Assisting the mobilization through subway networks by users with visual disabilities

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ABSTRACT

We introduce AudioMetro, application software for blind users that represents a subway system in a desktop computer to assist mobilization and orientation in a subway network. A user can organize and prepare a travel by using the software before riding the subway. Conclusions of the usability study revealed the critical importance of using key interface elements, such as audio-based hierarchy menu, travel simulation, and information about the subway network, stations and their surroundings. Cognitive study results show an advance in the development of mobility skills needed for using the subway system which represent a contribution for a much more integral development of blind users and one-step towards social integration and inclusion.

1. INTRODUCTION

Biological beings have the natural need of pursuing autonomy and effective ways of mobilizing. Human beings depend on the particular qualities of each person in order to mobilize and orient in the surrounding environment. Users with visual disabilities have limited capacity to learn autonomously and effectively diverse ways of mobilizing. Actually the ways they use to mobilize are different to other people mainly because sighted persons understand the world through the vision. People with visual disabilities have to use orientation and mobility techniques to learn to recognize the environment, the spatial relationships between objects and themselves, and to recognize tactile, auditory, and olfactory stimuli. Once blind people acquire the ability to use orientation and mobility techniques they increase their capacity to mobilize effectively.

Through discrimination and localization of audio sources the sense of hearing convey information to people with visual disabilities becoming one of the most important senses to perceive the surrounding world. Along with this, the sense of hearing favors to know reference points, to perceive description of some places, to develop the abstraction and concentration capacity, and to create mental schemas of diverse environments (Sánchez and Sáenz, 2005a).

In order to navigate through real environments blind users take higher risks than sighted users because the use of the cane cannot help them identify all objects into the space. For this reason, it is necessary to provide cues to users with visual disabilities to get more reliable information. Providing too much information to users in an unnecessary way may have a counter effect and thus confusing users (Koruda et al, 2002; Lahav and Mioduser, 2004).

The use of sound to support graphical interfaces is a fundamental requirement in diverse tools for sighted users. Technology advancement allows us to obtain better results in sound representations of different environments, such as the greater and better immersion of users into virtual environments. For example, entertainment and communication requirements demand both the use of better quality sounds. Blind users need audio-based interfaces because they use the sense of hearing as the chief source of awareness and knowledge for learning purposes (Sánchez 2006a). Sound conveys information to identify points of reference, receive complete descriptions of places, and create mental models of the physical environment.

Blind navigation is based mainly on a perimeter exploration strategy. They walk along the closest outline in order to reach a certain targeting point. However, diverse attempts exist to achieve a more straight movement from one point to another, or between objects (Lahav and Mioduser, 2004). Independent and safe

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navigation skills are obtained by a combination of motor, sensorial, and cognitive skills. Several studies have been made to promote the teaching and support the orientation and mobility of visually impaired people through virtual environments based on stereo or quadraphonic sound. Some of these studies present significant results on how visually impaired users are capable of mentally represent the navigated virtual environment as the first step in order to achieve a better movement (Lahav and Mioduser, 2004; Sánchez and Sáenz, 2005a; Westin 2004). Also, these studies show the importance of the utilization of haptic interfaces combined with sound to achieve the expected navigation in the virtual environment. (Lahav and Mioduser, 2004; Sánchez and Sáenz, 2005a; Westin 2004; Kapić 2003).

Visually impaired people need to describe their navigation routes with much more detail than sighted users. Specifically, blind people use objects like walls and railings to determine their direction, with special sounds and smells, such as water sources or bakeries. Relevant information can be obtained by the floor configuration and the changes present in it (Kapić 2003).

Interacting with different objects in real world distributed throughout the environment requires knowing and mentally representing the places walked or to be walked. Several studies have focused on the virtual representation of images, graphs, and textures, through haptic interfaces (Brewster 2002; Ramloll et al, 2001; Sjöström 2001). All these studies obtained important gains regarding the identification of the represented objects. However, most of them aimed at the need of always requiring an acoustic support of the object's representation, either as an introduction or to make clear certain aspects of it. The fact that the haptic sense is slower and less efficient than the vision channel has to be considered. Actually, that is why it is so important to support and complement it by means of the hearing sense.

Audio-based interfaces may have a speech or a non-speech audio. Non-speech audio allows the improvement of interaction and the presentation of information in different devices. This helps blind users to be concentrated on navigating the physical environment by being aware that information is perceived by their ears (Sánchez 2006a). Users with visual disabilities evidence many mobility problems. One of them is the particular case of mobilizing through the subway network. In Santiago city, the subway is a public transportation on way of expansion with better comfort and minor travel duration time than other type of public transportation, then it is very important that blind users can use these benefits more fully.

2. RESEARCH PROBLEM

The lack of knowledge about some aspects of the subway network is the principal mobilization and orientation difficulty for subway users. To obtain a whole knowledge of the subway network a person has to pass through three levels of knowledge: (A) Conceptual, to know subway network concepts such as subway lines, stations, and platforms. This level refers mainly to basic and generic concepts in a subway network in any city of the world. Once the concepts are learned, the user continues to the next level; (B) Knowledge, to know specific information of a particular subway network, such as the subway station name, surroundings, location, and lines names that identify a route or path and what type of station is it (transfer and local), and (C) Articulation, to utilize different concepts and knowledge learned by the user for an efficient use of the subway network. It includes mainly the planning, estimation, cost, and spatial orientation of the travel. When the three levels are accomplished, the user must also be able to master the orientation into the space to mobilize independently. When users lose spatial orientation, their autonomy is decreased.

Users with or without impairments that currently utilize the subway network present different spatial and knowledge problems. Spatial problems are easier to solve for sighted users because they can visually order and classify the physical environment by taking advantage of the visual memory thanks to the use of visual references such as stores, colours, and signals of the subway network. Users with visual disabilities orient themselves through sound interpreting the surrounding world and learning to localize sounds that serve as signals for orienting and moving with greater autonomy.

In the real world sounds are not necessarily fixed, nevertheless visual references are fixed. For this reason, it is necessary to have better tools that support to solve orientation problems. Blind people can face knowledge problems because the vision cannot be used as an imitation channel to acquire knowledge. The affordance of elements is a very important property detected by the vision.

3. PURPOSE OF THE STUDY

The main purpose of this study was to create, improve, and evaluate audio-based software to stimulate and/or develop tempo-spatial sensory and cognitive skills for mobilization and orientation in people with visual disabilities. These skills allow users to have safe and independent movements facilitating their autonomy when using different transportation media such as the subway.

In this study we also consider the implementation of a usability study during the design and development of the software. In order to know the cognitive impact of the use of the software, learners solved cognitive tasks specially designed and created for this purpose.

4. MODEL

AudioMetro is based on a model that incorporates diverse functionalities in order to evaluate and identify a correct feedback, and establish differences in the development of educational software for blind or sighted people (Sánchez and Baloian, 2005b). AudioMetro contains a metaphor that represents a simulation of a subway travel through a wagon. Travels are developed in a logical way because the software does not consider spatial representations of virtual spaces. The metaphor considers notions of consecutive stations, transfer stations, and terminal stations.

In the particular case of the subway network in Santiago, Chile, the subway wagon travels between two stations from one extreme to the other through a specific line that covers both directions. The stations have two platforms, one on each side of the rail. In these platforms, passengers wait for subway wagons at specific directions. Transfer stations consist of different levels where each level has a specific line and each line crosses the other, to allow associating each line to a level.

In each AudioMetro session before every simulation, the user must previously choose the initial and final station of the travel. In order to know at any moment the game state and to allow all necessary functionalities to execute in a virtual travel, AudioMetro utilizes techniques of object-oriented programming to model the stations, lines, network lines, and travels. This model calculates the optimal route from the current station to the final station in order to both, user and software, take strategic decisions during simulations. AudioMetro shows information to the user through an interactive menu hierarchy to transfer information in the three levels of knowledge. This menu hierarchy is presented through audio and can be complemented with the contextual help for interacting with the software. User actions are saved in a session log file for later analysis in order to evaluate the learning of the user by using the software.

The logic model of AudioMetro provides the possibility of representing any subway system, identifying the composing stations and lines by specifying boarding and terminal stations.

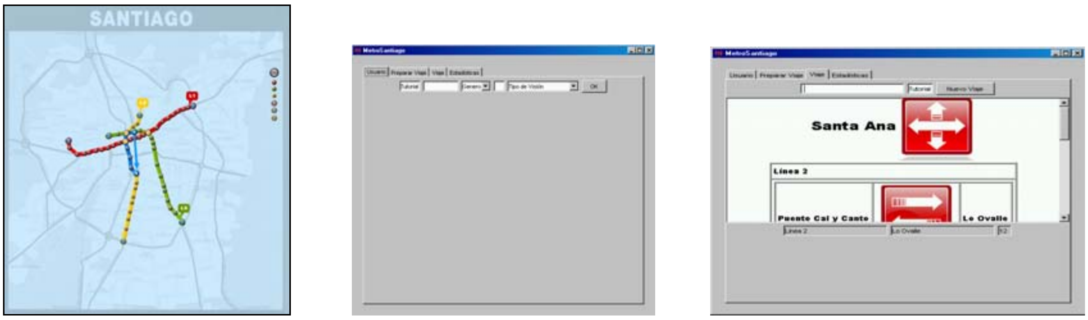
5. SOFTWARE DESCRIPTION

A work session with the software has two stages. The first stage consists in preparing a travel with a user defining starting and ending stations. In the second stage, the user virtually moves through the subway network, starting at the initial station.

At the beginning, the software does a random choosing of values for each of three main variables in a travel through the subway network. The three variables are: Subway line, travel platform (direction), and starting station (transfer or local).

Figure 1(A) shows a travel from the *Irarrázaval* station (line 5) to *Franklin* station (line 2) of the Santiago's subway network. The symbols used in figure 1 for the subway network are: Line 1 stations with red color, Line 2 stations with orange color, Line 5 stations with green color, transfer stations with yellow color, the way from the starting station to the ending station with light blue color, and the light blue arrow represents the direct way from the starting to the ending station.

AudioMetro was developed with Java using the Swing library. The software code is divided into four main packages: (A) *Metro*, defines the objects that represent a subway network; (B) *DomArea*, groups all classes related to XML documents management; (C) *Navegacion*, represents the navigation through menu hierarchies, feedback, sounds coordination, and others functionalities of the software, and (D) *Sonido*, groups all methods related to the use of sound.



(a) *(b)* *(c)*

Figure 1. *(a) Travel from Irarrázaval station to Franklin station. (b) AudioMetro user interface (c) AudioMetro´s trip interface.*

5.1 User-Software Interaction

The graphical objects of AudioMetro interface are organized into three panels. When starting the software the user must input personal information in the first panel. This information is saved into the session registry for a later analysis. Then, in the second panel, the user chooses both starting and ending stations. At last, in the third panel, the user explores the subway network and associated contents to the three levels of knowledge. The main graphical objects are text boxes, combo boxes and buttons, using the keyboard as input. The software provides the necessary audio feedback for users with visual disabilities in order to use these visual components. In the case of navigation using menu hierarchies, at the third panel, the user interacts exclusively with a text box that captures keyboard events without changing the focus between different graphic components (see Figure 1(B),(C)).

6. USABILITY EVALUATION

6.1 Participants

The sample consisted of 7 Chilean users with visual disabilities, 5 males and 2 females, ages 15 to 32, which attend the rehabilitation level of "Santa Lucía" School for the Blind in Santiago, Chile. Three of them have low vision and four of them with total blindness. All of them have acquired blindness. Two special education teachers and one usability expert also participated in the study.

6.2 Methodology

Usability testing with end-users had five stages: 1. **Introduction**. The user received explanations of the purpose of testing and how to use the keyboard to interact with the application. Teachers mediated to help users to orient when using the keyboard. 2. **Software interaction**. Users had to use the software. Each participant performed between two and three travels and according to their needs, teachers could assist them for better orientation. At the same time we wrote anecdotic records with key data and observations of the user's interaction with the software (see Figure 2). 3. **Application of usability questionnaires**. The user answered questions concerned with software interaction asked by special education teachers. 4. **Reports of sessions**. Each session was photographed to register the child's behavior during interaction. All data was registered to get comments and suggestions to improve the software navigation. 5. **Design and redesign**. According to the comments and observations, the software was redesigned and some new functions were designed.

Figure 2. *Users interacting with AudioMetro.*

6.3 Instruments

We used three evaluation instruments**: 1. End-user questionnarie** 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 of 1 to 10 points. It also contains 5 open questions. This questionnaire was read by teacher and answered by the user. 2. **Anecdotic record** was used to record information obtained through observation when the user interacted with software. 3. **Automatic record** was data automatically stored in XML format and registered the keystrokes and stations used, and the duration time of each action.

6.4 Procedure

The usability testing was implemented in 5 sessions between March and June of the year 2005, following three stages. In the first stage, users tested early prototypes of the software during interaction. The objective was to have an initial feedback about the sounds of the software in order to have early in the implementation phase, the information necessary to guide the redesign of the interface. The second stage was implemented after we processed the data from the first testing and redesigned and improved the prototype. Therefore at this stage we had a more advanced prototype. The results of the second testing allowed to guide the final design of the interface. Finally, the third stage was applied to the final results of software usability. The aspects evaluated were: motivation, importance, relevance of use, and the sound of the software.

6.5 Results

Figure 3 shows the results of the final usability test. The statements used to evaluate the motivation of the software were: “I like AudioMetro”, “The software is pleasant”, “The software is challenging”, “AudioMetro makes me to be active”, “I would like to play again the software” and, “AudioMetro is motivating”. For evaluating the importance of the software the statements were: “I recommend you this software to other people”, “I learned with AudioMetro”, and “The software allowed me to know new things”. For the relevance of use we considered the following statements: “I felt controlling AudioMetro”, “The software is easy to use”, and “AudioMetro adapts to my pace”. For sound evaluation, the sentences were: “I like the sounds of the software”, “The sounds are clearly identified”, and “The sounds of AudioMetro convey information”.

Users with residual vision showed a greater motivation and acceptance of the software from the beginning of testing to the end. Blind users did not show the same motivation, their scores were not significantly different in comparison to users with residual vision, reaching in the last test scores of 8.8 out of 10 points. One of the most relevant motivations for users was the assigned value to the tool to support the autonomous planning of routes and travels. These actions are currently made with the help of other person, especially in the beginning of independent displacements. All users assigned high importance to the help of tools such as AudioMetro. This is reflected on the statement “The sounds of AudioMetro convey information”, which always got the highest acceptance score. The easiness of use of the software is practically the same for both type of users, reflecting a good design of the tool. To users with residual vision, sound was improved during the implementation phase reaching the highest acceptance rate in the final testing. For blind users the final evaluation reached a score of 8.8 out of 10 points, showing a high acceptance of the sounds used in the software. The highest score was obtained in the statement “The sounds of AudioMetro convey information” (see Figure 3).

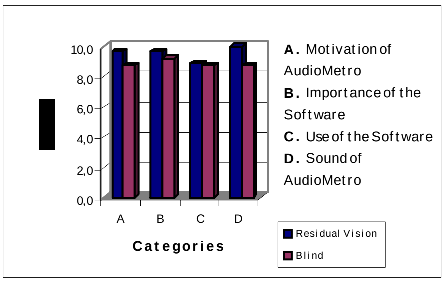


Figure 3. *Usability testing results.*

7. COGNITIVE EVALUATION

6.1 Participants

The study was designed with a sample of 10 users from the rehabilitation level of the School for the Blind “Santa Lucía” from Santiago, Chile, ages ranging from 20 to 32 years old. This group was divided into two equal subgroups: A control subgroup, which did not have any interaction with the software, and an experimental group. The subgroups were created so that the age and the number of people with residual vision were balanced.

6.2 Concrete Materials

To observe the mental image users created of the geographic distribution of the Santiago's subway we worked with two types of materials: 1. Cardboard base and LEGO© bricks. This allowed the sample to represent details of stations of the Santiago Subway network by building them with the different bricks, which varied according to whether it was a local or a transfer station; and 2. Cardboard base with stakes. It allowed users to represent the distribution of the Santiago subway network lines, by joining different stakes through rubber bands.

6.3 Methodology

The activities were divided into four steps: 1. **Pre-Test Application.** Users had to make a real travel route in the Santiago subway to evaluate and register the users' actions and their control in an independent journey. *2.* **Software or Class Interaction.** The experimental group knew and interacted with AudioMetro software by means of significant activities to assimilate, generalize, and take to reality their learning. The control group obtained similar information that is embedded in the software but through a regular lecture session in a classroom setting. 3. **Cognitive Tasks.** There were four cognitive tasks solved by users to observe the development of the following skills: to know and apply tempo-spatial concepts, to make an efficient use of senso-perceptive organs, and to select and apply concepts provided by the software for independent movements through the Santiago subway network. 4. **Post-test Application.** In the same way as in the pre-test, users made a real travel route in the Santiago subway to evaluate and register the learners' actions and control in an independent journey.

6.4 Instruments

There were three instruments for cognitive evaluation: 1. **Pre and Post-test**, Specific Route Displacement test (SRD), a particular route was elaborated for testing the participants. We evaluated their performance using an appreciation scale. In order to elaborate both the route and the evaluation range, we considered the use of certain orientation and mobility skills, the same route for everyone, departure hour, number of transfers, number of stations, visual degree, and knowledge with the real displacement through the Santiago subway. 2. **Cognitive task evaluation guidelines**, estimation evaluation guidelines were created for each cognitive task to observe and register orientation and mobility skills to be developed, stimulated or enhanced by solving the tasks and participating in the activities. 3. **Registry Graphs**, the software registered and graphed actions taken by learners during their interaction.

6.5 Procedure

The cognitive testing was carried out during four months. As the stages of the applied methodology were fulfilled, and depending on the subgroup to which each user belonged, the cognitive testing was implemented in different places. For both subgroups, pre-test and the post-test were applied on site. Experimental group users interacted with the software in the computer room whereas the control group users attended classes in a conventional classroom. All users in a classroom performed tasks with concrete materials. In order to avoid distortions in the results of the cognitive testing, only the experimental group interacted with AudioMetro and the entire group used the same version of the software.

6.6 Results

Results are divided in three areas or domains: Behaviors, skills, and competences. The first one refers to the specific handling of techniques with the white cane, which correspond to the orientation and mobility program applied to environments of medium complexity. The skill area includes aspects needed to make independent movements. Finally, the competence domain shows the development level that each user performed in each one of the described skills. Figure 4 displays comparative results of pre-test and post-test.

The results show that the greater improvement took place in the competence domain, with an increase of a 20% out of the total, followed by the skills domain, with a 16%, and the behavior domain with just a 6%. Nevertheless all areas obtained improvements after using the software and cognitive tasks. The variation in the behavior domain of the sample is the one that obtained the slighter difference in the scores. Learners required knowing certain concepts related to this transportation media and knowing how to use them, such as: climbing and descending stairs to reach the stations, navigating in their interiors identifying ticket offices, ticket gates, platforms, texture recognition, and remaining in a safe place when getting on and off the wagons. These behaviors did not show great enhancements since they are prerequisite of a relatively independent movement. Nevertheless, improvements in learning the stations, sequential order and its relation to the corresponding line, could be observed. The actions corresponding to behaviors require certain skills such as spatial orientation, observation of the environment, and acoustic information classification. These aspects were remarkably enhanced after using the software and applying the cognitive tasks, since the subjects could make a mental model of the space distribution closer to reality and were able to move with more security and autonomy.

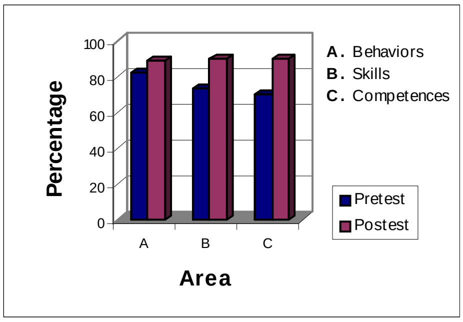


Figure 4. *Cognitive test results, pre-test and post-test comparison.*

During cognitive tasks each person had the opportunity to represent with concrete material the mental image of the subway, which helped the mediation of facilitators. This leaded us to modify the initial designs based on the experience, usefulness, and landmarks, to establish new concepts of orientation (north, south, east, west, northeast, northwest, southeast, etc.), that in spite of knowing them, they did not know their corresponding location in the space when applying these concepts.

User training by using AudioMetro software and supported by cognitive tasks, showed to be an important tool to encourage independent, safe, and significantly more integral navigation. This is verified in the comparative analysis of the results obtained by different users in the pre-test and post-test evaluations. This is also highlighted in the contrast between the time required by different users to follow a route assigned in the pre-test phase, and the time needed to take the same route after using the software, in the post-test phase. In all cases the time decreased in considerably way, almost in 20% average.

From the AudioMetro research, some questions emerged about the impact that a similar mobile-device oriented application would have on mobilization. For this reason, we later developed mBN (Mobile Blind Navigation), a pocketPC version of AudioMetro (Sánchez and Sáenz, 2006b). We believed that this mobile software does not have to be just a portable AudioMetro version. Rather, we had to redefine and study both the interface and the information displayed. We have to define the functionality to be exploited in the mobile version, as well as the cognitive impact. Although this new software aims to the same users, it is subtly different since it is oriented to a different context, but complements the scope of AudioMetro. The essential of the mobile version is that it can help to solve unexpected problems when mobilizing through the subway, which could hardly be anticipated in the PC version.

8. DISCUSSION

At a conceptual level, AudioMetro glossary allowed users to familiarize themselves with basic concepts of subway as a transportation source. The most important concepts (transfer stations, platforms, end stations, consecutive stations, and lines) were reinforced by the affordance created with travel simulations. When blind users interacted with the software, they were able to understand the subway network system as a means of transportation in the three levels of knowledge aforementioned without the need of using the subway with a guide companion. These trip simulations also supported the learning of specific knowledge of the subway network system of Santiago, by means of exploring the subway network names and characteristics of the stations, lines, surroundings, etc. Since these are simulations, they implicitly motivate the construction of virtual trips through the subway network.

AudioMetro was more useful for blind users in a pre-cane stage. We must remember that these users still did not possess the necessary autonomy to move throughout the subway network by themselves. Teachers valued AudioMetro as a support tool to their classes as it allowed them to apply, reinforce, and complement their mobility and orientation lessons. The usability test showed the importance of embedding in the software a glossary of concepts and surrounding information about stations. The anecdotic record permitted us to identify critical areas of the software, to debug feedback messages (voice and sounds), and to improve the software contents.

The variation in the mastering of behaviors by the user was generally the one that obtained the least indicators, which is explained by the fact that learners necessarily needed to know previously certain concepts related to this type of transportation and know how to use them. Among these concepts, there are activities such as going up and down stairs in order to have access to the stations, the ability to move inside the stations and identify ticket offices, turnstiles, and platforms, recognition of textures, and staying in a safe place when getting in and out the subway wagon. These behaviors did not show critical changes because they are pre-requisites for relatively independent movement. However, there was an improvement in the learning of the names of stations, their sequence, and their relation to a correspondent line. The execution of actions corresponding to the behaviors needs to master certain abilities such as spatial orientation, observation of the surroundings, and classification of auditory information. These skills were notable increased after using the software and performing cognitive tasks, because users were able to build a mental idea of the spatial distribution closer to reality and were able to move in a secure and autonomous way.

Finally, the most relevant results were observed in the domain of competencies of users that is explained by the information given by the software and its immediate transfer to reality that favored the rise of sensorial-perception information processing, problem solving without the need of a sighted guide, and a much more independent movement in and out of the subway network. This, without a doubt, represents a big contribution for a more integral development of blind users and one-step towards real social integration.

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