Three-Dimensional Virtual Environments for Blind Children

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ABSTRACT

Information technologies are increasingly helping to integrate and socially include people with visual disabilities. Computing technologies have contributed grandly to attain this goal through innovative techniques and applications. Virtual environments, I/O interfaces, and sound based applications altogether with usability and cognitive impact studies are some of the most used research designs for children with visual disabilities. This study presents the design and usability evaluation of three-dimensional (3D) interactive environments for children with visual disabilities. We introduce AudioChile and AudioVida, interactive virtual environments that can be navigated through 3D sound to enhance spatiality and immersion throughout the environments 3D sound is used to orientate, to avoid obstacles, and to identify the position of diverse personages and objects within the environment. Usability evaluation results indicated that sound can be fundamental for attention and motivation purposes during interaction.

INTRODUCTION

SOUND-BASED applications[1,14] and virtual environments[2,4,7,9,10] conceived to be used by users with visual disabilities and combined with the application of usability testing have been developed using auditory information as the main output channel and haptic devices for input.[11,12] For example, AudioDoom[9,10] is an interactive game mimicking the classic Doom with three-dimensional (3D) sound. In this application the user navigates throughout virtual environments finding aids to solve problems and to attain a specific goal. In the same way Terraformers[13] appends a sound compass and more actions to the blind user for spatial navigation purposes. AudioMath[11] is an interactive audio computer application based on the classic Memory board game. Through opening pairs of tokens in a board with several levels of difficulty, the child has to find the corresponding pair of tokens in accordance with the mathematical content.

These systems have been principally implemented to help blind people to develop and use cognitive skills. Other studies focus on the design of 3D audio interfaces to develop skills to recognize spatial environments through sound.

An experience with audio stimuli to simulate visual cues for blind learners[7] has found that 3D sound interfaces help blind people to localize specific points in a 3D space concluding that navigating virtual environments through sound can be an appropriate task for blind people. Other studies describe positive effects of 3D audio-based virtual environments.[2]

A research work evaluated the skills to hold in mind a specific localization without concurrent perceptual information or spatial update by using audio stimuli to trace specific places through sound.[5]

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Authors have also used virtual environments to study memory assessment and virtual reality applications for the assessment and rehabilitation of attention and visual-spatial cognitive processes of persons with Central Nervous System dysfunction.[8]

Finally, a study to evaluate and design a spatial audio system that models the acoustic response of closed environments with varying textures and sizes for people with visual disabilities was implemented concluding that there was almost no difference in user perception of room sizes between sounds in real and virtual worlds.[3]

This study analyses the design and usability evaluation of AudioChile and AudioVida, 3D interactive environments for children with visual disabilities navigated through 3D sound to enhance spatiality and immersion.

METHODS

Virtual environments

AudioChile is composed of diverse hyperstories.[6] Once immersed in the 3D world the user can adopt a personage that can be a girl or a boy. Each story consists of an adventure to explore one of three geographical regions of Chile by navigating, interacting, and solving tasks and problems.

Virtual personages and objects of an adventure have been designed for a 3D virtual world. All of them were designed according to real characters of the geographical zone in the story.

AudioChile has defined mobility environments of three Chilean cities. They consist of three different labyrinths where the user navigates by performing the selected personage. In addition, there are objects and personages with defined position and actions within the virtual world.

Three virtual environments represent the corresponding Chilean cities. Each virtual world can be navigated through interaction with textures and special sounds. Each city consists of an introduction through audio and a typical music of the zone. Within the travel environment there are some representative places of different cities in order to trace the trip through Chile (Fig. 1).

Virtual world navigation is delimited by labyrinths that allow mobility and freedom to the personage within certain parameters (can give turns of 90 and 180 degrees). AudioChile has a compass to orient the user when searching for interaction with different objects and personages in order to solve the problem posed.

To interact with the compass the child must select the object or personage. The child can obtain compass information by using a keystroke of the keyboard. The child can also deactivate the objects and personages and select a new one. The compass works with orientation variables and two matrices to map the location and the orientation of the objects for different labyrinths.

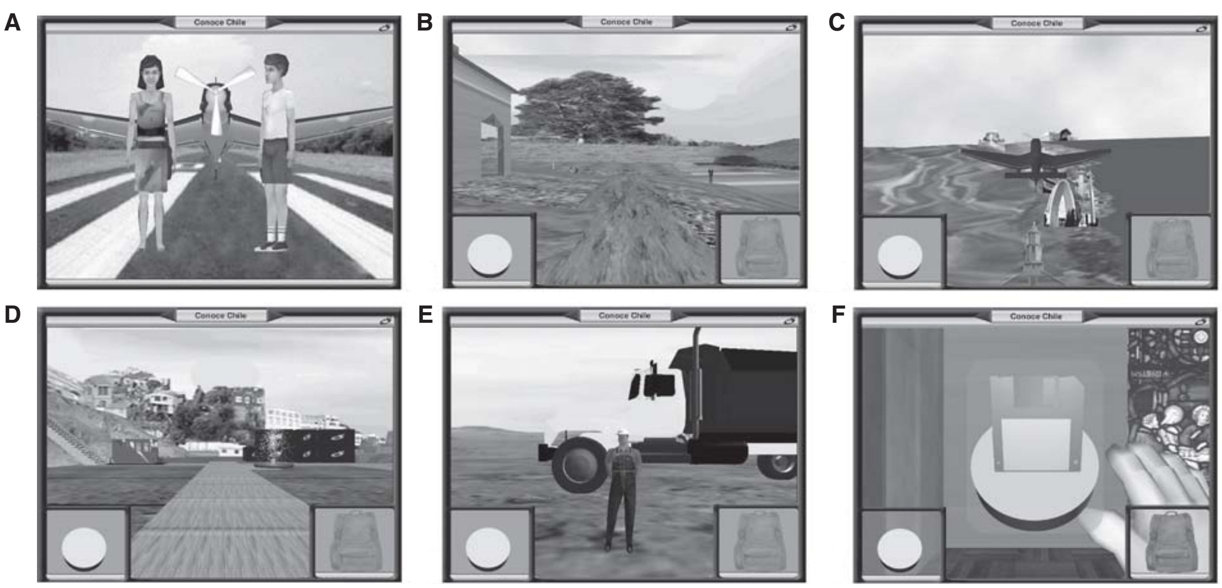

FIG. 1. Screenshot of the graphic interface of AudioChile: (**A**) personage menu; (**B**) Chiloé; (**C**) Travel; (**D**) Valparaíso; (**E**) Chuquicamata; and (**F**) Option menu (save game).

Interaction occurs through actions such as to take, give, open, push, pull, look, speak, use, travel, check the backpack, movements, and turns (90/180 degrees). Diverse interactive elements have associated actions defined by a matrix that crosses the user's behavior and different elements to represent the viability of the operation.

Through the "take" action the personage can load elements during the adventure that can serve in future actions. To do this there is a virtual backpack to save these elements. The backpack is an interactive point that can be accessed and the content inside can be saved and checked to be used in conjunction with the surrounding environment.

To attain immersion through sound we use sound hardware that allows at least quadraphonic sound by implementing front and back speakers. To navigate through the virtual world AudioChile uses 3D sound to get a better spatiality and immersion. Spatial sound is provided during obstacles orientation such as the boundaries of the labyrinth as well as the position of objects and personages within the virtual environment. When the user performs not allowed actions for a certain element an error feedback is provided.

To represent labyrinths we use four sound cones located dynamically together with the movement of the child. These cones represent the cardinal points (north, south, east and west). To locate the cones we use a virtual ray that goes from the personage to the walls within the labyrinths, and we put the cone in the intersection of both structures. Within the software there exists different type of walls and each wall has a characteristic sound for representing the environment. The volume of the sound intensity is calculated by the distance between the personage and the object.

AudioVida offers a virtual environment to simulate mobilization and orientation within a labyrinth with many sonar stimuli in the corridors of the virtual environment. The main purpose of this software is to help learners to solve problems by using higher order cognitive skills through mobilizing in virtual structures.

Interfaces were implemented by using colors for children with residual vision. The user interacts with a front interface where there are options to be chosen such as an introduction to the game, controls of the software, and views of the labyrinth, first person and global view. Also the application provides nutrition information about the foods encountered by the learner (Fig. 2).

The learner navigates through the labyrinth assisted by the audio orientation provided. Audio makes reference about walls, doors, and intersections to inform learners about context changes through volume and position variations of sound sources.

The user interacts with the software through keyboard. When starting the game the child has to walk through the corridors represented by specific sounds. For instance, to identify closeness or farness from the intersections with other corridors within the labyrinth there are some changes in the audio system by highlighting clearly to which side the user can advance.

As the user advances through the corridors s/he can encounter different types of foods that can be eaten to add or rest points to the whole score of the game. The goal is to attain a score of 300 points in 5 min. While the learner interacts with the game the system informs periodically the time left to attain the goal.

Each time learners find a food the software can help them by providing information about its nutritional components such as fats, proteins, and carbohydrates.

Learner's immersion within the virtual environment is induced through spatial sound indicating the position, corridors available for walking, and

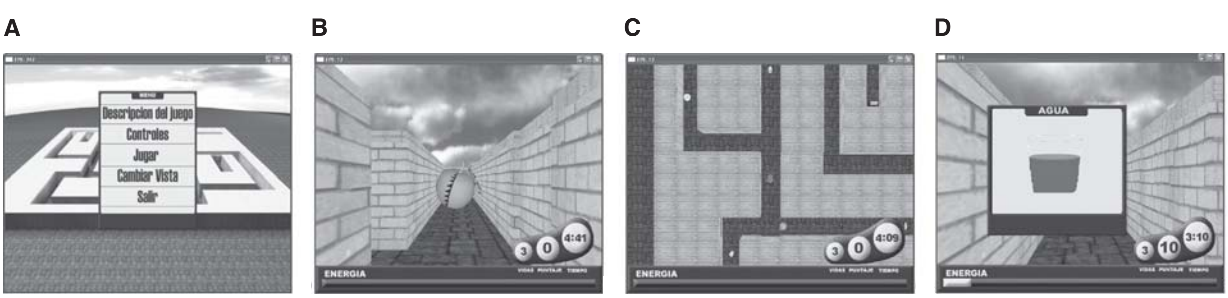

FIG. 2. Screenshot of the graphic interface of AudioVida: (**A**) main menu; (**B,C**) views of the interface; and (**D**) nutritious information menu.

the description of elements to interact with such as doors and food.

When changing context the learner receives an audio signal to define the address and closeness of the software components motivating learners to walk through the virtual labyrinth in the same way as if they were doing this physically.

Cognitive emphasis and usability

The cognitive emphasis of the software focuses on implementing different mobilizing routes in a complex audio-based virtual environment. Learners have to analyze and interpret the virtual space by using tempo-spatial notions to recognize different ways to move through the labyrinth, to exercise audio discrimination when walking through the virtual environment, to construct a mental representation of the navigated virtual space, to elaborate strategies to decrease the time spent when walking through the virtual environment, and to elaborate new routes to attain a goal.

Usability testing

To evaluate the software acceptability by children with visual disabilities we implemented a usability study from March to June 2004 with blind children.

Participants

The sample was composed by nine Chilean children with visual disabilities, seven boys and two girls, ages 10–15, who attend a school for blind children in Santiago, Chile. Five children have low vision and four are totally blind. Two of them are blind from birth, two acquired blindness during childhood, three have good residual vision, and two have poor functional residual vision. Two special education teachers and one usability expert also participated in the study.

Each child participated in four testing sessions during four months. Each session was especially dedicated to one child in order to allow him/her to walkthrough deeply through the software (Fig. 3).

Instruments

Three usability questionnaires were used during testing: (1) end-user questionnaire, (2) prototype interface evaluation questionnaire, and (3) problem solving understandability questionnaire. The end-user questionnaire was applied at the end of the usability sessions. It is basically a software acceptance test and consists of 18 closed statements with an answer scale from 1 to 10. It also contains five open questions. The prototype interface evaluation questionnaire was applied during usability sessions. It intends to evaluate images and audio feedback by including an observation instrument that has two parts: (1) a set of questions to identify images of personages and objects in the software as well as a sector to record observations during interaction and (2) a set of questions to identify input/output sounds and related associations made by blind children. It also contains observations recorded during interaction. The problem solving understandability questionnaire was applied during interaction and consists of a questionnaire with 10 open questions to evaluate the understandability of problems and tasks posed and related interface elements such as instructions, sounds, visual and sound cues, voice, navigation issues, and strategies to find hidden cues.

FIG. 3. Learners interacting with AudioChile and AudioVida.

Steps

Each usability testing consisted of the following steps: introduction to the software, software interaction, anecdotic recording, application of usability questionnaires, session recording through photography, protocol reports of the session, and software design and redesign.

Procedure

The usability testing was first implemented in March 2004. Children pretested early prototypes of both software during interaction. The objective was to have an initial feedback about the sounds and images of the software in order to have in the beginning of the implementation phase the information to orient the final design of the interfaces. To get more detailed information we used the interface evaluation questionnaire.

The second stage was implemented after we processed the data from the first testing and re-

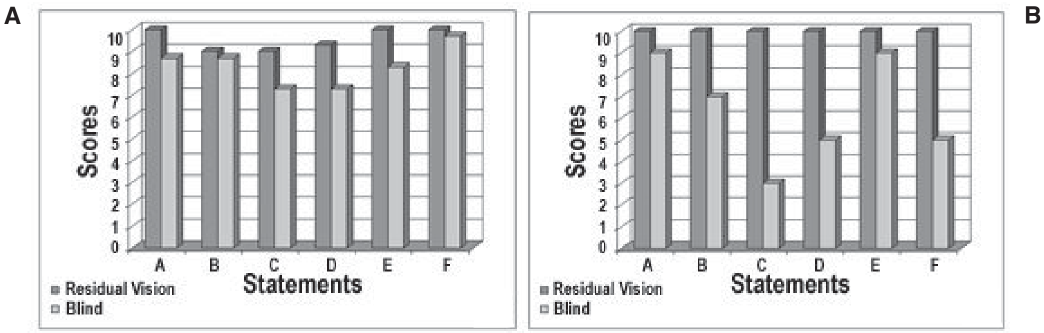

FIG. 4. Motivation when using AudioChile **(A)** and AudioVida **(B)**. A. I like the software B. The software is pleasant C. The software is challenging D. the software makes me to be active E. I would like to play again the software F. The software is motivating

designed and improved the prototype. Therefore at this stage we had a more advanced prototype. We used the prototype interface evaluation questionnaire.

The third stage was applied in two parts. We applied the end-user questionnaire to the same sample in two different moments.

After each application we analyzed data from open and closed questions and took decisions in the interface design/redesign. Both testings served to improve the usability of the software.

RESULTS

The results of the prototype interface questionnaire show that children are able to recognize sounds and accept them for interaction purposes. There were some volume issues that were finally solved. Some images were not adequate so we redesigned them to get better results in the interaction with children with residual vision. The results of the problem solving understandability questionnaire indicate that the help and direction sessions of the software were highly understood. Learners understood what to do through the use of the software with minimal supervision of facilitators. The results we analyze here were obtained by testing the final version of the software and applying the end-user questionnaire.

The motivation to interact with the software was evaluated. Children with residual vision showed a greater motivation to interact with the software obtaining average scores of 9 or 10. Blind children mentioned lower motivation but the scores were still high, between 7 and 9 points (Fig. 4). This is a very critical result because in general children with visual disabilities were motivated to interact and walkthrough AudioChile and AudioVida. However, totally blind users showed lower acceptance of AudioVida. This can be explained by the way labyrinths are represented for navigation purposes.

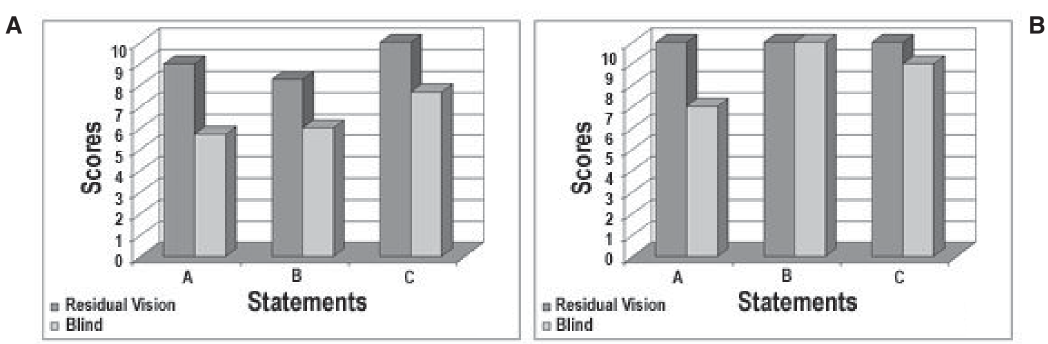

FIG. 5. The use of **(A)** AudioChile and **(B)** AudioVida. A. I felt controlling the software B. The software is easy to use C. The software adapts to my pace

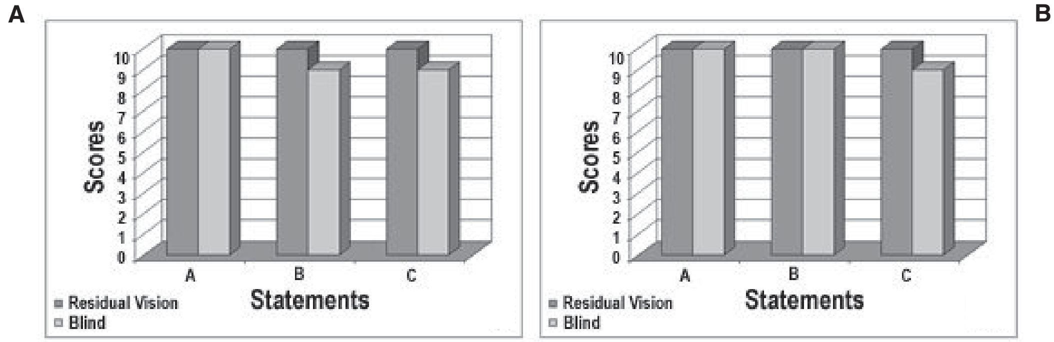

FIG. 6. Perception of sounds of **(A)** AudioChile and **(B)** AudioVida. A. I like the sounds of the software B. The sounds are clearly identified C. The sounds of the software convey information.

AudioChile uses cones of sounds distributed according to cardinal points while AudioVida uses specific sounds per corridor.

Users with residual vision did not mention to have difficulties when using the software (score 8–10). Blind users had more difficulties to map the interaction with software (score 5–7).

Controlling the software and the easiness of use were more complex to blind children. Most children with visual disabilities mentioned that the software adapts to their pace (score 7–10; Fig. 5).

As depicted in Figure 6, children with residual vision highly accepted the sounds (score 10). Blind children also accepted the sounds of both software (score 9 or 10). This was a very sensitive aspect of this study because the software relies heavily on diverse sounds and voices.

Children highly accepted the software when interacting and evaluating the products. The use of high contrast interfaces allowed users with residual vision to have a better control of the processes during interaction.

CONCLUSION

This study presents the design, implementation, and usability testing of two 3D sound virtual environments to assist the learning of cognitive processes and specific contents in learners with visual disabilities.

Children were able to orient themselves in the use of keystrokes without errors. Usability testing was crucial for mapping the end-users and their understandability of the applications. Children liked, accepted, used, and were very motivated with the software. After designing and redesigning 3D sound interfaces they mapped and navigated comfortably throughout the virtual environments.

After we implemented the first testing we added more instructions because learners needed many cues and instructions to orient themselves in the software to make it similar to the real environment.

The usability testing shows us that when designing graphics interfaces for children with residual vision we are confronted with a clear issue of mental modeling. Children with residual vision besides to their difficulties to recognize certain icons did not associate them for the designed actions. As a consequence we proposed and tested a solution to the problem by changing the icons and proposing others with more fidelity in their representation. We also used stereo sounds that were the antithesis in their related actions.

The use of the software has allowed children to differentiate and identify surrounding sounds that helped them to orient spatially. The results from our AudioDoom study showed that children attain a complete mental representation of the navigated virtual world. This new software have helped children to improve laterality and the concepts of up and down when using maps represented by north and south respectively. Sounds helped to catch the attention and motivated children. The contrasting colors of the interfaces were also important for the interaction of users with residual vision.

Sounds were highly accepted by children because they were clearly identifiable and easy to follow. Children felt a better control and navigability in the virtual world after redesigning the software.

Finally, right now we are observing the use of the software together with cognitive tasks. We need to know the impact of using these audio-based virtual environments on the development of higher order cognitive skills such as spatial representation, strategies for complex navigation, and problem solving.

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