# Memory Enhancement through Audio

**Jaime Sánchez**
Department of Computer Science
University of Chile
Blanco Encalada 2120, Santiago, Chile
jsanchez@dcc.uchile.cl

**Héctor Flores**
Department of Computer Science
University of Chile
Blanco Encalada 2120, Santiago, Chile
hflores@c5.cl

### ABSTRACT
A number of studies have proposed interactive applications for blind people. One line of research is the use of interactive interfaces based on sound to enhance cognition in blind children. Even though these studies have emphasized learning and cognition, there is still a shortage of applications to assist the development and use of memory in these children. This study presents the design, development, and usability of AudioMemory, a virtual environment based on audio to develop and use short-term memory. AudioMemory was developed by and for blind children. They participated in the design and usability tested the software during and after development. We also introduce AudioMath, an instance of AudioMemory to assist mathematics learning in children with visual disabilities. Our results evidenced that sound can be a powerful interface to develop and enhance memory and mathematics learning in blind children.

### CATEGORIES AND SUBJECT DESCRIPTORS
J.0 General

### GENERAL TERMS
Human Factors.

### Keywords
Virtual acoustic environments, blind children, cognitive memory, spatialized sound, audio-based navigation, usability

### INTRODUCTION
The design of audio-based interfaces to foster cognition in blind children has been one of major themes in the field of non conventional interfaces for blind people. Diverse studies have targeted the design of interfaces based on spatialized sound and evaluated their usability and cognitive impact [2, 10, 11, 12, 17, 18, 20, 22, 24, 25, 26].

One common theme in these studies is that they rely on interactive software that cannot be adapted to their needs and requirements. Likewise, most of them are proof-of-concept prototypes without enough flexibility and versatility.

Early, a seminal study developed a proof-of-concept application allowing blind children to navigate virtual environments through audio [10]. Authors used audio to enhance spatial cognitive structures concluding that spatialized sound can be used to map navigated spaces in a virtual world. Later, the same authors developed a field study combining similar audio-based virtual environments with specific cognitive tasks. As a result, they identified four progressive cognitive stages when using audio to foster cognition: entry, exploration, adaptation, and appropriation. The last two stages imply a high spatial representation and mental modeling. They ended up concluding that sound combined with cognitive tasks can help to construct mental images of the navigated space. Sound per se has little impact on cognition. Cognitive tasks are crucial in this interaction.

Other studies emphasize experiences with audio stimuli to simulate visual cues for blind learners [12]. Researchers have found that by using 3D audio interfaces blind people can help to localize a specific point in a 3D space. They performed with precision but slower than sighted people concluding that navigating virtual environments with only sound can be more precise to blind people in comparison to sighted persons [12].

A number of studies describe the positive effect of 3D audio-based virtual environments [5]. An interesting study using sensory virtual environments through force feedback joysticks simulating real places such as the school and work places probed the hypothesis that providing appropriate spatial information through compensatory channels the performance of blind people can be improved [8].


*ASSETS'04*, October 18–20, 2004, Atlanta, Georgia, USA.

A research work in the same line of [10] showed that a traditional computer game such as Space Invader can be replicated with 3D sound. Authors used Force Feedback Joysticks as input interface by letting to play blind to sighted children to share the same experience [11]. Blind and sighted people with covered eyes were tested in another study with audio stimuli tracing specific places through sound. Authors evaluated the skill to hold in mind a specific localization without concurrent perceptual information or spatial update [9].

A few studies have approached the development of computer applications to develop and enhance memory through virtual environments in people with disabilities. The development of memory processes such as spatial distribution through virtual reality environments was attained by active participation of people with disabilities [1]. They found that active participation enhanced memory for spatial layout whereas passive observation enhanced object memory. Other studies have also used immersive virtual reality to analyze spatial memory in patients with brain damage. They developed a test as proof-of-concept of the critical role that can be played by virtual reality as experimental tool for memory purposes [13]. Virtual reality was also found to be relevant to improve the validity and reliability of neurological evaluation and rehabilitation [16]. A final work analyzed the impact of spatial audio on memory concluding that audio stimuli improves memory and perceived comprehension by choosing spatial audio instead of non spatial [2].

A common theme of these studies is the absence of long-term usability studies. A growing movement in the field is sustaining that spatial audio may have a reduced impact when it is not associated with specific cognitive tasks. There is not only a need for sound-based virtual environment studies but also for more rigorous and systematic usability studies by and for children with visual disabilities.

## THE DESIGN OF AUDIOMEMORY

### Model

AudioMemory has different components. *Specific content* models the representation problem to generate a grid with a pair of related tokens between them to be solved by the child. *Random card generator* is the editor that allows setting the level of complexity and contents from a gallery. *Computer model* is the representation of the real problem. It includes state system variables such as number of correct token pairs, time, and score as well as parametric variables such as level, content, and user name. *Projection* implies transforming input signals to changes perceived by blind users either audible or tactile. It bridges system and interfaces through bidirectional feedback from and toward the user actions. *Interface* includes input/output interaction devices such as audio, keyboard, mouse, force feedback joystick, and tablets.

The model is based on a matrix with rows and columns. There are four levels of complexity: Level 1 with four tokens (two rows and two columns), level 2 with six tokens (three rows and two columns), level 3 with twelve tokens (three rows and four columns), and level 4 with sixteen tokens (four rows and four columns). Colors are used for children with residual vision [15].

### Software and hardware tools

AudioMemory was developed by using Macromedia Director 8.5 and a library of routines for external joystick control, Xtra RavJoystick. A joystick Side-Winder was used in conjunction with Force Feedback Joysticks, mouse, keyboard, and Wacon tablets.

### Interfaces

The main interfaces of AudioMemory for children with residual vision are displayed in Figure 1. Interfaces for blind children are only audio-based. A is the identification screen with two modes: facilitator or student (two buttons). B considers the level of complexity (list box), content (list box), and input device (buttons). Content can be filled, upgraded, and edited by using different media. C is the main interface of AudioMemory and includes options such as the position of the card grid, accumulated score, time elapsed (through speech), restart, register, and exit (through buttons). D includes a logging actual use register (buttons) describing each game and movements.

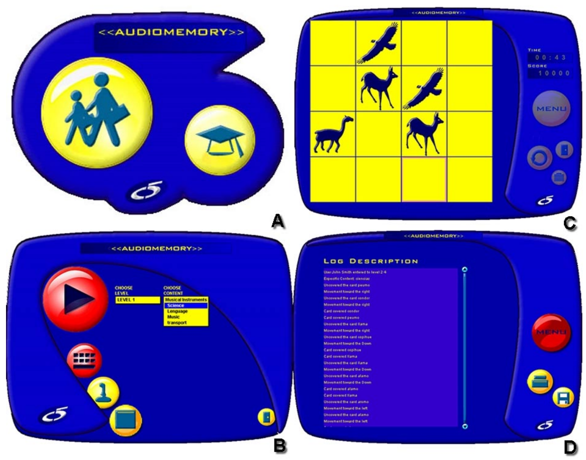


**Figure 1.** Interfaces of AudioMemory

### Interaction

AudioMemory allows interaction with available interface elements such as buttons and text screens through keyboard. Each interaction triggers an audio feedback and a high visual contrast screen to be perceived by children with residual vision. The child has to move through a grid and open the corresponding token. Each cell has associated music tones that identify the position in the grid. Sound is listened when moving through cells. When open a token the associated element is visible by triggering an audio feedback. For example, if the image is a car, a real traffic car sound is triggered. When open a correct token pair a feedback is set. Finally, when all pairs are made AudioMemory displays the time used, the final score, and feedback.

AudioMemory can be interacted through keyboard, joystick, and tablets. A few keystrokes are used with the keyboard. These devices have been used in different past applications developed by the research group after testing with children with visual disabilities. The Microsoft SideWinder joysticks in conjunction with Xtra RavJoystick for Macromedia Director allow grading the user position in the grid and give direct feedback with different forces. Counter forces to the movement are generated per each token position change as well as vibratory forces indicate to be close to the grid edge: up, down, left, and right. Force Feedback Joysticks allow direct interaction with diverse degrees of freedom. A plastic graphic grid is posed on the tablet defining the position of each token. A pen is used to point and select interface elements.

### Cognitive emphasis

AudioMemory was designed to enhance memory in blind children and children with residual vision. For reading and writing skills it is a prerequisite to have visual and audio memory to discriminate graphemes and phonemes. This memory prevents to be confused by graphemes for spatial orientation as well as by phonemes with similar sounds. AudioMemory allows these children to practice and rehearse their short-term memory. Basically, they did practice audio memory (blind and children with residual vision) and visual memory (children with residual vision). The tasks implied to exercise audio/oral, visual/oral, audio/graphic, and visual/graphic memory.

## THE EVALUATION OF AUDIOMEMORY

### Participants

The sample was conformed by 19 Chilean children, 9 boys and 10 girls ages 6 to 15 in a blind school setting. Children have diverse intellectual development: normal, slow normal, border line, below to normal, and with mental deficit. They were separated in two groups, introductory and advanced. Both groups were balanced by blindness and residual vision. Two special education teachers and two usability experts also participated.

### Concrete Materials

We used tangible objects during usability testing to construct a mental model of software functioning in the children's mind. The idea was first to represent AudioMemory structure concretely and then to explain them its functionality (see Figure 2). The design of used materials was divided in two scenarios: Global and Specific Scenarios. The global scenario corresponds to the entire software representation (see Figure 2A and 2B). This can be done by dividing the material in relation to screens and scenarios. Children create models of AudioMemory through tact by building objects without details. The specific scenario corresponds to the model of specific objects considering detailed characteristics of the application (see Figure 2C and 2D). The goal is to make children to learn about intervening objects of the software.
Concrete materials helped to improve notably the understanding of the software by blind children. They also gave information to the user during interaction about updating the board in relation to the state of the software. Children with residual vision did not use concrete materials.

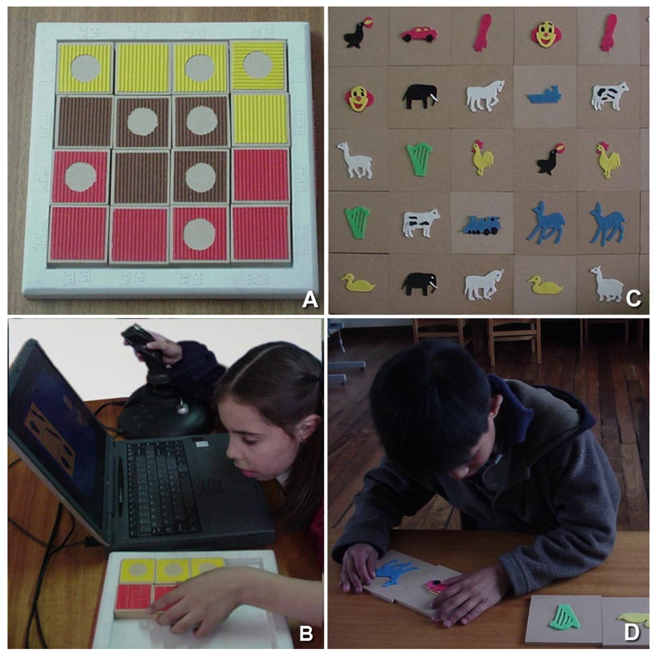


**Figure 2.** Examples of concrete materials in global (A and B) and specific scenario (C and D)

### Evaluation Instruments

Usability tests were used. We adapted to blind children questionnaire tests for end-users, facilitators, observers, and usability heuristic evaluation experts [17]. End-user tests focused on opinions such as how they like the software, what was pleasant to them, what not, how useful is the software to them, and how they like the input devices used. Questions were read and explained by the facilitator.

The questionnaire for facilitators considered them as final users by mediating the interaction of the child with AudioMemory. Observers used questionnaires to register the interaction. The heuristic evaluation was based on systematic inspections of the interface. We used heuristic evaluation questionnaires [17] built from Schneiderman golden rules and Nielsen usability heuristics. Twelve heuristics were considered: visibility of system status, match between system and the real world, user control and freedom, consistency and standards, error prevention, recognition rather than recall, flexibility and efficiency of use, aesthetic and minimalist design, help users to recognize, diagnose, and recover from errors, help and documentation, content design, and velocity and media.

### Procedure

During testing sessions there were end-users, facilitators, observers, and a video recorder and photographer. Usability evaluators also participated. There were four steps in each experience: introduction, interaction, interview, and observation. Introduction included an explanation about how to interact with AudioMemory, the objective, structure, and function. They learned how to use concrete materials during and after interaction with the application. During the interaction the children were helped by a facilitator to orient and assist them to decide on their own. They interacted 30 to 45 minutes with AudioMemory each session during six months twice a week. They were interviewed and then answered read and explained questionnaires. The interview was based on end-user questionnaires. During each session interaction observation methods were applied by using written questionnaires. Testing sessions were also video taped. Figure 3 shows a diagram of the testing scenario. Children interact with AudioMemory by choosing an input/output interface. They do this at the same time they interact with concrete materials and thus improving the understanding of the software.

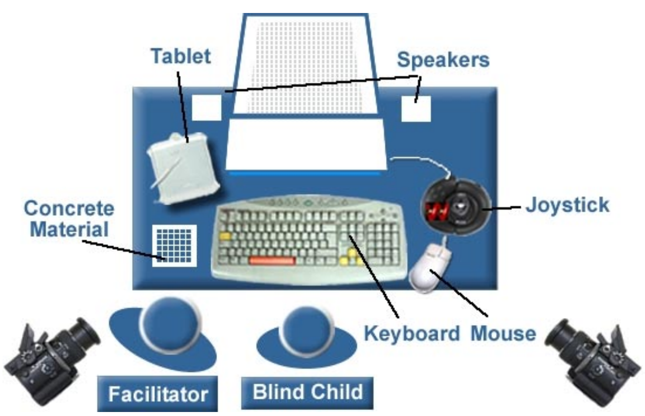


**Figure 3.** Testing scenario

### Results

To synthesize the usability evaluation results we present two graphics: one concerning blind children satisfaction and the other with results of the heuristic evaluation.

Blind children and children with residual vision were highly satisfied (see Figure 4). All of them scored higher than 9.5 out of 10 points. Children with residual vision were slightly more satisfied. This indicates that AudioMemory has a great potential to satisfy end-users after interaction. Children liked, motivated, enjoyed, and would like to play again the software. They also felt controlling the software when interacting with AudioMath (see Figure 5).

The perception they have about sounds is also a differentiating element for users with and without residual vision. Children with residual vision evaluated better the sounds of AudioMemory (see Figure 6). This can be explained due to the relevance it has for each type of user. Blind children need to perceive clear and meaningful sounds in comparison to children with residual vision that rely heavily on graphical interfaces to interact with the AudioMemory.

Results of the heuristic evaluation are displayed in Figure 7. Three experts inspected the software and answered a questionnaire. We highlight the results concerning heuristics such as the visibility of system status (I), match between the system and the real word (II), user control and freedom (III), recognition rather than recall (IV), and flexibility and efficiency of use (V). Answers were rated in a 1 to 5 scale in terms of the expert's acceptance. The highest score was given to the visibility of system status (I) meaning that AudioMemory keeps users informed about what is going on through appropriate feedback within reasonable time rate. This was followed by the match between the system and real world (II), and flexibility and efficiency of use (V) meaning that the software is fairly oriented to users, efficient when using, and that objects, actions, and options are visible. The lowest score was given to user control and freedom (III) meaning that we have to improve the interaction with children, provide ways to solve errors more easily, and support redo and undo functions.

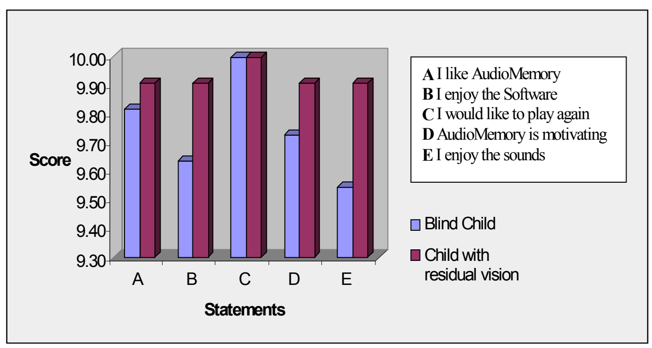


**Figure 4.** User satisfaction with AudioMemory

To know the impact of Force Feedback Joysticks on blind children we asked them if they liked to use joysticks and why. Most of them had not used this type of joystick before. To them "joysticks are easier than keyboards", "joysticks are motivating". A few of them expressed some fear because "joysticks shivered too much", and "joysticks have to be moved too much".

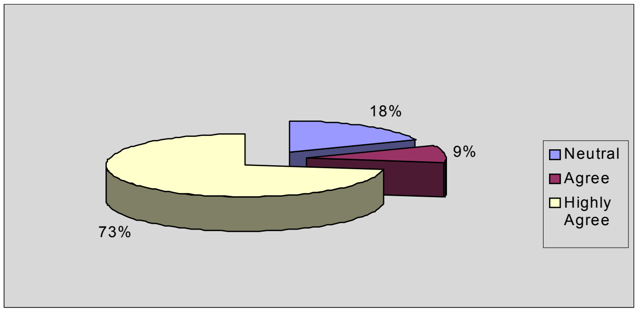


**Figure 5.** “I felt controlling AudioMemory”

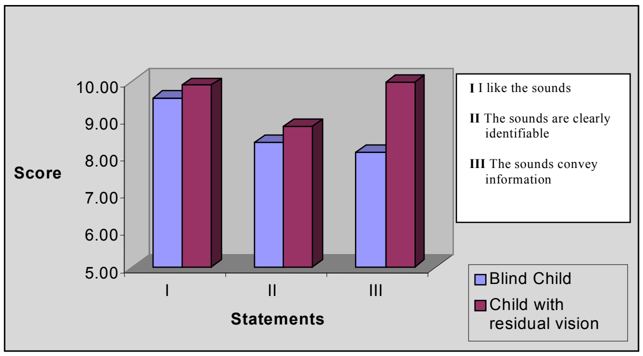


**Figure 6.** Children’s perception of sounds of AudioMemory

The results showed that 80% of children preferred to interact with AudioMemory through force feedback joysticks instead of keyboard. Actually the performance of children during interaction was not altered by the use of joysticks. This indicated that the information provided by force feedback joysticks was well understood by children. In spite of excellent user acceptance rates and a high use of joysticks we found that force feedback joysticks are good interaction supports providing a new media to convey information (input/output) and to avoid undesired sound that may end up with a confused user.

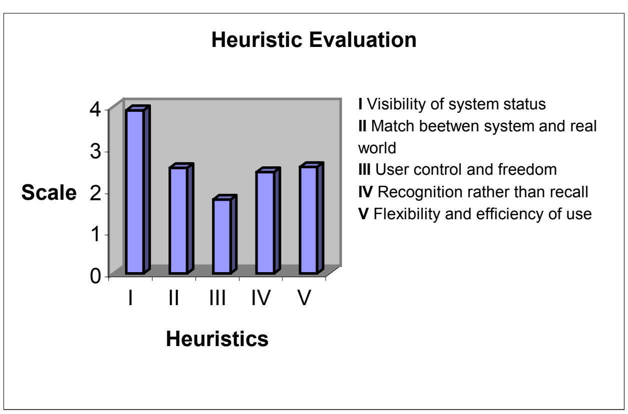


**Figure 7.** Heuristic evaluation results

## AUDIOMATH, AN INSTANCE OF AUDIOMEMORY

AudioMemory did not intend to assist the learning of a specific domain. Then, we later developed AudioMath, an instance of AudioMemory. This means that AudioMath uses the model of AudioMemory but instead of working with general domain content the software has built in mathematics content. AudioMath was used to assist learners with visual disabilities in learning concepts such as establishing correspondence and equivalency relationships, memory development, and differentiating tempo-spatial notions. We intended to foster learning and practice of mathematical concepts such as positional value, sequences, additive decomposition, multiplication, and division. AudioMath is targeted for teachers and learners. The teacher’s mode allows choosing specific mathematics curriculum content. The student’s mode contains different levels of difficulty and random access mathematics content.

### The Evaluation of AudioMath

#### Participants

We evaluated AudioMath with ten children ages 8 to 15 who attend a school for blind children in Santiago, Chile. The sample was conformed of 5 girls and 5 boys. Most of them have also added deficits such as diverse intellectual development: normal, slow normal, border line, below to normal, and with mental deficit. Four special education teachers also participated. All these learners met the following prerequisites: to be legally blind, to know the natural numbers, to express sequences orally, to order numbers, to decompose numbers through audio means, to mentally estimate results of additions and subtractions, to mentally determine products and coefficients, to mentally decompose numbers in additions, to manipulate multiplication tables efficiently, and to have notions of fractions.

#### Evaluation Instruments

Two measurement tests were used to evaluate the impact of AudioMath on learning and practice of mathematical concepts such as positional value, sequences, additive decomposition, multiplication, and division. We apply the immediate audio memory test [3] and the evaluation of mathematics knowledge test [2]. The immediate audio memory test has the purpose to measure logic, numeric, and associative memory from audio stimuli. The evaluation of mathematics knowledge test measures: 1. The capacity to understand numbers (oral and written); 2. The skills involved in making oral and written calculations; 3. The skills involved in counting numeric series and graphic elements; and 4. The skills involved in mathematics reasoning.

#### Procedure

Children were tested in the school from July to November 2003, twice a week, and two one hour sessions per week. They followed the steps of pre-testing (immediate audio memory and evaluation of mathematics knowledge tests), interacting with AudioMath, solving cognitive tasks (see Figure 8), and post-testing (immediate audio memory and evaluation of mathematics knowledge tests). Interacting with AudioMath and solving cognitive tasks were the main steps of the study. During these steps children were observed and assisted by four special education teachers filling check lists and registering observed behaviors. They also applied a usability evaluation test for end-users developed by the authors.

**Figure 8.** Children solving cognitive tasks with AudioMath

### Preliminary results

During the interactive sessions we realized that mathematical content used was appropriate to the educational level of the sample. We analyzed the results case by case because the sample was not homogeneous in key variables such as cognitive deficits and different degrees of blindness. Children performed increasingly well in both tests: audio memory and mathematics knowledge. An overall view of initial results shows pretest – posttest gains in mathematics knowledge (see Figure 9), thus indicating that interaction with AudioMath associated with cognitive tasks can improve mathematics learning in these children. Audio memory pretest-posttests show some gains after interacting with AudioMath, thus indicating that short-term memory can be enhanced by using this software. Gains were higher in mathematics knowledge than audio memory (see Figure 10).

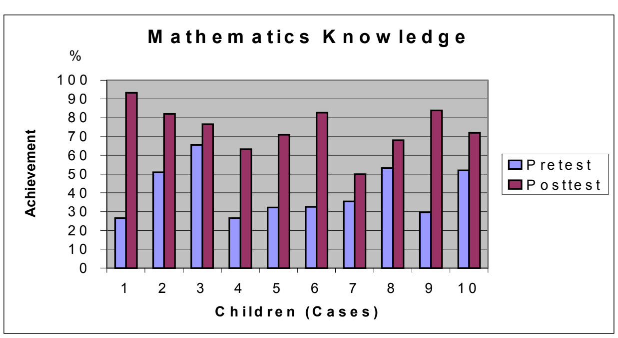


**Figure 9.** Pretest-Posttest gains in mathematic knowledge

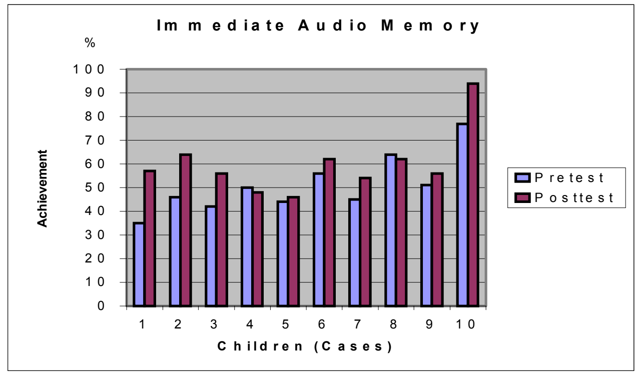


**Figure 10**. Pretest-Posttest gains in short-term memory

### DISCUSSION

We have introduced AudioMemory, a virtual environment to enhance memory in children with visual disabilities through audio. The software was made by and for children with visual disabilities. They participated actively in the development of the software. We have also designed interfaces for both blind and children with residual vision. A usability study was implemented with end-users, facilitators, observers, and experts.

AudioMemory was highly accepted by end-users. They liked, enjoyed, and were motivated when interacted with the software. The flexibility of this application is also a plus. Teachers, children, and parents can include new objects and sounds to adapt them to their needs. Thus, children with visual disabilities can choose sounds to be interacted with and embed them into AudioMemory. Content can be changed and updated easily. This is the case of AudioMath that can be used to support memory when learning specific concepts and processes in a given subject matter. AudioMath can be used for learning primary school mathematics.

The use of concrete materials was also a plus in this study. The children's understanding was easier when they first interacted with concrete materials and then with AudioMemory. Parallel interaction with both concrete materials and AudioMemory was also an advantage. Once they developed their own mental model of the software the interaction with AudioMemory was enriched.

After working with these children during a year we can conclude that their software needs are based on user satisfaction. This behavior is not different from sighted children.

Blind children tend to depend on facilitators for help and support, especially when they do not have available a context with diverse and abundant assistive technologies. Then feedback should be emphasized to interact fluidly and autonomously with the software. In contrast, children with residual vision can perceive some information from the screen avoiding the presence of a facilitator.

The usability evaluation results of this study indicate that we should include more functionality to AudioMemory to improve the interaction to make it more robust software. Most usability issues evidenced can be solved easily to improve the software such as to include more user information about what is going on during the interaction, more icons and audio stimuli to improve user control without relying on a facilitator, and more command accessibility. It is very important to provide through audio all the necessary information about the state of the software during interaction because this may involve many variables that may be difficult to handle by blind children.

Force Feedback Joysticks introduced a new scenario in virtual environment for blind children. They can provide information and tactile sensations through force feedback. This can help to decrease audio stimuli and relief possible acoustic pollution. Joysticks are devices with a high potential of use due to the availability of many buttons. They are also designed considering the physical profile of children (i.e., weight, size, buttons distribution) thus facilitating the use of software such as AudioMemory and AudioMath. Our experience with children using joysticks was positive. The results from the usability study probed that the information provided by force feedback joysticks was well understood by children. When we asked them about their input/output device preference they chose joysticks.

An interesting study can be drawn from this study: To analyze the organization and standard composition of menus and commands in software for blind children by studying menu usability by blind users. This idea comes from the need to provide to these users universally organized tools in such a way that blind learners have to have only experience using software with similar computer environments.

Our preliminary data from testing AudioMath is stimulating. The model fits well the learning of primary school mathematics concepts such as positional value, sequences, additive decomposition, multiplication, and division. Children performed increasingly well in both tests: audio memory and mathematics knowledge. Concrete cognitive tasks were crucial in this achievement. Interaction with AudioMath associated with cognitive tasks can improve mathematics learning in these children.

We are analyzing qualitative data from the AudioMath study. We designed this as case study because each child with visual disabilities is a whole case that deserves a deep analysis to construct meaning about the role that can play audio-based devices in learning general and specific domain skills.

Finally, we are building increasing evidence that audio-based interfaces can enhance memory and the learning of specific subjects such as mathematics. This can have a tremendous impact on the construction of learning and cognition by children with visual disabilities.

## ACKNOWLEDGMENTS

This report was funded by the Chilean National Fund of Science and Technology, Fondecyt, Project 1030158.

## REFERENCES

1. Attree, E., Brooks, B., Rose, F., Andrews, T., Leadbetter, A. & Clifford, B. (1996) Memory processes and virtual environments: I can't remember what was there, but I can remember how I got there. Implications for people with disabilities. In *Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technologies, ECDVRAT* 1996, 8-10 July 1996, Maidenhead, Berkshire, UK.
2. Baldis, J. (2001) Effects of spatial audio on memory, comprehension, and preference during desktop conferences. In *Proceeding of the ACM CHI 2001*, Seattle, Washington, USA, March 31 – April 5, 2001. Vol 3, 1. pp. 166-173.
3. Chadwick, M. & Fuentes, M. *Evaluation of Mathematics Knowledge* (adaptation of Benton-Luria test). Santiago, 1980.
4. Cordero, A. *Immediate Audio Memory*. 5th edition. TEA Editorial, Applied psychology publications, Madrid, Spain, 1977.
5. Cooper, M. & Taylor. (1998) Ambisonic sound in virtual environments and applications for the blind people. In *Proceedings of the Second European Conference on Disability, Virtual Reality, and Associated Technologies, ECDVRAT 1998*, Skövde, Sweden, 10-11 September, 1998. pp. 113-118.
6. Druin, A. (1999). *The design of children´s technology*. San Francisco: Morgan Kaufman Publishers, Inc.
7. Hanna, L., Risden, K., Czerwinski, M., Alexander, K. (1999). *The role of usability research in designing children´s computer products*. En Druin, A. (editor). The Design of Children's Technology. San Francisco: Morgan Kaufman Publishers, Inc.
8. Lahav, O. & Mioduser, D. (2000) Multisensory virtual environment for supporting blind persons' acquisition of spatial cognitive mapping, orientation, and mobility skills. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies, ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 53-58.

9. Loomis, J., Lippa, Y., Klatzky, R. & Golledge, R. (2002). Spatial updating of locations specified by 3-D sound and spatial language. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28(2),* pp. 335-345. 2002

10. Lumbreras, M. & Sánchez, J. (1998). 3D aural interactive hyperstories for blind children. International *Journal of Virtual Reality 4(1. pp.,* 20-28.

11. McCrindle, R. & Symons, D. (2000) Audio space invaders. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies*, *ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 59-65.

12. Mereu, S. & Kazman, R. (1996). Audio enhanced 3D interfaces for visually impaired users. In *Proceedings of CHI '96*, ACM Press.

13. Morris, R., Parslow, D. & Recce M. (2000). Using immersive virtual reality to test allocentric spatial memory impairment following unilateral temporal lobectomy. In *Proceedings of he 3th International Conference on Disability, Virtual Reality and Associated Technologies, ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000.

14. Nielsen, J.(1993). *Usability engineering*. New York: Academic Press Professional.

15. Rigden, C. (1999). The eye of the beholder-designing for colour blind. *British Telecommunications Engineering*, Vol. 17, January.

16. Rizzo, A., Bowerly, T., Buckwalter, J., Schultheis, M., Matheis, R., Shahabi, C., Neumann, U., Kim, L., & Sharifzadeh, M. (2002). Virtual environments for the assessment of attention and memory processes: the virtual classroom and office. In *Proceedings of the 4th International Conference on Disability, Virtual Reality and Associated Technologies, ICDVRAT 2002*, 18-20 September 2002, Veszprém, Hungary.

17. Sánchez, J. (2000). Usability and cognitive impact of the interaction with 3D virtual interactive acoustic environments by blind children. In *Proceedings of the 3rd International Conference on Disability, Virtual Reality and Associated Technologies*, *ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 67-73.

18. Sánchez, J. (2000). 3D interactive games for blind children. In *Proceedings of Technology and Persons with Disabilities, CSUN 2000*. Los Angeles, USA.

19. Sánchez, J. & Lumbreras, M. (1999). Virtual Environment Interaction through 3D Audio by Blind Children. *Journal of Cyberpsychology and Behavior, CP&B 2(2)*. pp. 101-111.

20. Sánchez, J. (2001). Interactive virtual acoustic environments for blind children. In *Proceedings of ACM CHI ´2001*, pp. 23-25. Seattle, Washington, USA, March 31 – April 5, 2001.

21. Sánchez, J. Interactive 3D sound hyperstories for blind children. In *Proceedings of ACM CHI ´99*, (1999). Pittsburg, PA. pp. 318-325.

22. Sánchez, J. Interactive virtual acoustic environments for blind children. In *Proceedings of ACM CHI ´2001*. Seattle, Washington, USA, March 31 – April 5, 2001. pp. 23-2.

23. Sánchez, J. AudioBattleShip: Blind Learners Collaboration through Sound. In *Proceedings of ACM CHI ´03*, (2003). Fort Lauderdale Florida. pp. 798-799.

24. Sjostrom, C. (2001). Using haptics in computer interfaces for blind people. *Proceeding of the ACM CHI ´01*, Seattle, Washington, USA, March 31 – April 5, 2001, Vol 3, 1. pp. 245-246.

25. Tan, H. (2000). Haptic interfaces. *Communications of the ACM, 43(3)*. pp. 40-41.

26. Winberg, F. & S. Helltrom (2000). The quest for auditory manipulation: the sonified Towers of Hanoi. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies*, *ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 75-81.