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Development of navigation skills through audio haptic videogaming in learners who are blind

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Abstract

This study presents the development of a video game with audio and haptic interfaces that allows for the stimulation of orientation and mobility skills in people who are blind through the use of virtual environments. We evaluate the usability and the impact of the use of an audio and haptic-based videogame on the development of orientation and mobility skills in school-age blind learners. The results show that the interfaces used in the videogame are usable and appropriately designed, and that the haptic interface is as effective as the audio interface for orientation and mobility purposes.

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Keywords: Haptic and Audio Interfaces; Orientation; Mobility; People Who Are Blind.

1. Introduction

For people who are blind, navigation through unfamiliar spaces can be a complex task compared to a sighted person. In order to achieve orientation & mobility (O&M) [1], blind people need to use other resources to receive feedback from the environment, such as sounds or textures. Various virtual environments have been designed in order to train blind people, and to assist them with the development of O&M skills [2][3][4].

To navigate through an environment it is necessary to have access to the information that can be recovered from the environment, in order to then filter out useful information in a way that is coherent and comprehensible for whoever needs it. It is for this reason that in the case of blind people, the use of virtual

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environments and appropriate interfaces allows them to improve their O&M skills [5]. These kinds of interfaces can be, for example, haptic or audio based.

Due to the impossibility of obtaining information through sight, blind people must employ their other senses, such as touch, in order to be able to perceive their surroundings [6]. In this way, it has been possible to establish two categories of perceptions used by people who are blind [7]: (i) Tactile Perception, which is information perceived exclusively by the skin, and (ii) Kinesthetic Perception, which is information provided by muscles and tendons. The combination of both concepts, in order to benefit a blind person regarding the acquisition of information, is called haptic perception [7].

Unlike the sense of sight, the functionality of haptic perception lays in the codification of the various properties of elements, objects and substances such as hardness, texture, temperature and weight. Such properties are difficult to quantify with the sense of sight [8].

Haptic interfaces have been provided through the use of devices that are capable of creating feedback through interaction with muscles and tendons [2]. This provides for the feeling of applying force over a certain object [2]. More recently, studies of haptic interfaces have become increasingly relevant, and in particular the use of the Novint Falcon device with videogames for training and rehabilitation has enjoyed growing attention [9]. This device is reasonably useful for representing virtual environments, and provides force feedback in such a way that when it is used the user can feel the volume and force of a virtual object in his hand [4].

Several studies have sought to compare vision with haptic perception, showing that for the perception of properties that are visible, such as a bumpy texture or porosity, haptic sense is able to match or even overcome visual perception in terms of specificity [8][10], and match it in the spatial perception of objects [11]. From this it can be gathered that the use of haptic sense is feasible as an alternative form of providing information on volumes and objects in context [12].

There are several studies that include the use of haptic sense with people who are blind in various contexts [13][14][15]. In the context of O&M, one important study is that of [16], who present and evaluate an application that allows for the construction of a virtual environment based on the design of a layout by using geometric shapes. Once the design phase has been concluded, the blind user can interact with the virtual environment thanks to the use of a haptic device. The user takes on an aerial perspective of the environment, for which reason the feedback that he receives is equivalent to having a hard model and tracing possible paths by using a pencil, in which collisions are transmitted through the sense of touch [16].

Another alternative for providing information to blind people is through audio-based interfaces. Through the use of audio-based cues, a blind person is able to locate objects of interest, just as a sighted person would do [17]. This kind of interface requires a careful design, as it is necessary to assure that the end user does not feel saturated by an excessive amount of information [18]. One example of audio-based virtual environments can be seen in the videogame AbES [4]. This videogame expands on the concept of the fictitious corridors used in its predecessor AudioDoom [3], in order to generate an audio-based virtual representation of real environments, thus serving as a videogame that allows for O&M training [4].

The purpose of this work was to investigate whether the use of audio and haptic-based videogame has an impact on the development of O&M skills in school-age blind learners. To attain this goal, it was necessary to design, implement and evaluate the usability of Audio Haptic Maze (AHM), an audio and haptic-based videogame. We also conducted a cognitive evaluation to determine the impact of AHM on the development of O&M skills in blind learners.

2. Audio Haptic Maze

Audio Haptic Maze (AHM) is a videogame based on AbES [4], and was designed to be used by a blind user either autonomously or with the supervision of a facilitator in contexts of research and practice, through the use of audio and haptic based interfaces either together or separately. AHM is a first-person videogame in which the

user must escape from a maze. In order to fulfill the mission, the player must find jewelry boxes dispersed throughout several corridors and rooms in the maze, which contain keys and treasures. The keys have geometric shapes that correspond to certain doors in the maze. The user must pick them up and try them out one at a time, until he identifies which key can be used to open the doors needed to get out of the maze. In order to add another entertaining component to the game, the score of the game increases with each treasure that the player finds. The time that the player takes to get out of the maze is also a factor, in which the less amount of time taken implies a higher score.

The entire process for the design and development of AHM was based on a user-centered design methodology [19], working directly with the end-user and making him an active participant in the design through interactions, conversations, interviews and end-user usability evaluations. The researchers' entire range of abundant team experience regarding interface design for blind children was also used in this design process.

AHM is based on a model for implementing educational software focused on children with visual disabilities [20]. The model is centered on providing facilities for evaluation purposes and prompt feedback to the end user. It also clarifies similarities and differences between software for people with and without visual disabilities, for implementation purposes.

2.1. Interfaces

AHM includes different interfaces in order to provide feedback to the user and information to the facilitator.

Graphic Interface, used by the facilitator, represents the current state of the game, using a third person perspective to show where the blind user is in real time. Fig. 1.i represents a screenshot of the graphic interface of AHM with the elements that can be found on the map, in which: (A) represents a jewelry box, which can have a key or a treasure inside; (B) represents the character controlled by the user; (C) represents a door in the maze.

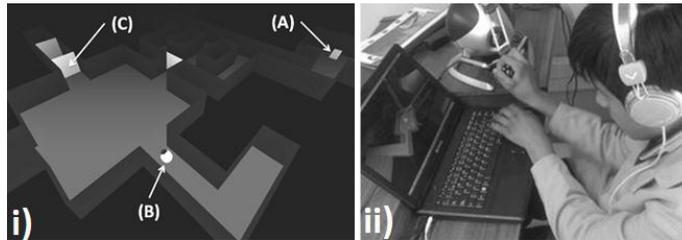


Fig. 1. i) AHM graphic interface, used by the facilitator. ii) A blind user interacting with the videogame.

Audio Interface is used by the blind user. AHM uses spatialized sound to represent the ambience of the corridors. For example, if the user has a corridor to the left, he can hear an ambience sound through the left-hand channel. The same kind of interaction is possible with other objects such as doors and keys, which are also represented by certain audio cues. All of the actions in the virtual environment have a particular sound cue associated to them. For example, if the user walks, a step sound cue can be heard. Examples of other possible actions are to bump into an object, turn in a specific direction, and pick up an object. In addition to this audible feedback, we use verbal audio to indicate certain situations. For example, when the user pick up a key, the context of the game changes, and the user is informed through verbal audio so that he can now listen a sequence of beeps indicating the number of vertices on the key.

Haptic Interface is used by the blind user. By using the haptic device, the user can control a 3D cursor inside the virtual environment. We emulate all the audio-based feedback using haptics. Thus, haptic textures are used to represent distinct objects on the map, so if the user touches a wall with the 3D cursor, the haptic feedback of

that object's texture will be different compared to that associated with touching a door. Also, the user will be able to identify shapes within the map. Regarding the feedback for actions, like walking or turning left or right, force feedback is applied, such as a vibration in the direction of the user's movement. In this way, if the user decides to walk forward, there is a vibration to the front and corresponding vibrations to either side if he turns to the left or to the right.

2.2. Interaction

The interaction with the videogame is carried out through the use of a standard computer keyboard, a Novint Falcon haptic device and earphones (See Fig.1. ii).

In the case of the audio-based interface, all of the user's immersion is achieved through the use of stereo sound, in order to provide information regarding the location of objects, walls and doors in the virtual environment. In this way, the user can create a mental model of the spatial dimensions. In navigating, the user can interact with each of the previously mentioned elements, and each of these elements provides feedback that helps the user to become oriented in the environment.

The Novint Falcon device was used for the haptic feedback, which works as a three dimensional pointer that allows for an interaction with 3D volumes, generating force feedback.

During the entire process of interaction in which the user plays with the videogame, the actions taken are stored in files that can then be visualized by the facilitator through a special application called "Path Analyzer", which marks the places on the map through which the user navigated. This allows for a more complete user route analysis, session after session, in order to show the evolution of the user's movements as he integrates the various areas of the map that have been navigated into his mental scheme.

3. Usability Evaluation

3.1. Sample

For the usability evaluation of AHM, a sample consisting of 10 blind learners with ages ranging from 9 to 15 years old was selected. None of these research participants have any additional, associated disabilities other than visual impairment.

3.2. Instruments

For usability testing, several key instruments were used. The Software Usability Elements questionnaire (SUE) allows for quantifying the degree to which the sounds and haptic feedback used in the videogame were recognizable. The Open Question Usability questionnaire (OQU) that was applied to the users included questions such as: Was it possible to perceive the relative position of the objects? Did you like the sounds/haptic interface used for feedback in the software? The idea was to collect knowledge regarding aspects related to O&M that represent the focus of the AHM videogame, as well as regarding the use of the controls, the information provided by the software, and the user's navigation in the virtual environment. The results of this evaluation allowed us to redesign and improve the user interfaces. Once the corrections and redesign of the software had been carried out, Sánchez's Software Usability for Blind Children (SUBC) [21] questionnaire was administered. This questionnaire consists of 14 items for which the users had to define to what degree each item was fulfilled, on a scale ranging from 1 ("a little") to 10 ("a lot"). The results allowed for an evaluation of the software's usability according to the user's satisfaction, using sentences such as, "I like the software" and "The software is motivating".

3.3. Procedure

The first step was to establish an activity revolving around the usability of each of the proposed interfaces. To these ends, two 20-minute sessions were held with each user. During these sessions the users were asked to listen to a set of 40 sounds, identifying or relating the object or action that each sound represented, focusing their attention mainly on the contextual sounds to be used in the videogame, such as footsteps and bumping sounds. Also, a set of 20 high relief objects and a set of the same 20 objects with low relief were used, and users were asked to interact with these objects through the haptic device to establish the haptic characteristics regarding shape and texture, in order to identify the object or element that was presented.

The SUE questionnaire was completed by the facilitators after each work session, in order to identify which of these audio and haptic elements were easier for the users to recognize and associate. Based on these results, the most appropriate sounds and elements were selected for use in the videogame.

Afterwards, the users interacted with AHM in a 40-minute session, in which they were asked to take a path from point A to point B on the map. During this process, the facilitator observed the user's position on the map through a graphic interface in order to detect if there were any difficulties with their navigation, and whether or not they were able to perceive the audio and haptic elements within the maze, and use them as references for orientation and mobility.

After having finished this activity, the users completed the OQU questionnaire with the help of a facilitator during a period of 10 minutes.

Finally, the users proceeded to respond to the SUBC questionnaire with help from the facilitator, who read the questions out loud and filled in their responses. Based on the results of these questionnaires, the team proceeded to make all of the changes and redesigns that would allow for an improved version of the videogame, in order to make it more usable.

3.4. Results

Initially, it was planned that the sounds utilized in the videogame would represent a "metallic" environment, which would create a spatial maze atmosphere in order to make the game more attractive to the students. However, according to the results obtained from the application of the SUE questionnaire for the evaluation of iconic sounds, it was observed that the sounds, which were altered in order to achieve the desired effect, confused the users. For this reason it was decided to use pure sounds.

For the usability evaluation of concrete shapes, the results obtained from the questionnaire show that the students correctly identified simple geometric shapes, but had problems identifying complex shapes. In the same way, in evaluating shapes through the use of the haptic device, it was observed that the majority of the users identified regular shapes with the device, but not complex shapes. Finally, in evaluating the usability of the virtual textures represented through the use of the haptic device, the results show that most users correctly described the textures.

When the users responded to the question "Did you like the videogame?" on the OQU questionnaire, all users answered positively, with phrases such as: "I liked the environment that the videogame generates, it is very realistic", "It is fun to move around in the corridors and escape from the maze". In response to the question "Do you want to add something else to the videogame?", in general the users replied that they would like the maze to include enemies to fight against. According to the results of this questionnaire, the videogame was well accepted, and in the future it would be possible to consider adding other components that would make it even more attractive. One relevant aspect regarding the use of the interface based on audio and combined sounds was the users comments that the experience was very enriching, but not necessarily because of the ability to transmit information from the virtual environment to the user; rather they noted that, in part, the

sound helped to generate an environment that is more associated with what they would expect from a videogame.

The results provided by the Software Usability for Blind Children (SUBC) questionnaire shows that AHM is usable for users with visual impairment. In order to perform the evaluation, the three kinds of interfaces involved in the videogame were analyzed: haptic, audio and haptic plus audio. The results show that the mean level of the “users’ satisfaction” was 7.0, 8.5 and 7.1 points respectively for each kind of interface, on a scale with a maximum of 10 points. For the “Satisfaction” category, the sentence with the highest score across the board for all three interfaces was “I would play this game again”, with a score of 7.6 for the haptic interface, 9.2 for the audio and 7.5 for the audio and haptic combined. This aspect is fundamental, as it allows for users to maintain an interest in the videogame, and not become bored too quickly. This result was consistent with the results obtained from the OQU questionnaire as well.

The “Control and Use” category obtained a score of 6.7, 7.5 and 7.8 points respectively for haptic, audio and haptic plus audio interfaces, respectively, on a scale with a maximum of 10 points. As all of these scores are above 6.0, they are considered to be acceptable. The score is lower for the haptic interface, as for the users the exclusive use of the Novint Falcon in order to obtain feedback from the game required a certain learning curve, as none of the participants in the sample had ever used this device before.

4. Cognitive Impact

4.1. Sample

An intentional sample was selected, made up of 7 blind learners with ages between and 10 and 15 years old, including four males and three females, all from the Metropolitan Region of Santiago. All of the participants attend the Santa Lucia School for the Blind. The requirements to participate were: 1. Be between 10 and 15 years of age, 2. Present Total Blindness, 3. Be enrolled in between Third and Eighth grade of General Elementary Education.

4.2. Instruments

In order to study the degree of the videogame’s impact, together with the cognitive tasks performed, on the development of the participants’ O&M-related skills, an O&M skills checklist was created for children with visual impairments between 10 and 15 years of age. This checklist was designed by special education teachers who are specialists in visual disabilities. The validation of the instruments was performed by these teachers applying the O&M skills checklist to blind users other than those involved in the sample, in order to detect errors in comprehension and the measurement of results.

The dimensions contained within this instrument are: (i) Sensory perception: The perception of information through the auditory and haptic channels are evaluated, taking into account the fact that sensory capacities are the primary functions that are developed to pick up on, integrate and react to information and stimulus from the environment. (ii) Tempo-spatial development: The users’ knowledge regarding their position in space is evaluated, in being able to understand the distribution and location in space of various elements based on their own bodies, while at the same time being able to establish a relation between these aspects in order to navigate through the space. (iii) O&M skills: The skills regarding navigation based on O&M training is evaluated, either through use of the cane as a technical aid in order to detect obstacles in the environment or not. The purpose of this was to show whether or not the users are able to navigate both real and virtual environments based on these techniques, thus validating them for facilitating and strengthening their navigation.

4.3. Procedure

Initially, the O&M skills checklist was applied as a pretest, in 45-minute sessions with each user. During these sessions, the users were provided with a set of materials in order to perform some of the actions required by the instrument.

In a second stage, the users performed cognitive tasks through the use of the videogame in which each of the dimensions contained in the O&M skills checklist was worked on (Perceptual development, Temporal-spatial development, O&M skills) in order to strengthen the development of these skills by using AHM.

This stage involved a total of twelve, 40-minute sessions with each user. Once the user had finished navigating through the maze, he was asked to create a graphic representation of the environment, in order to determine if the mental image created coincided with the spaces that had been navigated virtually while interacting with the videogame. Complementary to the cognitive evaluation, during each work session, once navigation through the virtual environment had been completed, each user was asked (in order of age) to form a graphic representation of the virtual environment they had navigated, in order to determine the adoption and restructuring of the mental model based on audio and haptic cues.

Finally, in a third stage the same O&M skills checklist used in the first stage was applied as a posttest.

4.4. Results

The results obtained from the evaluation of the 10-12 year old age group from the sample showed an increment in the pretest/posttest performance means in all dimensions. Based on a T Test that was performed with this data, it was found that the differences in the pretest/posttest means for the “Sensory perception” (pretest mean = 65.75 points; posttest mean = 70.75 points; range of scores from 0 to 72 points) and “Tempo-spatial development” (pretest mean = 24.45 points; posttest mean = 28.75 points; range of scores from 0 to 34 points) dimensions were not statistically significant. However, for the “O&M skills” (pretest mean=32.31 points; posttest mean=48.75 points; range of scores from 0 to 52 points) dimension the difference between the two means was statistically significant ($t = -4,323$; $p < 0.05$).

The results obtained for the evaluation of the 13-15 year old age group from the sample showed increments in their pretest/posttest performance means in all dimensions as well. Based on a T Test that was performed with this data, it was found that the differences in the pretest/posttest means for the “Tempo-spatial development” (pretest mean = 33.33 points; posttest mean = 34.00 points; range of scores from 0 to 34 points) and “O&M skills” (pretest mean = 34.00 points; posttest mean = 43.76 points; range of scores from 0 to 44 points) dimensions were not statistically significant. However, for the “Sensory perception” (pretest mean = 59.00 points; posttest mean = 68.00 points; range of scores from 0 to 68 points) dimension the difference between the two means was statistically significant ($t = -5,197$; $p < 0.05$).

5. Conclusions

The purpose of this study was to design, implement and evaluate the Audio Haptic Maze (AHM) videogame and determine whether the use of an audio and haptic-based videogame has an impact on the development of O&M skills in school-age blind learners. The results showed that playing and training with AHM improved the development of O&M skills in blind learners.

Regarding the usability associated with the videogame, it was found that the use of appropriate audio icons is crucial to be able to provide correct information. For this reason, applying sound effects to these sounds could generate a kind of special environment that can have a negative effect on usability. Both the haptic and the audio-based interfaces are able to transmit the same information on the user’s state within the virtual environment. The use of audio and haptic interfaces together showed that, more than just complementing the

provision of information regarding the user's state within the virtual environment, this combination allows for the creation of an environment that is much closer to what the user would expect from a videogame. The users utilized the haptic interface to navigate and the audio interface to imagine the situation in which they were immersed within the videogame's maze. As such, the use of the haptic and audio interfaces together allows the blind user who is navigating the videogame's virtual environment to be able to form a better perception of distances, shapes and the orientation of the objects on the map when updating his position. Due to this fact, the users could navigate through all of the areas that make up the maze, making intelligent decisions regarding what direction to follow in order to go from point A to point B thanks to the information provided.

Regarding the cognitive impact, the results of this study show that all the audio and haptic icons are useful for establishing navigational paths in the virtual environment. The icons that allow the users to measure the spaces that they navigate are especially helpful for this process, not only to establish a mental scheme of the virtual environment, but to apply this information to real navigational contexts as well. This was corroborated by the results regarding the effect that the intervention had on the users in the "O&M skills" dimension.

The results allow us to confirm that all of the users within the 10-12 year old age group presented significant development of their O&M skills due to their interaction with the AHM videogame. The results also indicate that the "O&M skills" dimension was that which experienced the most significant quantitative development, which is directly related to the efficiency of the user's movements when navigating within the videogame's virtual environment.

As far as the results for the 13-15 year old age group, all of the users presented a development in their O&M skills after having completed the cognitive tasks. There was an important increase in their scores as a result of their interaction with the videogame, although this increase was not statistically significant in the "O&M skills" dimension. Case studies were observed in which users were able to develop entire indicators that were unobserved in the pretest. One example of this is the development of techniques for the search and location of objects in the environment, which became visible in the videogame when the users had to locate the jewelry boxes that contained the keys needed to open the doors of the maze.

As for the graphic representations of the users' mental maps after having finished the navigation sessions, these representations included all of the elements involved in the videogame's virtual environment, but lacked precision regarding specific dimensions and the orientation of the corridors and rooms. The problem associated with dimensions is due to the users' tendency to perform a peripheral exploration while navigating in real life, a tendency that is transferred to their navigation in the virtual environment. This situation is only visible for the representations with concrete material, in that they virtually establish the dimensions that correspond to each area of the maze.

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