Multimodal Interfaces for Improving the Intellect of the Blind

Jaime Sánchez
Universidad de Chile
Chile
jsanchez@dcc.uchile.cl

Ticianne Darín
Universidade Federal do Ceará
Brasil
ticianne@virtual.ufc.br

Rossana Andrade
Universidade Federal do Ceará
Brasil
rossana@ufc.br

Windson Viana
Universidade Federal do Ceará
Brasil
windson@great.ufc.br

Jérôme Gensel
University of Grenoble Les Alpes
Francia
jerome.gensel@imag.fr

ABSTRACT

The development and enhancement of cognitive skills in people who are blind has been highly demanded in the literature. Digital technology targeting this need is widely desired and demanded. There is also a need beyond the technology development. Usability and cognitive impact evaluation studies of technology for people with visual disability are claimed and required for better understanding and adequate and pertinent use. Our research is targeting this need and demand. In this paper, we present the first results of KIGB international project. We focus on Knowing and Interacting while Gaming for the Blind (KIGB). The most global purpose of the KIGB project is to contribute from the computer science side to better develop the intellect of people who are blind, to help them to be more autonomous and independent in their life and their relations with people and surroundings, and thus helping them to be more integrated and included in our society and culture.

General Terms

Design, Human Factors.

Keyword

Orientation and Mobility, Users who are blind, Serious games.

1. INTRODUCTION

For people who are blind (in the context of this research, people who are blind or learners who are blind are meant to imply people who are legally blind, which is to say completely blind or with significant loss of vision), most of the time the absence of vision makes the performance of tasks that require spatial representation quite complex and difficult (Kolb & Whishaw, 2006). In this sense some initiatives of this research group have targeted to approach and solve the problem raised with the insufficient accessibility in different contexts.

This results in difficulties when moving about and determining other people's positions in physical space (Hub et al., 2004), in being aware of the direction in which one is facing when relocating, and in gathering information on surrounding objects in order to decide where to go and how to reach a desired destination.

For this reason when people who are blind want to move about by themselves, they tend to prefer to move in a perimetric fashion, and not cut through the center of places and rooms. This is because it is easier for them follow the lines of a building with their hands or using a mobility cane (Lahav & Mioduser, 2001). This makes for choosing a certain route based on safety considerations, rather than on the efficiency of the route, opting for the distances and/or directions that are needed to move through spaces where there are not many obstacles and thus less risk of tripping or bumping into anything (Pressl & Wieser, 2006). This is where the construction of mental maps emerges as an option in order to form an internal representation of space, as an effective tool for the planning and execution of actions that allow for higher levels of mobility, movement and navigation through a certain physical space (Carreiras & Codina, 2003).

One way of understanding the spatial representation that people with visual impairments make of the physical surroundings that they navigate is through the creation of mental maps (Sanabria, 2007). This is because such maps are related to the coding and recovery of the stimuli within a certain environment (Blades et al., 2002). A series of processes, transformations and mental organization choices are involved in the creation of mental maps, in which it is feasible for the subject to store, recover and decode information on the location and specific attributes of a regularly transited physical spaces in order to achieve higher levels of mobility (Sanabria, 2007). For this reason, the construction of mental maps can occur through direct contact with the environment, or through aids such as descriptive or verbal maps, or the use of technology (Carreiras & Codina, 2003).

In this context, the main goal of the Knowing and Interacting while Gaming for the Blind project (KIGB) is to design, implement and evaluate multimodal videogames for enhancing cognition in people with visual disabilities. The focal point is (mobile) gaming for further developing cognitive processes such as mental models, cognitive spatial structures, and navigation skills in people with visual disabilities. A game evaluation, usability evaluation, and educational software evaluation are key in the context of this project. By implementing KIGB we aim to produce serious games that are usable, understandable and effective. In this paper, we present some of the results of KIGB Project.

2. RELATED WORK

2.1 Mobility and Orientation

The biggest problems that people who are blind have when navigating is determining their position in the surrounding area, knowing in which direction they are facing or that their body is moving, and the loss of information on important objects in the environment, such as how far away they are from such objects (Hub et al., 2004). In this context, any information on the characteristics of objects in the surrounding area could prove to be very significant and relevant for people who are blind.

In a regular environment, whether indoor or outdoor, a blind user can perform conventional navigation, as the surroundings and the general context are familiar. In an unfamiliar environment, this experience is usually far more complex and completely dynamic (Kulkuyin et al., 2004). Examples of this are navigating an airport, a hotel or a corporate building, all of which are unfamiliar environments in which any kind of autonomous aid would be ideal. The most traditional and commonly utilized forms of aid are guide dogs and mobility canes. Such tools are limited in the context of complex environments, as they cannot provide information regarding the distribution of the space or topological aspects, and as a result are not capable of guiding the user to choose the best possible route to a given destination (Sánchez & Elías, 2007). In particular, guide dogs and the cane present problems when the user faces stairs, steps, elevators, revolving doors or automatic doors, all of which are elements that can be harmful and dangerous for the user during navigation.

In order to avoid such risks and move more safely, blind people prefer to navigate in a perimetric fashion rather than through the center of a room. It is easier for them to follow a route by touching the walls, as this allows them to locate doors and obtain a route that would not require moving through other spaces (Lahav & Mioduser, 2004). This way of exploring the environment can lead users to finding inefficient solutions to their problems (Kulyukin et al., 2004). Knowing the size of a room is not easy for a blind person, although such information would be quite useful in order to be able to move about through such a space. In general, what legally blind users do in order to determine the size of a room is to detect the level of the eco created within it by either speaking or clapping (Focus Group, 2005). When a legally blind user has more time to navigate and dedicates time to getting to know and moving through an enclosed space, he or she is willing to listen to descriptions and identify details that would allow the user to achieve a higher degree of precision when navigating (Lahav & Mioduser, 2004).

In selecting a route, people do not necessarily choose the shortest route, as other aspects such as safety (which is the most important in most cases) also influence these decisions. This is the same for people who are blind, as it is not always preferable to choose the most efficient route, but rather the safest. For these users, in addition to safety, other factors such as fewer obstacles and lower risk of tripping or bumping into things are also considered, in which the cane may not be able to detect certain objects (Pressl & Wieser, 2005). This is complicated, given the fact that the problems that blind users face in a mobile context are varied and dynamic, making it difficult to reach decisions on the best routes to take, which leads to diminished autonomy when moving about (Kulyukin et al., 2004).

It is for all of these reasons that having a mental map of a space to be navigated is essential in order to achieve an efficient development of orientation skills and mobility techniques. As it is well known, most of the information required for such a mental representation is collected through visual channels (Lahav & Mioduser, 2008; Sánchez & Zúñiga, 2006). For blind users it is impossible to access such information as quickly as a sighted person can through the use of vision, and thus blind users are obliged to utilize other sensory channels (audio and haptic) in order to compensate for their lack of vision, in addition to other methods of exploration (Lahav & Mioduser, 2008). Lahav and Mioduser (2004, 2008, 2008a) research the relationship between mental representations of space produced by blind users through the use of virtual environments with audio and haptic interfaces, and the navigation of these users in the real world. To achieve this, the authors utilize a virtual environment for training that is similar to a real-world environment that the blind user regularly navigates, in order to improve navigation in the real-world environment.

Among the existing literature, there are several studies that have dealt with the adoption of reference models in order to resolve navigation-related problems, both through training activities and direct assistance (Seki & Sato, 2011; Lahav & Mioduser, 2008). The training exercises include a virtual representation of the real world environment, for which it is sought to improve navigation, and the blind user is able to interact with this virtual world in order to simulate real-life navigation. If this kind of methodology is mixed with applications such as videogames, it is possible to stimulate the use of navigation skills among blind users. Among such applications are AudioDoom (Sánchez & Zúñiga, 2006) and AbES (Sánchez et al., 2009a; Sánchez et al., 2010), which are focused on the mental construction of both real-world and virtual environments, forming a virtual route in which a user can travel through the spaces by using the computer keyboard and audio feedback.

2.2 Serious Games for people who are blind

Games have historically been part of daily life for school-aged children and young people. With progress in ICTs, electronic games have emerged with great force, making up part of the daily activities of children and young people today (Mayo, 2007). In Chile, for example, 50% of students use the Internet to play games (Adimark, 2006), while in the USA young people between 8 and 18 years of age play an average of 49 minutes of videogames per day, almost the same amount of time dedicated to doing homework (50 minutes) and more than what they spend reading (43 minutes) (Rideout et al., 2005). On the other hand, another study shows that playing is the second most frequent activity that students take part in on the Internet, after doing homework (59% and 81%, respectively), and that even children between 6 and 11 years of age utilize the Internet more for playing (76.2%) than for school work (75.7%) (El Mercurio/Opina, 2008).

A study in Santiago de Chile (ADIMARK & UNIACC, 2011) showed that men and women alike have fun with video games, hovering around 50%, with very little difference depending on age. 59% of individuals prefer to play in the evenings and 54% do so on weekdays, compared with 46% who practice this activity on Saturdays and Sundays. The 40% of the players belong to low socioeconomic. Among the reasons to play, 31% believe it is exciting, 15% believe it is a sport and 9% think through them can develop their mental ability as well as their skill. Among the

positive aspects of video games, highlights the fun with 50%, 29% think that there is nothing positive in them, and 10% rate their qualities with mental ability, education and sharing with others. On the negative side, there are factors such as addiction with 29%, the loss of time with 18%, violence with 17% and 7% sedentary lifestyle.

Other studies, such as Liu et al. (2007), pose the question: what makes players want to play increasingly more often? The answer that was found is that players like the challenge posed by videogames, requiring insistence in order to fulfill the game's objectives. In particular, young people like videogames in which they participate together with other users, and in which the characteristics of all of the players begin to reach similar levels, which produces a more interesting competitive atmosphere.

In recent decades videogames have forcefully entered people's lives, becoming increasingly accessible and part of everyday, habitual activities (Lutz, 2006). Currently, there is a wide variety of research that point to the importance of the use of videogames for learning (Squire, 2003; Steinkuehler, 2004). In particular, research on the impact of videogames on the development of problem solving skills has established that through the use of such games learners improve their strategies for dealing with and resolving problems (Yu et al., 2002; Klopfer & Yoon, 2005; Sánchez et al., 2007, 2009). Videogames also allow for the development of other specific skills, such as mathematics content (Sánchez & Flores, 2005; Sánchez et al., 2007, 2009). Some studies propose that games can promote high order learning (Steinkeuhler, 2008), as well as increase dialogue between students (McDonald & Hannafin, 2003). Other studies describe aspects of videogames that are significant for the development of social (Pellegrini et al., 2004) and cultural (Cipolla-Ficarra, 2007) skills in students. Games also generate a high level of motivation and commitment among students, both of which are fundamental for helping to improve their commitments to learning activities (Sánchez et al., 2008, 2007b; Klopfer & Yoon, 2005).

In the work of Kelly et al. (2007) an educational or serious game is presented for science learning, and three key aspects in the design process are pointed out. These aspects are: (A) Game design, in which the strategy and contents of the game must be made clear; (B) integration of the videogame, implying the way of presenting the content and the interaction with the various elements of the videogame; (C) providing multiple scales for creating the simulations and visualizations of the processes present in the videogame. The authors emphasize that the joint work between videogame designers and content reviewers is not easily achieved, but is essential for an educational videogame to be successful. Soute & Markopoulos (2007) developed a videogame, named Camelot, which utilizes the pervasive computing paradigm (the tendency to use computer devices that are inter-connected and portable), in which players collaboratively construct a castle. This kind of game allows children to interact freely, without necessarily realizing that they are using technology. This generates a higher level of social interaction spontaneously. The possibility of using educational videogames opens up tremendous possibilities for working with learners, in which one of the closest ways in which young people are associated with technology is used to develop skills in such a way that, through other means, would be far less motivating (Go & Lee, 2007).

In this way, several authors consider videogames to be a tool that allows teachers to integrate the learning styles of 21st century learners (McMichael, 2007; Proserpio & Viola, 2007). However, it is not enough to simply create educational videogames; rather, it is necessary to adopt a new (or ad-hoc) pedagogical methodology based on the way of learning in school (Kickmeiser-Rust et al., 2007; Squire, 2005). Squire (2005) proposes five essential aspects in this regard: 1. Focus content on more transversal and less specific aspects, in such a way that the students study and understand causes and effects, and the reasons for things. 2. Consider the heterogeneity of the course group regarding interests, abilities and learning skills. 3. Accommodate schedules so that a student who is interested in a certain issue is able to deepen his or knowledge of that issue. Time slots outside of class time can be used for students to study specific issues. 4. Diversify the means of transmitting knowledge, not limiting oneself to the classic media used by teachers (books, movies or presentations). For example, utilizing videogames allows learners to work outside regular class time, as they are motivated and take on a different perspective regarding the content. Finally, 5. Orient evaluations as an opportunity to support learning.

There are several different experiences with the design and use of videogames for stimulating the development of various abilities in people with visual impairment (Yuan, 2009; Yuan & Folmer, 2008). Some studies present the use of videogames for mathematics learning by blind students. These videogames allow students to learn and practice mathematical operations and processes during daily activities through the use of audio interfaces (Díaz et al., 2004; Sánchez & Flores, 2005; Sánchez, 2007). Other studies utilize videogames for the development of problem solving skills, such as in the case of AudioLink (Sánchez & Elias, 2007). This audio-based game for blind children allows for the learning of science concepts and scientific thinking in an entertaining environment. In the same way, AudioVida and AudioChile (Sánchez et al. 2009) are games oriented towards developing problem solving skills and orientation and mobility skills in blind children. In the case of AudioChile (Sánchez & Sáenz, 2005), the software allows players to navigate virtual environments based on cities and other places in Chile through the use of 3D sound. MovaWii (Sánchez et al., 2013c) and Audiopolis (Sánchez et al., 2013b, 2013d) are videogames based on haptics to develop and enhance orientation and mobility skills in learners who are blind.

Other studies propose that games are able to promote high order learning (Nikolakis et al., 2005; Rashid et al., 2006), as well as to increase dialogue between students (McDonald & Hannafin, 2003; Steinkuehler, 2008). Other studies describe the significant aspects that videogames provide for the development of cultural (Sánchez et al., 2009) and social (Pellegrini et al., 2004) skills in students. Games also produce commitment and motivation, for which reason they are an effective tool for the generation of learning in students (Klopfer & Yoon, 2005; Sánchez et al., 2007; Sánchez et al., 2008).

Terraformers (Westin, 2004) is a videogame for players with low-level vision, using 3D graphics and spatialized sound. This game was developed in order to test the use of such tools, and to replicate the experience in other areas, such as virtual reality, e-commerce and distance learning. Sepchat et al. (2006) presents two videogames, one a maze-based game and the other based on the classic Snake videogame. Although the results are significant, the authors warn that it is important to be able to study the impact

that a videogame with haptic and audio cues can have, which is dealt with in this project. Grammenos et al. (2006), through their Access Invaders videogame, allow legally blind students to be able to play the classic Space Invaders game. The design considers the mental model of blind users and allows them to play together with other users (sighted or blind) on line, through a graphic and audio interface. The main objective of the study is to make certain areas of technology accessible that are often restricted for certain people, such as the blind.

Eriksson & Gärdenfors (2004) mention and detail games for web designers, made for various children with visual problems. They differentiate games into two types, depending on whether or not the user is totally blind, or has partial vision. For a totally blind child, there are sound-based games such as Towers of Hanoi, Memory, Tag, and Skybells; while for children with low-level vision there is Memory, as well as other puzzle and action-based games.

The TIM project (Archambault & Olivier, 2005) is a project that developed a software editor in order to create videogames for blind people. This software allows designers to define the interaction that the user will have with the videogame, as well as the interfaces to be utilized. Some aspects that are strengthened by the editor are the temporality of sound, association between different objects, and the sense of spatiality. One of the videogames designed through the use of TIM is X-Tunes (Friberg & Gärdenfors, 2004), a videogame that allows blind players to compete through different tasks, such as musical composition, recording, sound manipulation and the creation of collections of sounds. Another videogame is Tim's Journey (Friberg & Gärdenfors, 2004), which allows a blind user to navigate through virtual spaces that are defined through specific sounds that stimulate spatial representation.

Finger Dance (Miller, Parecki & Douglas, 2007) is a sound-based videogame that allows a blind user to develop temporal skills through sound sequences that have to be synchronized with other audio bases, in order to achieve the highest possible score. When legally blind users that have partial vision interact with videogames that include visual cues, they take advantage of their partial vision in order to achieve better results from the interaction. In the case of totally blind users, this is not a possibility and it is necessary to provide them with all of the information regarding the environment through other sensory channels, such as touch and audio (Sánchez, 2007a).

3. METHODOLOGY

3.1 Systematic Review

We carried out a bibliographic review from July to November 2014 according to the steps of the systematic review approach (Kitchenham and Charters, 2007; Peterson et al., 2008). The systematic review consists in a secondary study method that reviews existing primary studies in-depth and describes their results (Kitchenham and Charters, 2007). In this research approach, a set of search strings correspondent to á research questions is posed to suitable sources. Then, we filtered the obtained papers according to a set of exclusion and inclusion criteria. The resulting papers are analyzed in order to answer the initial research questions. There are three main phases of a systematic review: planning, conducting and reporting the review (Kitchenham, and Charters, 2007). We used the tools StArt (Fabbri et al, 2012) and Mendeley (Singh, 2010) to support the

realization of the three stages of the study, and to manage the papers.

For the planning phase, we defined a protocol that guided the research objectives and clearly defined the research questions, the query sources and the selection methods. Two researchers and two experts performed incremental reviews to the protocol. The research questions are: Q1: What strategies have been used for the design of multimodal games for learners who are blind to enhance cognition? Q2: What strategies have been used to evaluate usability and quality of multimodal games for learners who are blind? Q3: What technologies have been used for the development of multimodal games for learners who are blind, to enhance cognition?

After defining the research protocol, we posed the search string addressing the research questions Q1, Q2, and Q3 to eight sources. The sources were the following digital libraries: ACM Digital Library, Engineering Village, IEEE Xplore, Scopus, Science Direct, Springer Link, PubMed, and Web of Science. The result of submitting the search string to the eight selected bases was an initial set of 446 papers. Then, using the snowballing sampling technique (Lewis-Beck et al, 2004) we manually added a set of 52 papers to the original sample. Snowballing sampling is a technique for gathering research subjects through the identification of an initial subject that is used to provide other related subjects. In this research from the initial set of 446 papers we also gathered 52 relevant related research works cited in these papers. Thus, the total of papers obtained was 498. From this amount there were 48 papers from ACM (9.6%), 136 from IEEE (27.3%), 28 from Scopus (5.6%), 181 from ScienceDirect (36.3%), 50 from Springer (10%), 4 papers from Web of Science (0.8%), 1 paper from Pubmed (0.2%) and 52 added manually (10.5%). Although ScienceDirect had the higher quantity of papers, there were not many outcomes related to the desired area. It happened due to this source returned a vast amount of articles related to cognition and/or people who are blind, but under the medical point of view, unrelated to videogames and technology.

```
(
        ((Evaluation AND (usability OR quality)) OR Design OR
        Development)
     AND
        (Serious AND (Videogame OR Game))
)
AND
(
        ("blind learners" OR (("eyes-free" OR "visually
        impaired" OR blind) AND ("education" OR "learning")))
     AND
        (Multimodal OR haptic OR audio OR auditory OR
        vibrotactile OR device OR "I/O" OR gadget OR
        technology)
     AND
        ("cognition" OR "Cognitive spatial structures" OR
        "Navigation Skills" OR "Mental map" OR "Walking
        Simulation")
)
```

Figure 1. Search string submitted to the eight selected sources.

In order to choose the most suitable studies to answer the research questions, we filtered the papers (Figure 2) according to the inclusion and exclusion criteria (Table 1). The inclusion criteria helped us selecting studies describing multimodal serious video games, some specific entertainment video games and navigational virtual environments, whose goal was to enhance cognition. The inclusion criteria also selected studies describing no application but introducing a model for the design or the evaluation of multimodal games or environments for people who are blind. The exclusion criteria helped us to eliminate papers related to

audiences other than people who are blind and those unrelated to mental models, navigational and similar cognitive skills.

The first filter (F1) consists of removing the duplicated and short papers (i.e. less than four pages) and secondary studies or those published before 1995. F1 excluded 172 papers (34.5%) so that 326 studies went to the second filter. The second filter (F2) consists of the application of the specific exclusion criteria and the inclusion criteria, after reading the papers' title and abstract. F2 excluded 216 papers (43.4%) and included 68 papers (13.7%). These papers went to the third filter (F3), intending to refine the initially accepted set of studies. F3 consisted of the examination of the full text of the 68 articles and the review of the assigned inclusion and exclusion criteria. F3 excluded 34 articles by criteria and four duplicated papers (7.6%) and included 30 papers (6%). Most of the papers eliminated were related to cognition, but not to multimodal games for people who are blind. From the 30 papers finally selected for data extraction, one paper was from ACM, two from IEEE, four from Scopus, two from ScienceDirect, two from Web of Science. Finally, 19 papers were added manually, through a snowballing sampling.
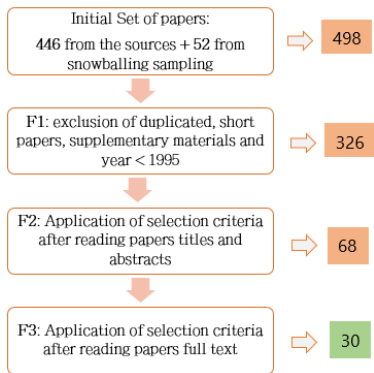

Figure 2. Filtering process

Table 1. Criteria used for the selection of papers

INCLUSION CRITERIA

(I) Studies presenting initiatives to evaluate multimodal videogame (including virtual environment) for blind learner;

(II) Studies presenting initiatives to develop multimodal videogame (including virtual environment) for blind learner;

(III) Presents results related to the impact of multimodal technology for enhancing cognition;

(IV) Studies presenting technologies to support multimodal videogames (including virtual environment);

EXCLUSION CRITERIA

(I) Studies describing videogames for any public other than blind learners;

(II) Studies presenting initiatives to develop or to evaluate other multimodal software besides videogames (including virtual environment);

(III) Studies describing no results related to cognitive impact for blind learners;

(IV) Studies describing evaluation or design of non-multimodal software;

(V) Study validating specific assumption related to brain function, learning, navigation or gaming;

(VI) Studies related to cognition but not related to multimodal games for blind people;

(VII) Studies introducing or evaluating specific technologies for accessibility in general;

(VIII) short paper publication (less than 4 pages);

(IX) Paper under review or not a paper, but course notes or other supplementary materials;

(X) Paper published before 1995;

(XI) Secondary studies or surveys;

The relevant papers are from 1999 to 2014, being 80% of the papers from 2008 on. The selected papers were: (Lahav and Mioduser, 2008; Westin, 2004; Connors et al, 2014; Sánchez et al, 2010; Dulyan and Edmonds, 2010; Espinoza et al, 2014; Guerrero and Lincoln, 2012; Lahav et al, 2013; Lahav and Mioduser, 2008; Lumbreras and Sánchez, 1999; McCrindle and Symons, 2000; Sánchez, 2007; Sánchez, 2012; Sánchez and Aguayon, 2008; Sánchez et al, 2014; Sánchez and Espinoza, 2013; Sánchez et al, 2014; Sánchez et al, 2013; Sánchez et al, 2010; Sánchez and Mascaró,2011; Sánchez and Flores, 2008; Sánchez and Sáenz, 2010; Sánchez and Sáenz, 2009; Sánchez and Sáenz,2006; Sánchez et al, 2009; Sánchez et al, 2010; Sánchez and Sáenz,2006; Torrente et al, 2014; Torrent et al, 2009; Trewin et al, 2008). Among these, 25 papers described 21 distinct applications: 17 multimodal games and four multimodal navigation virtual environment. Some papers discussed the same application, but from another point of view.

The analyzed papers show trends in interface characterization and the interaction style, as well as instruments and activities for evaluation of usability and cognitive impact. However, there are some gaps related to when and how to employ the interface and interaction elements to fulfill the application's cognitive requirements. Significant issues remain neglected in the evaluation of multimodal video games for blind learner's cognition enhancement. To help reducing the problems aforementioned we discussed, in previous works, some insights for the practical understanding of the issues involved in the design and evaluation of such applications (Sánchez et al, 2015; Darin et al, 2015). Based on this analysis, we identified that the multimodal applications differentiate mainly in the interface and interaction characterization, along with the cognitive aspects and

the evaluation performed. We also presented a classification of the features existing in the multimodal video games and environments in four dimensions related to Interaction, Interface, Cognition, and Evaluation (Darin et al, 2015).

4. VIDEO GAMES

4.1 AudioSIM

The use of simulation devices and virtual environments with learners who are blind is a support for the teaching and for the improvement of O&M skills, leading to the development of adequate cognitive maps. By using such applications, the blind learner can interact freely with a virtual world, creating mental images from the sensations, movements, memories, textures, sounds and other elements provided by the virtual environment. The final goal is that, once the proper mental images have been created, the blind learner is able to act with confidence, safety, efficacy, agility and independence when within known and unknown real environments.

In this context, we developed AudioSIM, a social and strategy desktop videogame for the simulation of an athlete's daily life, based on Electronic Arts' The Sims. The player personifies an outstanding young man or woman who receives a special scholarship and lives in the Sports Campus C5SIMS, a virtual space unknown to her, until the moment. The athlete has not yet decided what sport to perform professionally, and being in the Campus is an opportunity to demonstrate her skills as a high-efficiency athlete. Her weakness is being late for training. To avoid looking like an amateur to technicians and teachers, the athlete must hurry in an unknown place, so the player need to orient herself in the environment using the game compass and the environment's audio clues.

The user plays using an Xbox 360 joystick. In the directional control, the player can move by pressing "Up" and "Down" and, "Left" and "Right" to rotate. The user cannot rotate and move simultaneously. Each time the user presses "Up" or "Down" it is equivalent to a step, which allows counting how much steps from point A to point B. Each rotation is 45 °, allowing discrete movements. The "Y" button draws out the player's virtual cane, while the "A" button allows consultation on directions, considering there are no other characters in the game that can give indications. Game interfaces are based on audio and haptic. The audio focuses on 3D sounds, so the user can associate the sounds emitted by objects to landmarks on the virtual environment. The player can consult at any time what building or object is in front of her. There is also information about the place the user is entering. Other built-in sounds are related to touches and clashes when using the virtual cane, as well as buildings, objects and textures. The haptic component is presented through the Xbox 360 joystick, using vibration to represent collisions with objects in the game.

4.2 AudioGeometry

Geometry allows the development of skills to learn to deal with objects the real world in their abstract and concrete dimensions. The spatial awareness is conformed of simple concepts, complex ideas, locations and relationships held in mind by cognitive images. Therefore, the proper comprehension of Geometry improves the capacity of a blind person of create useful mental images and, in the last instance improve his O&M skills.

In this context, we developed AudioGeometry, an adventure mobile game that simulates a shipwreck and the arrival of a single survivor to the Geometric Island, an unknown and dangerous place from where the survivor needs to depart. The player must decipher the various geometric puzzles and collect a number of elements that will allow her to feed, build a boat and finally return home. The game runs in a 10.1-inch touchscreen tablet, using Android technology. The feedback to the player is in the combination of the vibrating screen (haptic), individual sounds for each movement and the own video game design.

To help the learner's orientation, specific sounds characterize each of the environments of the island (beach, temple, waterfall, volcano). Besides, the player begins to approach each one of these locations, the characteristic sound will be played, acclimating the user. Meanwhile, the movements as forward, rotate or collide, have an iconic sound associated. In the specific case of the rotations or collisions, the sound plays on the corresponding side, right or left. When the user explores the island and finds the geometric puzzles, a narrator explains the riddle and the answer options, which may be alternatives (two or four) or interaction with the tablet. Three frequencies of vibration were established to develop the presentation of figures and shapes on the screen, along with a particular vibration for certain gestures like moving or colliding during the exploration of the island.

4.3 Ongoing prototypes

There is a huge variety of technologic options for implementing multimodal games for the cognition of people who are blind. However, according to Sánchez et al., (2015) the mobile paradigm should be better explored, taking advantage of the resources available in the mobile context to provide contextual information that may help in orientation and mobility of legally blind users.

In this context, we are developing a mobile multimodal adventure game for improving O&M skills of people who are blind, in the context of visiting new environments. The goal is that the user may play the game at home, before going visit the new environment, so the place will no longer be an unknown place by the time a blind user visits it. The prototype currently in development models the Seara da Ciência (Science Harvest) environment, at the Federal University of Ceará. Seara da Ciência offers playful and fun experiences that make concepts and theories of science accessible to people of different age groups. After playing the game, the user can acquire information about the actual spatial arrangement of the experiments and the physical environment of the Seara's building (e.g., bathrooms, hallways, doors, reception, obstacles).

The ongoing prototype uses stereo techniques, binaural sound effects and voice synthesis, aggregated to 3D maps and to the gyroscope sensor of the mobile device. The goal of combining such technologies is to extend the possibilities to investigate the use of new strategies, methods, processes and tools to develop and assess multimodal mobile games for cognition of people who are blind. The game has a first person perspective. To control the game, the player can use the touch controls on the screen to move and to obtain directions. For a more immersive experience, the player can also use the smartphone gyroscope to rotate in the environment. This approach simulates a close-to-real situation for the displacement within the physical space of Seara's environment. The game follows the principles of universal design and can also be used by non-disabled people.

The first scenario proposed to validate the controls of the game with the users is trying to find a dog that is jumping at different points around the character, guided by the sound of his barking. The goal of this task is that the user can practice the first practical notions of orientation and mobility using the gyroscope. So we present him to the cardinal points (N, S, E, W) and points in the diagonal directions (NE, SE, SW, IN), through the alternated positions of the dog. The second scenario is to move around an environment seeking three elements: a barking dog, a playing piano, and a singing bird, which are spread in a room.

The process of developing and validating the Seara's mobile game prototype with visually impaired users is enhancing our understanding of their psychomotor development, the acquisition of perceptual-motor skills and patterns, and finally the development of a mental map in people who are blind.

5. USABILITY EVALUATION

5.1 AudioSIM

A usability evaluation was performed with 5 end users, using the developed prototype, in two schools for blind children in Chile. The aim of this study was to identify initial usability errors or problems on using and understanding the game. The study was developed satisfactorily and diverse problems were corrected in the redesign of the prototype, especially related to the game controls and turns. The sample consisted of 2 blind users, and 3 with low vision, ranging from 9 to 16 years old, being 4 men and one woman. The educational level of the children ran from 4th to 8th grade, but we did not consider this parameter because it was not relevant to this preliminary study usability. The usability evaluation tool used is a summarized end-user questionnaire, the "Evaluation Software for Blind Children" (Sánchez, 2003). The questionnaires had 18 closed questions associated with 10-point Likert Scales and 5 open questions.

The initial results (Figure 3) obtained indicate that the users like the game (average 9 points on a scale of 1-10). In addition, they also seemed amused (avg. 9.8). Likewise, they indicated they wanted to replay (avg. 9) and they would recommend the game to friends (avg. 9). The lowest average concerned to how challenging the game is (avg. 4.6) and if the game suits the user's pace (avg. 5.2). The open questions showed that users that already use joysticks felt comfortable using the joystick of the Xbox. Of these, 2 users had used it before and 2 use other joysticks constantly. For other users, the development was more complex tasks to advance and turn, as they were not accustomed to using joysticks.
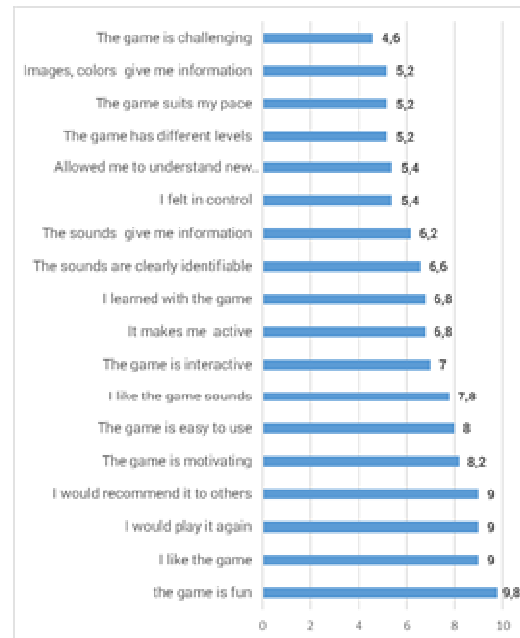

Figure 3. Average results of the usability questionnaire for AudioSIM

5.2 AudioGeometry

To early detect opportunities for improvement, a usability evaluation was performed with end users, using the developed prototype. The sample was a group of 9 learners, being 8 men and one woman, aged between 10 and 17 years old, of which 4 have low vision and 5 are blind. Their schooling was from 3rd to 8th of basic education.

According to the information gathered, it was possible determining the positive acceptance of the game. The issues raised by the users were improved. The results (Figure 4) indicate that the users like the game (average 8.3 points on a scale of 1-10). Likewise, they indicated they wanted to replay (avg. 8.29) and they would recommend the game to friends (avg. 7.7). The lowest average concerned to how challenging the game is (avg. 6). It is interesting to point out that the users considered the game easy to use (avg.7.4) and in control over the situations presented in the game (avg.7.2). From the perspective of the feedback and the auditory and graphical interface, there was a good acceptance. The problems perceived during the evaluation were resolved by improving the resolution of the graphical interface, expanding the area of action in each level, to increase the complexity of the paths and redesigning shapes and sizes of the scheme in some activities, to increase the occurrence of vibration and sound, thus facilitating their sensory perception.
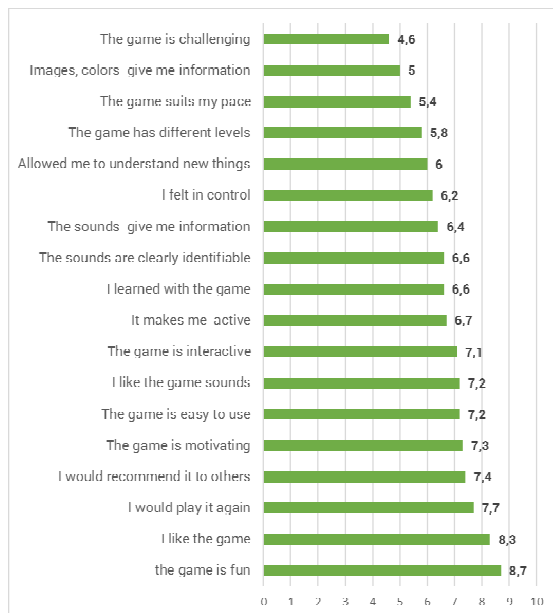
Figure 4. Average results of the usability questionnaire for AudioGeometry

6. DISCUSSION

In this paper, we present some of the results of KIGB international project. We focus on Knowing and Interacting while Gaming for the Blind (KIGB). The main purpose of the KIGB project was to develop the intellect of people who are blind, to help them to be more autonomous and independent in their life and their relations with people and surroundings, and thus helping them to be more integrated and included in the actual society.

We mainly present and discuss the videogame applications developed and evaluated, and a full state of the art through a systematic review study.

AudioGeometry and AudioSim games are already developed while others such as Seara da Ciência are under development and testing. These prototypes were developed by researchers from Brazil and Chile and having discussion and interactions with French researchers, evidencing the integration of researchers from three countries around a common research problem.

Initial results indicate the appropriateness of the technology used for developing mental maps in blind learners. We believe that multimodal interfaces can make a point in developing the intellect of blind learners. To confirm our hypothes more full field testing is needed.

The next step after doing more testing will be to investigate new technologies for developing the cognition of the blind, such as Internet of Things, big data, and context aware. We believe that this may expand the possibilities of using technology to improve the quality life of life of people who are blind through the construction of mental models by interacting with smart technologies.

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