Techniques dimension, it is observed that the mean score of the pretest (92.00) is lower than that of the posttest (94.11), but with no statistically significant difference (Student's t-test(8)= -0.828, p=0.432).

The means obtained by the 7 to 9 year old users in the Sensory-Motor Coordination dimension show that the mean score of the pretest (92.93) is lower than that of the posttest (97.93), but with no statistically significant difference (Student's t-test(8)= -1.145, p=0.285).

In comparing the means obtained for the 7 to 9 year old users in the Tempo-Spatial Orientation dimension, it is observed that the mean score for the pretest (68.04) is lower than that of the posttest (83.15). In this case, we found that this difference is statistically significant (Student's t-test(8)= -4.973, p=0.01), which means that there is a higher level of achievement after having used the software.

In comparing the means obtained by the 10 to 14 year old users in the Orientation and Mobility Techniques dimension, it is observed that the pretest mean score (78.09) is lower than that of the posttest (80.00), but this difference is not statistically significant (Student's t-test(10)= -0,489, p=0.636).

If we compare the means obtained by the 10 to 14 year olds in the Sensory-Motor Coordination dimension, it is observed that the pretest mean score (95.55) is lower than that of the posttest (96.5), but with no statistically significant difference (Student's t-test(10)= -0.726, p=0.636).

In comparing the averages obtained for the 10 to 14 year old users in the Tempo-Spatial Orientation Dimension, it is observed that the pretest mean score (64.88) is lower than that of the posttest (78.91). This difference is statistically significant (Student's t-test(10)=-3,648, p=0.004), which means that there is a higher level of achievement after having used the software.

6. DISCUSSION

In this article, a usability evaluation is presented for a haptic device especially designed for this study (Digital Clock Carpet, DCC) and a 3D video game (MOVA3D), both for the development and use of orientation and mobility skills in closed, unfamiliar spaces by blind, school-aged children. These evaluations were used to redesign and improve usability, as well as to inquire unto the degree of acceptance and satisfaction with the end user's interaction with these products regarding O&M. In addition, we evaluated the impact that the use of the DCC haptic device in combination with the MOVA3D video game and cognitive tasks that represent a real navigational space has on the development and use of orientation and mobility skills in situations pertaining to closed, unfamiliar spaces by blind, school-aged children.

The heuristic evaluation helped mainly to redesign and improve the representation of the virtual world by means of spatial sound in the software. This has a relevant impact on the design and development of the MOVA3D video game if we consider that audio is an input mechanism that provides essential information for people who are blind. This aspect facilitates and improves the blind user's interaction, making it so that he can complete the tasks efficiently.

The initial usability evaluations allowed us to determine the degree of the users' acceptance of the haptic interface (DCC) that had been designed, as well as the quality of the video game's sounds. The results obtained indicate that this kind of multimodal interface is a good combination for the development of orientation and mobility skills in users who are blind.

From the original design of the carpet, it was necessary to include haptic and visual cues for the children to be able to interact with the DCC device and to be able to easily identify the association between the time and the keystroke with which they were interacting. For this, material with a highly distinguishable texture was included in order to generate a high level of haptic sensation. In addition, the different parts of the device had a high degree of visual contrast so that those users with low vision could take advantage of their partial vision as a kind of support during the interaction.

The results obtained from the end-user usability evaluation, after having used the final versions of the Digital Clock Carpet and MOVA3D video game, allowed us to infer in more detail unto the degree of the users' acceptance of the interfaces and the users' satisfaction with using this kind of multimodal interface. This shows how powerful it is to design accessible interfaces that allow users to enjoy and take advantage of technology in different contexts. There were no significant differences between the results obtained for users with low vision and those who are totally blind. Both groups found that that this kind of interaction was pleasant for them and could be of use for studying the development of orientation and mobility skills.

So the results show that both the haptic device and the video game are usable, accepted and pleasant to use for blind children, independently of the amount of time that they took with the technology and their initial enthusiasm. Thus, the video game and haptic device were ready to be used in order to determine their impact on the development and use of O&M skills.

The fact that the differences between the totally blind users and those who possess partial vision are not significant is positive for the case of the game's usability. This shows that both the MOVA3D video game and the DCC device work and are useful for both sets of students. Independent of their degree of visual impairment, the students were able to interact, play, get to know and navigate the virtual environment without any major difficulties, taking full advantage of the tools' capacities.

By taking the usability results obtained in this study into account, we implemented a second step that consisted of evaluating the impact that the use of a tool like the DCC (haptics), in combination with a 3D video game (sound) that represents a real navigational space, has on the development and use of orientation and mobility skills in situations pertaining to closed, unfamiliar spaces by blind, school-aged children.

The orientation and mobility results denote that the skills contemplated in the Tempo Spatial Orientation dimension were strengthened. At the same time, each of the participants learned that the possibility of moving through space and establishing a relationship between himself and external objects makes it possible to know of one's surroundings.

The only result that was statistically significant for all of the children between the ages of 7 and 14 was in the Tempo-Spatial Orientation dimension. This denotes that the users, after having used the video game and the DCC device, improved their ability to locate themselves in space with a higher degree of ability regarding laterality, directionality, and spatial concepts. We believe that this is due to the training that they received when playing with the DCC device, in which they carried out all of their movements with their own body, thus internalizing the degree of the turns and better positioning themselves in the navigated space.

Not having had any significant differences in the other dimensions may be due to the fact that the users' initial results were high. Thus the degree of improvement could not be that much higher. However, participants were able to improve substantially in the dimension that obtained the worst pretest results, the Tempo-Spatial Orientation dimension.

The blind participants were able to create a map of the environment through sound, which was evident when they took the same route in the real world that they had navigated virtually through the MOVA3D video game. As the student played with MOVA3D and interacted through the use of the carpet, he/she learned the distribution of the rooms, how close together or far apart they were, and the sizes and distances involved in each room. Some students counted their steps to then repeat their same movements in the real environment. Each one of the students adopted a strategy that was useful to them in being able to learn the topology of the place, to gain a mental representation of this place, and to then successfully navigate the real space.

However, there was a certain degree of uncertainty among the participants when they were taken to navigate the real-world routes which did not occur when playing the video game. Despite the fact that they had navigated the space virtually, for them there were many aspects of the surroundings that were still unfamiliar and this caused a certain degree of uncertainty, as observed by the educators. This translated into their using a considerable amount of time to execute the proposed task, but in any case they were able to orient themselves in the space, find the different rooms and recover the watch. In order to minimize the uncertainty, more information on the environment must be provided during the video game. Although they are able to put together a mental map, they cannot get to know the textures or differentiate, for example, between glass walls and cement walls through the video game. Nor are they able to know how the banister in the stairway feels from playing the game. This is a natural process for people when they get to know an unfamiliar environment in which they must relate the different objects in their surroundings and learn to interact with them.

7. CONCLUSION

We believe that the learning progress that was made by each child was favored by positive emotional will, interest in the MOVA3D video game and in the associated DCC device. This allowed him to strengthen this knowledge, which went in favor of acquiring new knowledge regarding the use of the video game and the associated haptic device.

Without a doubt, the new knowledge allowed the users to integrate new lessons they had learned regarding the environment into the skills involved in the research. Such skills are not only those associated with the ability to adopt postures in line with visual needs in order to be able to perform actions on the carpet (in the case of the participants with low vision) and the ability to situate themselves in space based on an initial position (in the case of the blind users); rather the skills include the ability to integrate the clock technique by associating the position of their body with a particular time, processing this information and transforming it into a movement that can be made with the haptic device. This generates movements within the virtual environment and strengthens the conceptualization and construction of a mental map of the space navigated in the video game in order for them to be able to then navigate the same route in the real world.

The MOVA3D video game with DCC and cognitive tasks emerge as an audio-based tool that can be used for the stimulation of tempo-spatial orientation skills in blind children. The children who participated in this study were able to transfer what they learned from the video game to performing the same tasks in the real world, thus achieving a successful transfer of knowledge and skills. This transfer is not easy because the children feel uncomfortable at first; with time, however, the game becomes a significant tool for training.

As a proposal for future research, it would be interesting to add new cognitive skill indicators to those used in the evaluation, thus widening the age range for the evaluation, in order to be able to include more participants from middle school education. In the same way, we propose to identify whether the participants are able to create mental schemes of the environment rather than maps that merely have some precise elements of the environment, using the proposed activities. This is a way to research the real effect that the MOVA3D video game has on the development of orientation and mobility skills through the use of spatial sound. We really believe that virtual training is better than real world training, as in the virtual environment it is easier to control all of the variables and to create different situations in order to improve children's skills. In the same way, in the virtual environment the children do not risk endangerment through their actions.

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Received December 2009; revised March 2010, May 2010; accepted June 2010