Usability of a Multimodal Videogame to Improve Navigation Skills for Blind Children

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ABSTRACT

This work presents an evaluation study on the usability of a haptic device and a sound-based videogame 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 project (Digital Clock Carpet) and a 3D videogame (MOVA3D), in order to redesign and improve the usability, as well as to learn of its acceptance and the degree of the user's satisfaction with the interaction with these products for O&M purposes. The results show that both the haptic device and the videogame are usable, accepted and pleasant regarding their use by blind children, and that they are ready to be used in the following stage, which will determine their impact on the development and use of O&M skills.

Categories and Subject Descriptors

K.4.2 [**Computing Milieu**]: Computers and Society – Social Issues: *Assistive technologies for persons with disabilities*

General Terms

Human Factors

Keywords

Blind children, virtual environments, navigation, haptic and audio interfaces.

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 affect later development of the child's cognitive functions and comprehension [14]. When a child experiences movements he or she also experiences notions of time, space and the logic of the events, learning as such to make sense of the entire surrounding environment, and achieving an understanding of reality [14]. For this reason, when children do not develop sensory-motor coordination correctly, they can experience problems in the future related to their navigation through the surrounding environment.

In particular, the biggest problem that blind people have when they move 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 [4]. Thus, any information on the qualities of the objects in such a context could be important and relevant for a blind person [7].

To avoid any potential risks and to move about safely, blind people prefer to navigate by using the room's perimeter ("shorelining") rather than the center of a room. It is simpler for them to continue their route by touching the wall and thus locating the access points more easily and obtaining a specific route, than it is for them to move about in open space [23]. This way of exploring the environment can lead users to find inefficient solutions to problems [7]. 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 [2]. 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/she is willing to listen to descriptions and is able to identify details that allow for a more accurate level of navigation [23].

It is for all these reasons that having a mental map of the space is fundamental for the efficient development of orientation and mobility techniques. As it is well known, most of the information required for such mental representation is collected through visual channels [9],[16],[23]. 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 [9]. Lahav and Mioduser [9], [8] 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

ASSETS'09, October 25–28, 2009, Pittsburgh, Pennsylvania, USA.
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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/her real life navigation skills.

A variety of studies highlight the importance of the use of video games for learning [26], [27]. 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 [21], [30], [6], [22]. Videogames can also allow for the development of specific skills [19], promote high-order learning [28], increase students' interactions [10], as well as improve social [13] and cultural [1] 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 [22], [17], [6].

In the work done by Kelly et al. [5] 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 work as split between the videogame designers and those who review the content is not easy to achieve, but it is essential for the success of an educational videogame.

Sánchez & Flores [20] 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 visually impaired users, 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, Hanson & Laff [29] present PowerUp, a virtual, multiplayer, educational videogame that provides users with a great degree of access. In their paper, the authors discuss the characteristics necessary for virtual worlds to be able to be used by users with some kind of disability. In particular, the game is accessible to the visually impaired 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 videogames and the virtual environments, being able to interact without any major difficulties.

Soute & Markopoulos [25] 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 [18] is a game that uses mobile technology so that blind and sighted children can interact, become socially integrated and learn science. AudioGene was designed considering the mental models of both blind and sighted users. 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.

The possibility of using educational video games opens enormous possibilities for working with blind learners. 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 [31], this method is closer to their natural ways of associating with technology [3]. For this reason, several authors believe that videogames represent a tool that allows for a closer approximation to 21st century learners' ways of learning and interacting [11], [15].

A visually disabled user can enjoy a conventional degree of navigation in a familiar environment, because he/she knows the surroundings, or because he/she has adequate aids for navigation. In a closed and unfamiliar environment, the experience of navigation can be complex and completely non-deterministic [7]. 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 non-technological (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. As a result, they cannot guide the user to choose the best possible route for a certain destination [16].

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, sensory-motor coordination and tempo-spatial orientation. An adequate dominion over these abilities is key for school-aged children, in that without such skills their communication, interaction, movement and, above all, their autonomy and independence can be altered, all of which are key for appropriate school integration and social inclusion.

In this report, we present the results of a usability evaluation study of a haptic-based device (Digital Clock Carpet) and a 3D sound videogame (MOVA3D) for the development and use of orientation and mobility skills in unfamiliar, closed spaces by school-aged, blind children.

2. HARDWARE AND SOFTWARE

Our research was carried out in two main stages. The first stage consisted of the design and development of the Digital Clock Carpet (DCC) and an audio-based, 3D videogame (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 of them had low vision while others were totally blind.

2.1 Digital clock carpet

An hour system for directions was used for informing the user about directions to the destination point. The hour system is a metaphor used for indicating a certain direction and consists basically 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 or her 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.

For the children to be able to understand and learn the hour system, in order to provide them with directions 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 the users have an alternative and complete input tool device that goes beyond the mere use of the hands through a keyboard or other input device. In fact, the interaction is carried out in the same way as if he or she were moving in the real world. Basically, the user performs the turns that the videogame 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 Figure 1 we can see how the carpet communicates with the computer, just as 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 portal of any personal laptop or computer, allowing the program to function without any problems, and thus representing a plug-&-play device.

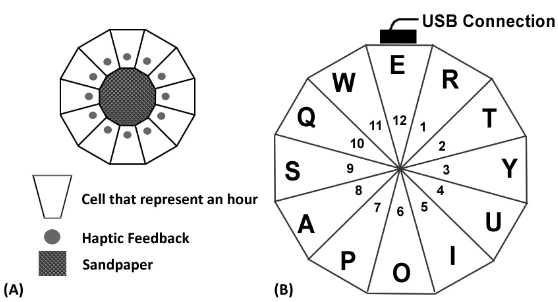

Figure 1. Design of the Digital Clock Carpet

The user interacts with the device by using his/her body, pressing the different keys with his/her feet. In the first version of the DCC, so that it would be easy for the users to be able to locate the different keys, a cylinder that juts out just 1 centimeter above the cell was placed in each cell. 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 80 cm radius and it was 5 cm high.

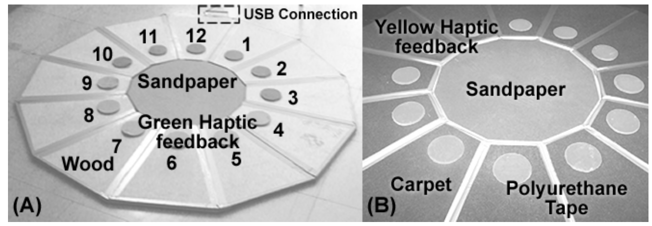

Figure 2. Concrete Digital Clock Carpet

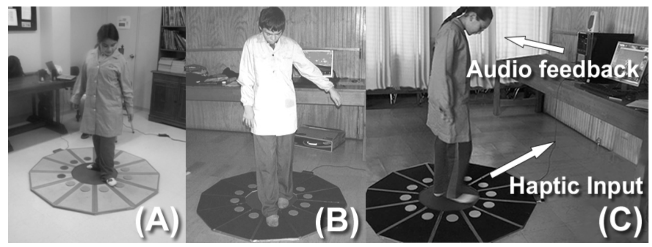

Figure 3. Children interacting with the first (A) and second (B) version of the Digital Clock Carpet (DCC). (C) The child plays with the videogame MOVA3D through interaction with DCC.

The software for testing the DCC informs the user which direction he/she should turn, at which point the child presses the direction (time) that he/she believes to be correct with his/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 which time he/she is really pressing.

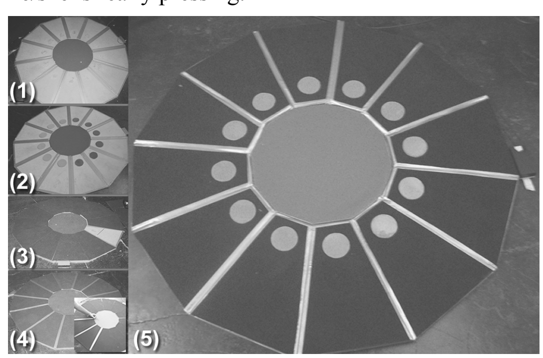

Figure 4. Evolution of the design and development of DCC (1) The DCC has only the sandpaper in the middle, (2) First design of the DCC with green haptic feedback, (3) Carpet is added to each key, (4) The keys are secured with polyurethane tape, and (5) The second and final version of the DCC, with each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

After the usability tests, described in the sub-chapter 2.3.3 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 and the haptic feedback were painted yellow, achieving as such 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 the sub-chapter 2.3.4 End-User Usability.

2.2 MOVA3D

The 3D videogame 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 videogame. This videogame was developed with a user-centered methodology, incorporating children from primary school, aged 6 to 12, from the very beginning of the design process.

The metaphor that is used in the videogame 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/she is close, a spatial alarm begins to sound, allowing him/her to locate the object in space. Once the user picks up the object, he/she must bring it to a special area in the virtual environment. On the way to this special area, the user must make sure that the aliens that inhabit the surrounding area do not steal the object that he/she has found.

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, it is only necessary to have the coordinates of the corners of the walls. In the videogame, real spaces can be represented on their scale of representation, as can the objects that are found in the virtual environment. The user can navigate several floors of a building using stairs, in which he/she always receives audio feedback from the space that he/she is traveling and the actions that are performed.

Initially, the videogame was designed with graphics based on high-contrast colors to be able to include children with low vision, but who are still legally blind. After realizing that the user interacts by making several turns on the carpet, and does not always end up facing the screen, it was no longer deemed necessary to have a very advanced graphic interface. In any case, having a high-contrast color interface is possible (that which is seen in black in Figure 5A corresponds to a plain blue color, and the lines that delineate the construction are in pure, plain yellow) as well as a graphic interface with textures (Figure 5B), which make the videogame attractive enough so that sighted users could eventually play with their blind classmates.

Although the videogame 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 videogame 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 3C).

When the user interacts with the videogame 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.

In the case that the user utilizes the DCC keypad, he/she will always be facing 12 O'clock, as the hour system shifts together with the user. Once the child moves towards a certain hour, the hour system shifts so that the user is again facing 12 O'clock, which allows the user to orient him/herself correctly in space. For example, if the user turns towards 4 O'clock, once the turn has been made 4 O'clock becomes 12 O'clock, and so on.

The spatial sound is relative to the user's orientation, and thus accompanies him/her. For this reason, the audible cues that the user receives are always correct, and are relative to how the user happens to be situated in the virtual space.

The videogame was developed using Visual Studio.NET and C# programming language, to be used with a Windows XP operating system 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.

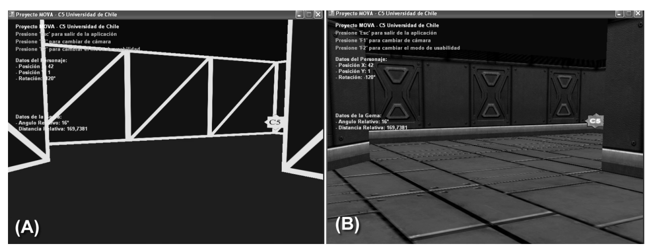

Figure 5. (A) Graphic User Interface of the MOVA 3D videogame using high contrast color for children with low vision. (B) Graphic User Interface of the videogame using normal textures for the walls and floor.

3. USABILITY EVALUATION

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

3.1 Heuristic Evaluation

3.1.1 Sample

The evaluators were 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 worked with software for blind people for several days out of every week.

3.1.2 Instrument

The heuristic evaluation was based on systematic inspections of the interface. We administered a heuristic evaluation questionnaire (HEQ) based on Schneiderman's golden rules [24] and Nielsen's usability heuristics [12]. This instrument has been used in other research projects related to interactive systems for visually disabled users [17]. 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.

3.1.3 Procedure

The heuristic evaluation consisted of the free use of an advanced and operational prototype of the videogame. It began with an introduction to the videogame, explaining the objective and the level of development at the time of the evaluation. Then each evaluator proceeded to interact with the videogame, selecting the different options on the menus and navigating independently through the virtual environment, using the available functions 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 answer the evaluation instruments. Finally, a brief session of analysis and discussion with each evaluator was held in order collect opinions and comments from the experts on the software, as well as new ideas and focuses to consider.

3.1.4 Results

Of a maximum of five points in all the heuristics studied, the results of the NEV came out to an average value of 3.8 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, as they were quite critical and rigorous when evaluating the heuristics (Figure 6). The strengths detected in this evaluation are related to content design (4.5 points), velocity and media (4.5 points) and recognition rather than recall (4.5 points). The heuristics with the lowest scores were visibility of system status (3.0 points) and error prevention (3.0 points). The main problem found was with the use of unrestricted spatial sound, which caused confusion with its use as it, at times, generated erroneous feedback for the users. After the HEV, the sound was restricted to the rooms in which an object could be found, in addition to providing the user with feedback on his/her location in virtual space.

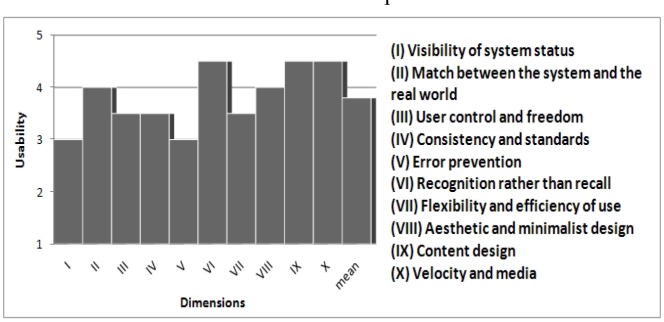

Figure 6. Results of the heuristic evaluation of the videogame (HRV)

3.2 Initial Usability Evaluation

3.2.1 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 men and 9 women; 15 had low vision and 5 were totally blind; all had different ophthalmologic diagnoses. The age of the users fluctuated between 6 and 12 years old. A usability expert and a teacher specializing in blind children worked alongside the students.

3.2.2 Instrument

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 videogame. These instruments have already been used in other, similar projects [21]. The aspects evaluated by the users, through the use of the scale, 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 I 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).

3.2.3 Procedure

A 20-minute work session per child was established, time in which they performed movement activities designed for 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, asking them all the while about the perceptions or sensations they were feeling, providing space for their comments and criticisms.

Once the participant felt confident enough with the DCC, he/she was asked to take a position in the central part (where the sandpaper is) as a way of providing him/her with the necessary position to initiate the activity. At that same time, without giving them any instructions on the clock system, the participants were asked to situate themselves facing 12 O'clock.

3.2.4 Results

3.2.4.1 DCC

In general terms, the carpet was perceived as easy to use (9.1 points of a total of 10) (Figure 7). This fact, to a certain degree, is strengthened in that it is an external device that captures the attention of the participants, because 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 was perceived quite favorably (9.3 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 against 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 7). 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 (9.3 points of a total of 10) (Figure 7). This is explained by the fact that, thanks to the visual remnants or indirect touch (through the shoes), the users were allowed to not only know on what part of the carpet they were positioned, but to establish a point of reference at the time when they change directions as well. The graphic/tactile signs served as a reference for the participants 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 (8.8 points of a total of 10) (Figure 7).

3.2.5 MOVA 3D

Regarding the sounds and voices used in the videogame, the level of appreciation by the children obtained an above-average score (7.35 points of a total of 10) (Figure 7). 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 videogame.

From the very beginning the videogame 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 7). Of the total number of participants, not one expressed that the videogame was boring or tedious; to the contrary, all the participants found it to be very fun and relaxing (9.9 points of a total of 10).

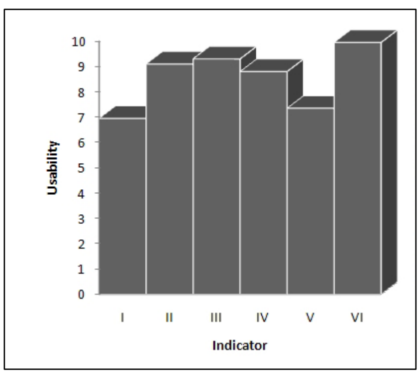

Figure 7. Results of the Initial Usability Evaluation (IUE)

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 on 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=0.296; $p<0.05$; Haptic Feedback: T=0.440; $p<0.05$).

3.3 End-User Usability Evaluation

3.3.1 Sample

The End-User Usability Evaluation (EUE) was performed with 19 students (10 men and 9 women) from the Hellen Keller and Santa Lucia schools for the blind in Santiago, Chile. The ages of the students fluctuated between 6 and 12 years old. The users possessed varying ophthalmologic diagnoses, in that 15 had low vision and 4 were totally blind. None of the students presented any associated deficits, and thus 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.

3.3.2 Instruments

For the EUE the Software Usability Questionnaire for Blind Children was administered. This instrument has been used in several projects related to sound-based software and blind users [17]. The questionnaire consisted 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".

3.3.3 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. The application of the videogame associated with the device was also improved, obtaining better audio feedback. The evaluation was performed during 2 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 worked for 10 minutes, time in which he/she interacted with the device in order to complete the orientation tasks that the virtual environment proposed.

3.3.4 Results

The EUE of the software shows a high degree of valuation in the 3 dimensions considered, obtaining scores higher than 9 points for all areas (on a scale of 1 to 10 points, in which 10 is the maximum score). The most highly evaluated scales were Satisfaction and Sounds, with 9.2 points each. The Control & Use dimension obtained a score of 9.0 points, while the average evaluation for the three dimensions was 9.1 points (Figure 8).

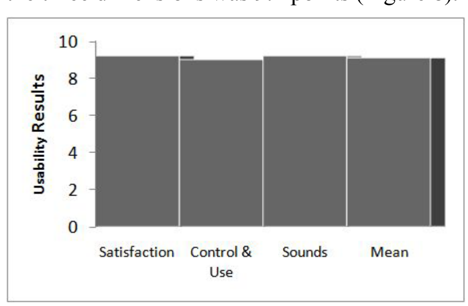

Figure 8. Results obtained in the End-User Usability Evaluation (EUE)

In analyzing the opinions provided by the users on usability, and differentiating by the kind of user involved (low vision or totally blind), some differences were observed. Users with low vision presented higher scores in the Control & Use and Sounds dimensions (9.2 and 9.5 points respectively), compared to the 8.5 and 7.9 points presented by the totally blind users. 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, $T=0.724$, $p<0.05$; Sounds, $T=2.439$, $p>0.05$) (Figure 9).

In the Satisfaction dimension, the totally blind users presented 9.4 points, compared to the 9.1 points presented by those with low vision (Satisfaction, $T=-0.320$, $p>0.05$) (Figure 9).

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 9.3 and 8.6 respectively (Mean, $T=0.977$, $p>0.05$) (Figure 9).

All of this indicates that even though low vision users accepted the DCC and MOVA3D videogame to a higher degree than totally blind users, these differences were not statistically significant.

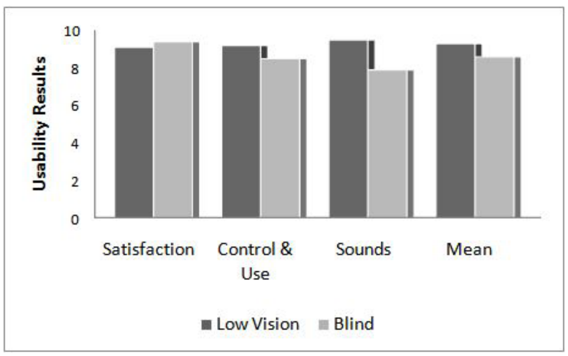

Figure 9. Results according to type of vision in the dimensions evaluated with the end-user usability evaluation

4. DISCUSSION

In this paper, a usability evaluation is presented for a haptic device especially designed for this study (Digital Clock Carpet) and a 3D videogame (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.

The results show that both the haptic device and the videogame are usable, accepted and pleasant to use for blind children, independently of how much time they used the technology and their initial enthusiasm. Thus, they are ready to be used without any difficulties in the following stage, which will determine their impact on the development and use of O&M skills.

The heuristic evaluation helped us 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 videogame MOVA3D if we consider that audio is an input mechanism that provides essential information for visually disabled people. This aspect facilitates and improves the blind user's interaction, making it so that he/she 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 videogame's sounds. The results obtained indicate that this kind of multimodal interface is a good combination for visually disabled users to be able to develop orientation and mobility skills.

From the original design of the carpet, it was necessary to include haptic and visual clues for the children to be able to interact with the device (DCC), and to be able to easily identify the association between the time and the keystroke with which the child was interacting. For this, material with a high degree of texture was included in order to generate a high level of haptic sensation. In addition, the different parts had a high degree of visual contrast so that those users with low vision could take advantage of their visual remnants 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 videogame 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. Although there were differences between the results obtained for users with low vision and those who are totally blind, both reinforce the idea that this kind of interaction is pleasant for them, and can be of use for studying the development of orientation and mobility skills.

Finally, by taking the usability results obtained in this study, we are planning a second step that consists of evaluating the impact that the use of a tool like the DCC (haptics) in combination with a 3D videogame (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.

5. ACKNOWLEDGMENTS

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

6. REFERENCES

[1] Cipolla-Ficarra, F. (2007). A Study of Acteme on users Unexpert of VideoGames. J. Jacko (Ed.): Human-Computer Interaction, Part IV, HCII 2007, LNCS 4553, pp. 215-224, 2007.

[2] Focus Group (2005). Discusión generada en base a preguntas de Orientación y Movilidad a usuarios legalmente ciegos. C5, Universidad de Chile.

[3] Go, C. & Lee, W. (2007). Digital Game-Based Learning: An Agent Approach. C. Stephanidis (Ed.): Universal Access in HCI, Part III, HCII 2007, LNCS 4556, pp. 588-597, 2007

[4] Hub, A., Diepstraten, J. & Ertl, T. (2004). Design and Development of an Indoor Navigation and Object

Identification System for the Blind. Proceedings of the 6th ACM SIGACCESS conference, ASSETS 2004, Atlanta, GA, USA, Vol. 77&78, pp. 147-152

[5] Kelly, H., Howell, K., Glinert, E., Holding, L., Swain, C., Burrowbridge & A., Roper, M. (2007). How to Build Serious Games. Communication of the ACM, July 2007 (20)7, pp. 45-49

[6] Klopfer, E., & Yoon, S. (2005). Developing Games and Simulations for Today and Tomorrow's Tech Savvy Youth TechTrends. Linking Research & Practice to Improve Learning, 49(3), pp. 33-41.

[7] Kulyukin, V., Gharpure, C., Nicholson, J. & Pavithran, S. (2004). RFID in robot-assisted indoor navigation for the visually impaired, Proc. IROS 2004 Conference, September - October 2004, Sendai Kyodo Printing: Sendai, Japan, pp. 1979- 1984

[8] Lahav, O. & Mioduser, D. (2008). Construction of cognitive maps of unknown spaces using a multi-sensory virtual environment for people who are blind. Computers in Human Behavior 24(3), pp. 1139-1155.

[9] Lahav, O. & Mioduser, D. (2008). Haptic-feedback support for cognitive mapping of unknown spaces by people who are blind. International Journal Human-Computer Studies 66(1), pp. 23-35.

[10] McDonald, K., Hannafin, R. (2003). Using web-based computer games to meet the demands of today's high stakes testing: A mixed method inquiry. Journal of Research on Technology in Education, 55(4), pp. 459-472.

[11] McMichael, A. (2007). PC Games and the Teaching of History. The History Teacher, 40(2), pp. 203-218.

[12] Nielsen, J. (1994) Usability engineering. New York: Morgan Kaufmann Publishers, 1st edition, p.362

[13] Pellegrini, A., Blatchford, P. & Kentaro, B. (2004). A Short-term Longitudinal Study of Children's Playground Games in Primary School: Implications for Adjustment to School and Social Adjustment in the USA and the UK. Social Development 13(1), pp. 107–123.

[14] Piaget, J. (1962). Play, dreams, and imitation. New York: W.W. Norton.

[15] Proserpio, L., & Viola, D. (2007). Teaching the virtual generation. Academy of Management Learning & Education, 6(1), pp. 69–80.

[16] Rodrigues, C. (2006). Um Dispositivo Háptico de Auxílio À Navegacao para Deficientes Visuais. Trabalho de Graduacao ao Centro de Informática da Universidade Federal de Pernambuco para a obtencao do grau de Bacharel em Ciência da Computacao, 2006.

[17] Sánchez, J. (2008). User-Centered Technologies for Blind Children. Human Technology Journal, 45(2), November 2008, pp. 96-122

[18] Sánchez, J., Aguayo, F. (2008). AudioGene: Mobile Learning Genetics through Audio by Blind Learners. In IFIP International Federation for Information Processing, Volume 281; Learning to Live in the Knowledge Society; Michael Kendall and Brian Samways; (Boston: Springer), pp.79-86

[19] Sánchez, J., Flores, H. (2005). AudioMath: Blind children learning mathematics through audio. International Journal on Disability and Human Development, IJDHD, 4(4), October-December 2005, pp. 311-316.

[20] Sánchez, J., Flores, H. (2008). Virtual Mobile Science Learning for Blind People. CyberPsychology & Behavior 11(3), pp. 356-359

[21] Sánchez, J., Sáenz, M. (2006). 3D sound interactive environments for blind children problem solving skills. Behaviour & Information Technology, Vol. 25, No. 4, July – August 2006, pp. 367 – 378

[22] Sánchez, J., Salinas , A. (2008). Science Problem Solving Learning through Mobile Gaming. MindTrek 2008 Conference, October 8-9, 2008 , Tampere , Finland , pp. 49-53

[23] Sánchez, J., Zuñiga, M. (2006). Evaluating the Interaction of Blind Learners with Audio-Based Virtual Environments. Annual Review of CyberTherapy and Telemedicine. Virtual Healing: Designing Reality. Volume 4, pp. 167-173.

[24] Shneiderman, B., Plaisant, C. (2004) Designing the User Interface: Strategies for Effective Human-Computer Interaction. New York: Addison Wesley, p. 652

[25] Soute, I.., Markopoulos, P. (2007). Head Up Games of the Future Will Look More Like the Games of the Past. C. Baranauskas et al. (Eds.): Interact 2007, LNCS 4663, Part II, pp. 404-407.

[26] Squire, K. (2003). Video Games In Education. International Journal of Intelligent Simulations and Gaming, 2(1), pp. 49–62.

[27] Steinkuehler, C. (2004). Learning in massively multiplayer online games. In Kafai, YB, Sandoval, WA, Enyedy, N., Nixon, AS & Herrera, F. (Eds.), Proceedings of the 6th International Conference of the Learning Sciences, Mahwah, NJ, USA: Erlbaum, pp. 521-528.

[28] Steinkuehler, C. (2008). Cognition and literacy in massively multiplayer online games. In Leu, D., Coiro, J., Lankshear, C. & Knobel, K. (Eds.), Handbook of Research on New Literacies. Mahwah NJ: Erlbaum, pp. 1-38.

[29] Trewin, S., Hanson, V., Laff, M., Cavender, A. (2008). PowerUp: an accessible virtual world, Proceedings of the 10th international ACM SIGACCESS conference, ASSETS 2008, Halifax, Nova Scotia, Canada, October 12-15, 2008, pp. 177-184

[30] Westin, T. (2004). Game accessibility case study: Terraformers – a real-time 3D graphic game. In Proceedings of the 5th ICDVRAT 2004, Oxford, UK, pp. 95-100.

[31] Prensky, M. (2001). Digital Natives, Digital Immigrants Part 1. On The Horizon - The Strategic Planning Resource for Education Professionals, 9 (5), 1-6.