Usability and Cognitive Impact of the Interaction with 3D Virtual Interactive Acoustic Environments by Blind Children

J Sánchez and M Lumbreras

Department of Computer Science, University of Chile
Blanco Encalada 2120, Santiago, Chile

jsanchez@dcc.uchile.cl, mlumbrer@dcc.uchile.cl

ABSTRACT

It is known that blind children represent spatial environments with cognitive difficulty. This can be decreased if they are exposed to interactive experiences with acoustic stimuli delivered through spatialized sound software. A few studies have approached this issue by using interactive applications that integrate virtual reality and cognitive tasks to enhance spatial orientation skills. The aim of this research was to implement a field study to detect and analyze cognitive and usability issues involved in the use of an aural environment and the issues of representing navigable structures with only spatial sound. This experimental study has arisen from a challenging pilot research project to a full fledged field-testing research with eleven children during six months in a Chilean school for blind children. The research was implemented by using a kit of cognitive representation tasks, which includes exposure to the 3D acoustic environment, corporal exercises, and experiences with concrete representation materials such as sand, clay, storyfoam, and Lego bricks. The cognitive kit also included activities to represent the perceived environment, the organization of the space, and problem solving related to the interactions with the software. The usability testing of the environment was an explicit issue in the research by using both qualitative and quantitative methods including interviews, survey methods, logging actual use, still pictures, and video tape recording session analysis. The idea was to motivate and engage blind children to explore and interact with virtual entities in challenge-action software and to construct invisibly cognitive spatial mental representations.

The results of the study revealed that blind children can achieve the construction of mental structures rendered with only 3D sound and that spatial imagery is not purely visual by nature, but can be constructed and transferred through spatialized sound. Our hypothesis was fully confirmed revealing that each blind child passes four clear stages in their interaction with the sound environment and performing cognitive tasks: entry, exploration, adaptation, and appropriation. We also conclude that the child possesses both unique skills and pace referred to mental and spatial development, impacting directly on the quality of the topological features obtained in comparison to the ideal reference spatial structure embedded in the software.

1. INTRODUCTION

Integrating Virtual Reality (VR) to medicine appear to be an attractive combination that has been received media attention interest recently. The main stream comes from the fact that VR or more accurately Virtual Environments (VE) provide novel methods of visualizing and interacting with complex data sets. The first applications of VE are related to education and training, such as teaching of anatomy content [Weghorst 92], minimally invasive surgery training, diagnosis -visualization and navigation of medical image data sets-, rehabilitation [Whalley 93] -control of fears and phobias-, prosthetic use of advanced computer interfaces -i.e. glove talker system allows a person with speech difficulties to communicate by means of hand gestures while wearing a DataGlove virtual hand controller [Greenleaf 92]-, numerical cadavers, surgical simulators, visualization of data sets, and telesurgery.

Recently, VR and VE are used to enhance or ameliorate the cognitive and navigation problems of blind users. If we study how this technology assist blind users we can classify it according to the following type of applications:

- Web browsers: Web speech browsers designed for users that wish to access the Internet in a non-visual or combined auditory and visual manner such as BrookesTalk [Zajicek 98], WebSpeak [Hakkinen 96], MarcoPolo [Owen 97], AHA (audio HTML access) [James 98], DAHNI - Demonstrator of the ACESSS Hypermedia Non Visual Interface- [Morley 98]. All these approaches explore the fundamental issues of auditory navigation through hypermedia information.
- Universal access to computer systems: the main idea here is to provide generic access to the legacy of resources of standard computer systems. For example, Emacspeak [Raman 96] was designed to provide impaired users with productive access to the wealth network computing resources available on UNIX platforms. Other projects are Mercator [Mynatt 92] to provide generic access to the X-Windows platform without visual cues, and the european GUIB (Graphical User Interface for the Blind) to enable access to the MS Windows operating system.
- Presentation of information from graphical nature: A promising area for sound issues is the sensory substitution of information for visual nature by audio information for visually impaired users. Schemes for auditory rendering of maps and diagrams embedded in are being developed. Some authors have developed means for scanning arbitrary visual images and presenting them in sound. Also, there has been increasing interest in augmenting haptic displays with sound for purposes of presenting graphical information.
- Interactive 3D environments: The Spatial Auditory Environment in a Ring Topology [Savidis 96] aims to provide a multimedia toolkit for non-visual interaction to provide a 3D auditory navigation environment. This system will enable blind users to review a hierarchical organization of auditory interaction objects by using direct manipulation techniques through 3D-pointing hand gestures and speech recognition input.

The use of VR as interactive technology to explore users representing and interpreting symbolic objects and simulated environments in their minds has received little attention in the literature and empirical arena. It is known that blind children represent spatial environments with cognitive difficulty. This can be decreased if they are exposed to interactive experiences with acoustic stimuli delivered through spatialized sound software. A few studies have approached this issue by using interactive applications that integrate virtual reality and cognitive tasks to enhance spatial orientation skills. In this study, by using 3D acoustic interactive virtual environments fully described elsewhere [Lumbreras & Sánchez, 1998, 1999a], we attempt to assess cognitive and usability issues involved in the rendering of spatial structures in the mind of blind children through acoustic navigable virtual environments. The idea behind this is to motivate and engage blind children to explore and interact with virtual entities in challenge-action software, and to construct invisibly cognitive spatial mental representations.

The aim of this research was to implement a study to detect and analyze cognitive and usability issues involved in the use of an aural environment and the characteristics of representing navigable structures through spatial sound. This study has arisen from a challenging pilot research project [Lumbreras & Sánchez, 1998, 1999a] to a full fledged contextualized and field-testing research with eleven blind children during six months in a Chilean blind school. In this work we also describe the cognitive effects on children when interacting with this software environment in terms of the development of cognitive spatial representations as a result of interacting with a 3D acoustic environment [Lumbreras & Sánchez 1999b; Sánchez & Lumbreras 1999; Sánchez 2000 a, 2000b, 2000c].

2. METHODOLOGY

The research was implemented in a Chilean blind school. We extract an intentional sample of eleven first and second grade children coming from social and deprived suburbs. The size of the sample was established by considering some restrictions such as: school time slots and space available, structural and topological conditions of the school, PC availability, and the number of special education teachers and assistants we work with. Some of these children live in their homes and others live in the school in an internship system that allows them to go home during the weekends. The ages of the children spanned from seven to twelve years old. There were children with total blindness and some with residual vision. In addition, some of them have some degree of cognitive and learning disabilities. Diagnostic tests were applied to develop a profile of each child that included ages, type of blindness, affective background (maturity, tolerance to frustrations, irritability, emotional capacity, self-esteem), and cognitive (Wechsler verbal scale) and psychomotor level.

Besides to the 3D virtual environment designed for a pilot experience [Lumbreras & Sánchez, 1998, 1999a], we built a *kit of cognitive representation tasks* (see Fig.1). They include different levels of exposure to the interaction with the 3D acoustic environment, experiences with corporal movements in the schoolyard, model building in a sand table and with other concrete materials such as clay, styrofoam, Lego bricks, plastic images, wood cubes, metal pins, small balls, and sand paper. Six tasks were carefully planned with objectives, time, and number of pedagogical sessions and procedures. The kit also includes learning activities to represent the perceived environment, the organization of the space, and problem solving related to the interactions with the software. The usability testing of the environment was an explicit issue in the research by using both qualitative and quantitative research methods including interviews, survey methods, logging actual use, still pictures and video tape recording session analysis.

Figure 1. *Sequence of activities from interacting with the 3D virtual environment to model building.*

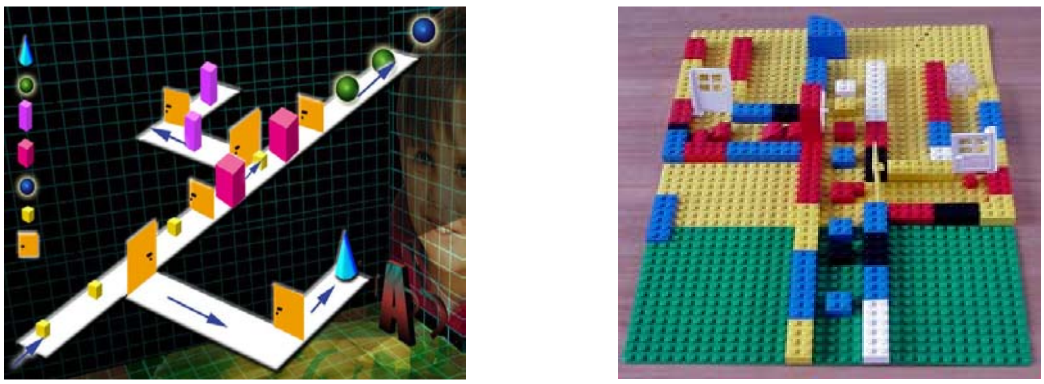


Figure 2. *Left, spatial map embedded in the 3D virtual environment to be represented by the blind children. Right, final map built by a blind girl.*

3. RESULTS

3.1. Cognitive achievement

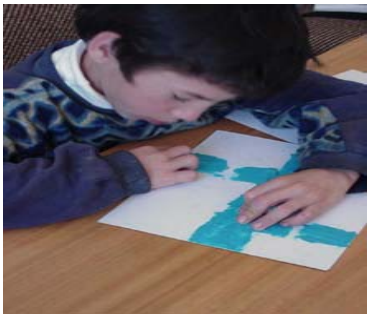
As a result of the empirical research we have arrived to the description of four clear stages in the interaction of the child with the 3D sound environment and the mental mapping of the spatial structure. The achievement of the stages was manifested by different levels of fidelity in the model design in comparison with the ideal software embedded structure (see Fig 2). The stages are:

- Entry
- Exploration
- Adaptation
- Appropriation

The *entry* was the initial interaction with the 3D virtual environment. The child learns different spatial concepts that are prerequisite to make an adequate organization of the environment. The child develops self-esteem and autonomy when interacting with the environment. The child starts representing the space mentally through the story of the software. The representations are very incomplete and unclear. The main characteristic of this level is that the child interacts with the software and is highly motivated to do this. The child's level of control of the software is low.

The *exploration* was represented by a general representation of the structure embedded in the 3D sound environment made through corporal movement in the schoolyard (see Fig 3, right). The main attention is centered on the exploration of the software. The child reaches the representation of the main corridor but no details and secondary corridors are represented with concrete materials (see Fig 3, left). The child develops spatial notions through virtually moving through a virtual space oriented by acoustic information. The child can represent the mental images of the virtual story space with concrete materials exclusively based on acoustic information, showing coherence between concrete representations and story virtual space navigated through acoustic means. The interaction with the story of the software gives confidence and autonomy to the blind child. The child's level of control of the software is medium.

Figure 3. *Left, concrete representations reach only the idea of a main corridor. Right, corporal movement made by a blind girl to make a general representation of the map embedded in the 3D sound environment.*



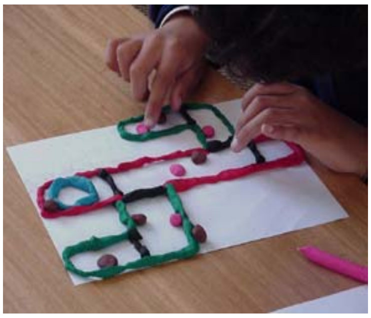


Figure 4. *Representations with clay when the child is in the adaptation stage (left) and the appropriation stage (right).*

The *adaptation* was attained by the representation of all corridors. The child understands that the structure embedded in the 3D sound environment is composed of one main corridor and two secondary corridors that are perpendicular to the main one. The child solves the conflict created by the entrance of the secondary corridors by understanding that this involves a change in the orientation of his/her movements. Even though the corridors are mapped the representation is incomplete (see Fig 4, left). The child's level of control of the software is high. The child makes more complex representations of the virtual environment.

A complete understanding and mapping of structure embedded in the 3D sound environment was reached in the *appropriation* stage. The main characteristic is the child's mastery of the environment The child understands the story of the software and use it effortlessly as an interesting tool. The child maps a main corridor with the possibility to move throughout divergent corridors passing by doors that make changes in the orientation of the movement, evidencing a full comprehension of the story virtual space (see Fig 4, right). The child's level of control of the software is complete. As a result, the child constructs a complete mental image of the 3D environment, which are represented concretely with high fidelity, quality and complexity in terms of the structure of the navigated story, elements used, and entities involved.

3.2. Levels of cognitive achievement

Not all children attained the level of appropriation. This was explained by the fact that there were other uncontrolled (but known) variables playing a significant role in the expression of our dependent variable, level of mental spatial representation. Actually, the sample was diverse. Some children have total blindness and some have residual vision. Some could use their residual vision to interact with the visual interface and localize visually the keystrokes of the keyboard. Others have just color, light/shadow vision with almost no effect in the interaction. Two children have mental disorders and spasm hemiplegy.

We identify three levels of achievements in our research: high, medium, and incomplete. *High achievement* was reached by students with residual vision and totally blind. They represent the virtual space with high fidelity, comprehend completely the spatial structure of the software and move easily through the software making flexible changes in the orientation of the movements. They make correct design mock-ups with corridors, door distribution in the space, organizing elements and entities, and showing correctly the entry and end points of the story. There is a high coherence between the concrete representations and the virtual space navigated through sound. The narratives given by the children when explaining their work include important details such as different modes to end the story depending on the corridor they enter.

Students with residual vision attained the level of *medium achievement*. They comprehend the existence of lateral and main corridors but cannot orient him/herself when passing through lateral doors. They are unable to make a complete second change in the orientation when moving through the virtual space. They do it with only one lateral corridor. The cognitive mapping of the story complexity is incomplete.

Students with cognitive and learning disabilities reached the level of *uncompleted achievement*. Because of their limited cognitive development their performance stops when we added complexity: more corridors, more elements, more entities, and more orientation movements. The children cannot related corridors, they perceived them as entirely separated from the main corridor.

3.3. Comparative results between sighted and blind children

A group of sighted children of the same ages and characteristics of our blind children sample coming from a regular primary school was exposed to the interaction with the 3D environment. Our goal was to check how they behave and represent an audio-based virtual environment and compare their representations with the ones made by blind children.

As a result, on the one hand, the sighted child (left side of figure 5) only represents the main corridor and some entities in the surrounding space (sand). The child represents the navigated environment partially, including some elements that do not exist in the software (clay). The representation is unclear, including different elements of the environment (Lego).

On the other hand, the blind child represents completely the main and additional corridors (sand). The child maps the main corridor with high fidelity, but additional corridors are incompletely represented (clay). The child represents an exact map of the environment with the main and additional corridors displayed as in the original model of the software (Lego).

Figure 5. *Comparative representations with sand, clay, and Lego between sighted (right) and blind (left) children interacting with the 3D sound virtual environment.*

4. DISCUSSION

This research revealed that it is possible to achieve the construction of mental structures rendered with 3D sound in conjunction with a set of cognitive tasks. The 3D environment by itself does not make any difference in the development of spatial structures in blind children. Cognitive tasks with pedagogical implementations are critical to get good results.

Spatial imagery can be transferred through spatialized sound delivered by 3D-software environments and appropriate methodology. However, not all the children reached the same cognitive stage in their spatial representation. The highest level we defined, the appropriation level, can be attained by most children but they need different rhythm, pace and emphasis. When the blind child has another deficit besides to his/her blindness the development of spatial structures is more complicated and requires a dedicated coaching with more time and slow pace. We believe that all blind children can reach the stage of appropriation if there is a careful design that maps the needs, background and requirements case by case.

As a result of exposing blind children to the aural environment, we believe that each child possesses both unique skills and pace referred to mental and spatial development, impacting directly on the quality of the topological features obtained in comparison to the ideal reference spatial structure embedded in the software.

An interesting testing came out when we compared sighted and blind children. The picture shows us that sighted children (and probably adults)do not rely on sound to construct their spatial structures as blind children could do. The learning through sound is very poor in sighted children. 3D environments such as the one used in this study can be used to enrich the cognitive experience of sighted children heavily based on images. Perhaps there is an entire new story in terms of using sound not just for emotions as we see mostly today, but rather to help to construct richer mental experiences.

Finally, we have confirmed the results obtained in a pilot testing. This research design was deeper, longer, more systematic, cognitive focused, and full of diverse experiences with concrete materials. We also arrive to a clearer picture of the role of 3D sound software in the construction of spatial structures. With a set of clear concepts we are moving to a direction of making more powerful and flexible the maps embedded in the software. Right now we are building a set of 3D sound editors for special education teachers and parents. We also are studying another effects of 3D sound environments such their impact on the construction of temporal cognitive structures and the development of perspectives in the mind of blind children.

5. REFERENCES

W Greenleaf, J; Dataglove, Datasuit and Virtual Reality Advanced Technology for People with Disabilities. In *Proceedings of Virtual Reality and Persons with Disabilities*, Los Angeles, March 18-21, 1992

M Hakkinen, Dewitt J., *WebSpeak:User Interface Design of an Accessible Web Browser. White Pa*per, The Productivity Works, Inc., Trenton, New Jersey, USA, 1996.

F James, Lessons from Developing audio HTML Interfaces. *Proceedings of ASSETS'98*, *The Third International ACM SIGCAPH Conference on Assistive Technologies*, April 15-17, 1998, Marina del Rey, California, USA.

M Lumbreras & Sánchez, J. 3D Aural Interactive HyperStories for Blind Children. *Proceedigns of the 2nd European Conference on Disability, Virtual Reality and Associated Technologies*, 1998, pp. 119-128.

M Lumbreras & Sánchez, J. (1999). Interactive 3D sound hyperstories for blind children. *Proceedings of ACM-CHI*, pp. 318-325.

S Morley S., Petrie H., O'Neill M, McNally P, Auditory Navigation in Hyperspace: Design and Evaluation of a Non-Visual Hypermedia System for Blind Users. In *Proceedings of ASSETS '98, the Third Annual ACM Conference on Assistive Technologies*, April 15-17, 1998, Marina del Rey, California, USA.

E Mynatt, D., Edwards W K., *The Mercator Environment: A Nonvisual Interface to the X Windows System*, Technical report, GIT-GVU-92-05, Graphics, Visualization & Usability Center, Georgia Institute of Technology, Atlanta, Georgia, USA, February 1992

D Owen., James F., Interview Pat & Mike, Live at the *6th International World Wide Web Conference*, April 9, 1997

T Raman , V, Emacspeak – Direct Speech Access, in *Proceedings of ASSETS '96, the Second Annual ACM Conference on Assistive Technologies*, Vancouver, British Columbia, Canada.

A Savidis, Stephanidis C., Korte A., Crispien K, Fellbaum K., Generic direct-manipulation of 3D-auditory environment for hierarchical navigation in non-visual interaction. In *Proceedings of ASSETS 96, the Second ACM Conference on Assistive Technologies*, April 11-12 1996, Vancouver, British Columbia, Canada.

J Sánchez (2000). Interactive worlds for blind children: computing, usability, and cognition. *Proceedings of NIMIS Workshop: Designing tomorrow´s classrooms today, collaborative technologies for early literacy*. Waldeck, Germany.

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

J Sánchez (2000). 3D Usability and cognitive impact of the interaction with 3D virtual interactive acoustic environment by blind children. *Medicine Meets Virtual Reality: 7*, Newport Beach, California, USA.

J Sánchez & Lumbreras, M. (1999). Virtual environment interaction through 3D audio for blind children. *Medicine Meets Virtual Reality: 7*, San Francisco, USA.

S Weghorst., Inclusive Computing in Medicine, *Proceedings of Medicine Meets Virtual Reality*, SanDiego, June 4-7, 1992

L Whalley, *Ethical Issues in the Application of Virtual Reality to the Treatment of Mental Disorders, in Virtual Reality Systems*, Eds R A Earnshaw, M Gigante and H Jones, Academic Press, 1993, pp 273-287

M Zajicek, Powell C., Reeves C., A Web Navigation Tool for the Blind, in *Proceedings of ASSETS '98, the Third Annual ACM Conference on Assistive Technologies*, April 15-17, 1998, Marina del Rey, California, USA.