

Inclusive Games: a multimodal experience for blind players

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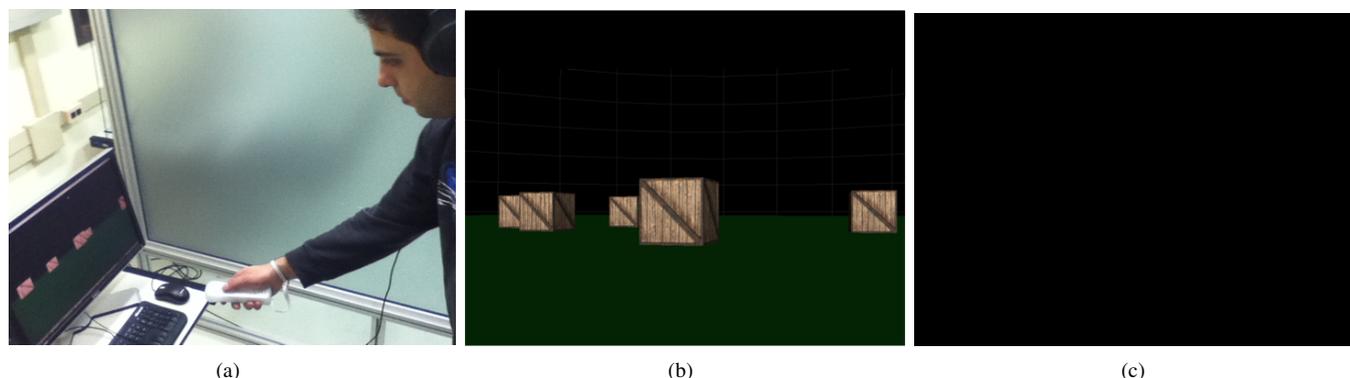


Figure 1: The images show the game, including: a user playing with the Wiimote (a); a screenshot of the game (b); and a black screen, representing what a blind person could see (c).

Abstract

Electronic games have an important role in the human development so we can face the world of constantly changing technologies. Considering that the most of games is grounded in the interaction through visual elements and that the most of alternate games for blind is less attractive to non-blind people, we have developed a prototype of a 3D environment with dense sound experience and haptic feedback that would allow to blind and non-blind users orientate and move through it. Designing this environment like a game, we have employed blindfolded and non-blindfolded users to evaluate the major interaction issues in order to refine the software and make it mature to be used for the research with blind subjects.

Keywords: accessibility, haptics, 3D sound, blind people

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1 Introduction

We live in the century of technology, communication and information. In this world of rapid changes, much of human activity happens in virtual and digital spaces [Castells 2003]. Among these spaces, electronic games build an important set of resources for human development in society. Often used by children, teenagers and young adults, these games have a significant role in the formation of mental structures that will aid in the use of other technologies present in the individual's life. Supporting this idea, Griffiths [Griffiths 2002], Wood et al. [Wood et al. 2004] and Teng [Teng 2008] point out some benefits of these games: videogames can provide elements of interactivity that may stimulate learning; equip children with state-of-the-art technology that helps to overcome technophobia and to develop transferable IT skills; improve problem solving, communication and teamwork skills; and stimulate creativity, organization and extroversion from players when compared with non-players.

Videogames are also popular for its high degree of interaction: unlike reading a book or watching a movie, they provide a different level of immersion in which users interact with the world. The participation in creating a story or in overcoming a challenge proved to be a promising industry that has moved billions of dollars in the last two decades [Miller et al. 2007].

Currently, supported by technologies of computer networks (especially the Internet), the "virtual worlds have developed to the point where millions of people use them for fun, social interaction, education and even employment." [Trewin et al. 2009]. Thus, the participation in this game universe becomes even more relevant at global scale, and the questioning of Santarosa et al. [Santarosa et al. 2010] on the Internet as a democratic, inclusive environment is also valid for network games: "due to problems of physical and cognitive limitations, or [...] the incompatibility of technological interfaces, people with special needs have been unable to participate in digital spaces to boost their cognitive development."

According to IBGE [IBGE 2000] (the acronym for Brazilian Institute of Geography and Statistics), people with disabilities represent 15% of Brazilian population. In this portion, 16.6 million people have difficulty (in a greater or lesser degree) to see. We also observed that the proportion of people with disabilities in developing countries is very similar to the proportion in developed countries [BUREAU 2005], although the most common disability groups are not often the same.

Vision problems are known as the most disabling disorder for orientation and location at same time that graphics are the main features for interaction and orientation in computer games [Yuan and Folmer 2008]. Therefore, blind people are the most excluded audience from mainstream games, while environments capable of enhancing skills and reducing disadvantages represent opportunity to equal access to technology and entertainment by this group.

Despite its popularity, the majority of electronic games are designed for people with perfect cognitive, sensory and physical development. Although computer games often allow the use of alternative input devices – joysticks and assistive technologies replacing keyboard and mouse –, most of the games currently depends on the ability of players to see the screen [Yuan and Folmer 2008]. "Currently, blind and severely visually impaired children can not independently access multimedia games on the market [...]. In addition, assistive technology such as augmentative software or screen readers are not compatible with these games" [Buaud et al. 2003].

Considering the disadvantage that blind people face to experience the current games, researchers and organizations have mobilized efforts to produce text-based games or audio games (games where audio content receives the same or more attention of the graphics content) [Friberg and Gårdenfors 2004; Archambault and Olivier 2005; Miller et al. 2007; Yuan and Folmer 2008; Allman et al. 2009]. Many of these audio games, however, deposit the entire user experience in an audio-only interface, making them unattractive to

non-blind people. The lack of a rich virtual environment also makes text-based games less interesting to people with normal vision.

Other alternatives for these games are based on specific hardware [Yuan and Folmer 2008; Allman et al. 2009] in most cases handcrafted or very expensive to be purchased by the families of people with disabilities (often economically disadvantaged).

Since the blind people have access to a very limited set of games often designed just for them, we propose the creation of a 3D game with intensive sound experience, using common and inexpensive hardware (the keyboard that can be replaced by compatible assistive technologies or the Nintendo Wiimote controller). This study contributes to promoting interaction among users with visual disabilities and users without disabilities according to the current policies of inclusion.

This paper is organized as follows. Section 2 describes the main studies related to our research. In Section 3, we present the main features of our proposal, the environment adopted to develop the prototype and the architectural aspects of the solution. Section 4 indicates the importance of early tests with users, the use of testing methodologies and planning, the choice of the participants and our hypotheses of work. Section 5 presents and discusses the results achieved and Section 6 lists our conclusions and future works.

2 Related Work

Friberg and Gärdenfors [Friberg and Gärdenfors 2004] have proposed a collection of three sound-based games in TiM project: Mudspat, X-tune, and Tims Journey. All of them present auditory interfaces and interactive, complex soundscapes. As discussed in the previous section, this is an environment where, according to the authors, “[we] combine audio with visual output, but it is always the sounds that are central to the game”.

Audioquake [Atkinson et al. 2006] is a first-person shooter game adapted from the original Quake that replaces visual feedback based on the idea of earcons (sound structures that represent events and objects in-game). Both visual and enriched audio information are available to players, but the concepts of 3D sound (including refinements as Doppler effect) are not present, although the game uses stereo sound.

The game Blind Hero [Yuan and Folmer 2008] uses the same game model from the Guitar Hero that consists in activating buttons or triggers synchronized to the music. The indication to activate a trigger that was given by visual feedback was replaced in Blind Hero by haptics stimuli from a handcrafted haptic glove with estimated cost of US\$1,500.00.

The Rock Vibe game [Allman et al. 2009] is a modification performed on the Rock Band video game that uses specific hardware to provide vibrations in upper and lower arms to represent the visual feedback to activate parts of a drum kit. Again we notice the need of special hardware assumed by the authors: “because of the costs associated with Rock Band and its peripheral instruments, this project would probably fail to reach a large number of people with no or limited vision”.

Considering these main features, we can assume that our approach differs from related studies because we are giving the same importance to visual and audio resources, our proposal uses 3D sound to orientate players, and the alternative interaction (with haptic feedback) relies only on the cheap, industrial device Wiimote.

3 The Game

In this section we present an overview of the game, as well as information about the design and implementation.

3.1 Overview

The game proposed consists of a flat 3D virtual environment with a set of boxes and a black, wired sky dome (Figure 1(b)). We still
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applied 3D sound resources to allow the user to locate the spatial position of his target.

The user has a first-person perspective from the world and his movement is limited to the flat surface. He cannot jump or climb barriers – the character must go around the boxes to avoid them, otherwise he will collide. There is forward and backward movement, but there is not side movements (also called strafing). Following the same logic of some first-person games and ensuring that mouse (a great problem for blind people) is not used, the character can change his orientation (the 3D auditory perception from the target shall indicate how the user has rotated).

The objective of the user is to find the only box – into the collection of boxes – which emits the sound of a crow. If the user collides with the wrong box, a red flash indicates the mistake and the sound of a collision is played. The game ends when the user arrives to the box that emits the crow sound, thus receiving visual and auditory feedback (background and box receive green colors, and the audio narration of success is played).

We have also implemented a feature called *virtual white cane* that mimics the cane used by the blind people for orientation. Through the virtual white cane the user receives sound and haptics information when there are obstacles around. If the user activates the white cane and there is a box nearby, the knock sound is emitted from the position of the obstacle and the Wiimote vibrates, allowing the user to identify the location of the barrier. We also emphasize that the cane detects obstacles around whole character, including behind. The activation of white cane is made by means of pressing a button (in the keyboard or Wii controller) or shaking the controller horizontally (as a blind person does in real life).

The player can use a Wiimote (connected via Bluetooth to the computer) to move around and interact with the environment. Using this device, the user will get haptics feedback (through Wiimote vibration) beyond the standard auditory feedback in case of collision with obstacles or detection by virtual white cane. If the controller is not detected by software, the keyboard can be used to play.

As mentioned before, the use of 3D sound in the game is the main feature in our proposal. Sounds in the game involves: the crow in the target box (spatially located), the white cane collision with any box (spatially located), the collision with the wrong box (spatially located), the success message, an environmental sound of a forest (crickets and wind), the steps of the user (important feedback to blind users), and the narration of goals and commands at the beginning of the game.

This approach also differs from other similar proposals that use a first-person view. This was motivated by the lack of resources that this model of game provides so that blind users can participate equally.

3.2 Designing and Implementation

The prototype was developed in C programming language and have used the following libraries during development:

- OpenGL for 3D graphics environment
- OpenAL for 3D sound capabilities
- Wiiuse for integration with Wiimote controller

Figure 2 presents the main structure of the system discussed below. The Initializer module loads the libraries and verifies what resources are available (controller, images and sound samples), configuring the system variables.

In the *Game Rules* module are the main business rules: state and win condition analyzer, logic view from the game, mapping the input information to graphical and audio responses, etc. Naturally, the majority of the logical and code complexity lies here.

The *Handler* homogenizes input information and call changes in game state and variables.

The *Wiimote* module receives data from the Wiiuse library and converts it in logical information, e.g., it captures the accelerometer

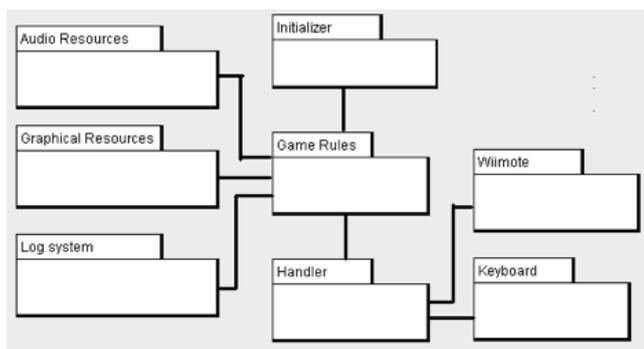


Figure 2: Structure of the game system

position in a buffer and evaluate whether it is the *virtual white cane* trigger movement. The *Keyboard* module has the same function as the *WiiMote*: to capture keyboard interaction and make the information available to the *Handler*.

Both *Audio Resources* and *Graphical Resources* have the role of receiving calls from *Game Rules* and processing the required changes in his domain. *Log System* receives calls to update the control variables and to persist them into files.

4 User Tests

Usability testing relies on a combination of techniques including observation, questionnaires and interviews as well as user testing, but user testing is of central concern. Indeed, while accessibility guidelines and checklists are important, it is also vital to observe real users in action. A very important component of any usability testing tool is user involvement and the best way to ensure your software meets the expectations of your users is to conduct user testing.

According to Preece et al. [Preece et al. 2002], user testing is an applied form of experimentation used by developers to test whether the product they develop is usable by the intended user population to achieve their tasks. In practice, user testing involves measuring the performance of typical users (usually 5-12 users, but often there are fewer, sometimes one or two users in a ‘quick and dirty’ test) doing typical tasks in controlled laboratory-like conditions.

The key to successful user testing is to get inside the head of the user and determine why they did what they did and what would make things more simple for them.

Users can help to identify problem areas before the work is completed, saving considerable amounts of time and effort.

User tests can be performed at any or all stages of the game development lifecycle but if user tests are held to the very end you run the risk of identifying a large issue that requires extensive rework. Not only does user tests help to identify potential problems with your game, it also ensures that your game is compatible with the accessibility-oriented universal characteristics of your target user profile.

There are many things to consider before doing user testing. Our user testing procedure involved five stages that were prepared in advance and were used for each participant to ensure that all participants were treated in the same way.

Controlling the test conditions is central, so careful planning is necessary. This involves ensuring that the conditions are the same for each participant, that what is being measured is indicative of what is being tested and that assumptions are made explicit in the test design.

In the next subsections we describe procedures and methods adopted (Section 4.1), the five stages in user testing (Section 4.2) and the hypotheses and subjects (Section 4.3).

4.1 Procedure and Methods

We have adopted the following methods to evaluate the game: background questionnaire [Marconi and Lakatos 2001], satisfaction questionnaire [Filardi and Traina 2008], log analysis, and user testing with extensive observation [Marconi and Lakatos 2001; Rubin 1994].

The first questionnaire was applied before the user testing and it intended to collect information to form a user profile. In this profile we aggregate information about vision and physical problems, the frequency of use of computer games and – specifically – first-person shooting games, usage of keyboard/mouse/controller while playing, and previous experience with the *WiiMote*.

In the satisfaction questionnaire we have verified positive and negative points of the user experience in our game prototype. We have evaluated the main difficulties related to the interaction with the game: the localization into the environment, the control of the character, the detection and avoidance of obstacles, the recognition of the direction of sounds, and the influence of the *WiiMote* vibration during the game. In addition, we intended to evaluate the difficulty level perceived by the participants to perform the task, such as fatigue and frustration.

The user testing with each subject collected information by means of an activity log and extensive direct observation. The execution of the tests included the following steps [Rubin 1994]: presentation of the study, researchers and procedures; interaction for empathic link formation; completion of the profile questionnaire; presentation of the game (controls and sounds); conduction of the test itself; and completion of the satisfaction questionnaire.

During the test, the following interaction data were recorded into a log for further analysis: success or failure in finding the crow, time spent to find the crow, number of movements performed to find the crow, amount of collisions with obstacles and collisions that occurred at the same obstacle.

We have used the think-aloud protocol [Ericsson and Simon 1993] to interact with the participants and to collect information during usability testing. Some considerations (problems and suggestions noticed) will be presented in Section 5.

The tests were performed on a 12” screen notebook with Windows Vista OS and on a 17” screen desktop computer with Windows XP OS. Users have used standard headphones to have an appropriate experience with 3D sound (Figure 3).



Figure 3: Subject playing with the *WiiMote* in a 17” screen desktop computer.

4.2 Stages

Tests with every participant were divided into five stages. Each stage has a configuration and a fixed amount of boxes, indicating a different difficulty to achieve the goal. Figure 4 shows the configurations used in every step: the initial position is represented by the black spot – always at the center –, the black arrow indicates the initial orientation of the user, the target box (the one with the crow) is the green spot, and the wrong boxes are the red spots. We present below the description of three configurations to illustrate:

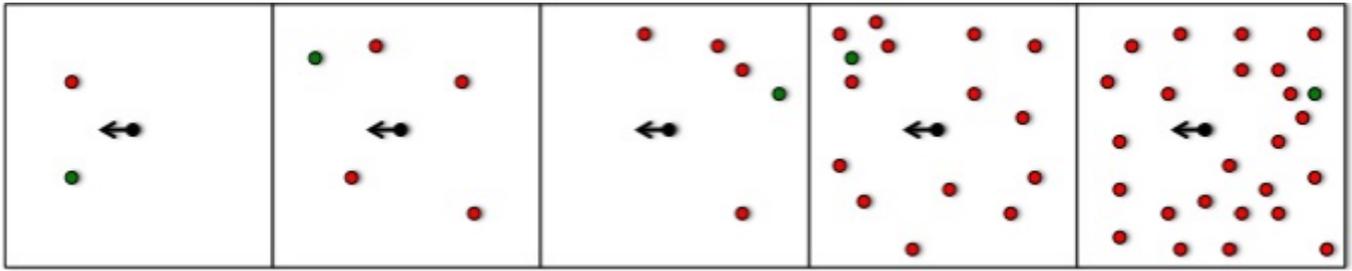


Figure 4: Five stages in the user test. Each square area represents one instance of the game environment. Black circles indicate the avatar position, with the orientation given by the arrows. Red circles are boxes and green circles represent the crow (hidden inside a box).

- In the first stage, there are only two boxes in front of the character and the right one is at left
- In the third stage, there are five boxes and the box with the crow is behind the initial position of the participant
- In the fifth stage, there are 25 boxes and the target box is behind the starting position and hidden behind other three boxes (the user cannot see it just rotating the camera)

4.3 Hypotheses and Subjects

The twelve subjects who participated in the tests were divided in four groups: the first group has used the keyboard to interact with the game, the second has used the Wiimote controller, the third also has used the keyboard but had no visualization of the environment (they were blindfolded and have used only sound and haptics references to locate themselves into the environment), and the fourth group has used the Wiimote and also have been blindfolded.

Due to limitations to recruit blind participants in early stage of this research, we have used only non-blind participants for now. Nevertheless, as indicated in the previous section, half the participants were blindfolded during the tests in order to play the game guided only by their auditory experience. Naturally, this approach is not equivalent and does not replace the need of blind subjects participation because the skills of sound sources localization and the skills of mental maps creation without any visual references are overcompensated by blind people [Vygotky 1997].

On the other hand, this criticism/hypothesis (that the blind people are more proficient at locating sound sources and building mental maps from non-visual information) does support the validation of our research. If the results of success in locating the target, time spent to find the target, and number of collisions showed similar results for blindfolded sighted users and non-blindfolded participants, the differences tend to be even smaller if compared blind and non-blind users.

As shown in Figure 5, most of our sample (58.3%) is comprised of subjects between 21 and 25 years old. Although half of the participants had visual impairments or diseases, all of them were using corrective lenses at the time of user testing.

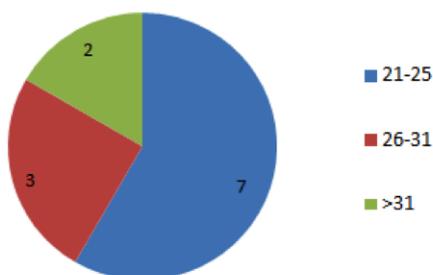


Figure 5: Subject and age groups

All subjects have had contact with video games or computer games at some point in their lives: 66.7% reported still play sometimes (one or two days in a week) (see Figure 6). Other frequencies were

also found: always (every day), rarely (few times per month), and almost never (played once or twice). In addition, 75% of participants reported using (more often) keyboard and mouse for gaming.

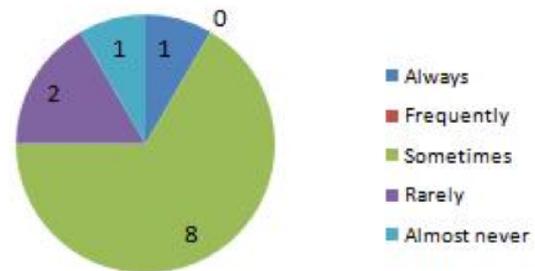


Figure 6: Subject and frequency of the use of video games

We also observed that 66.7% of participants already had contact with the Wiimote or similar controller on the market. That familiarity is positive to reduce problems related to unfamiliarity with the device, but we believe that is not significant on the results.

We note that 83.3% of subjects have experienced first-person shooting games, and the highest frequency of use among those who use to play are rarely (50%), and occasionally (40%).

5 Results and Discussion

Among the six categories of potential problems (locate yourself into the environment, usage of the Wiimote, usage of the keyboard, bypass obstacles, locate the sound source, and detect elements with the white cane) defined by us as the most important, two of them appear as critical (Figure 7). Difficulties in bypass obstacles were marked by 91.7% of participants into the questionnaire. We believe that the mechanism chosen to collision detection and avoidance of obstacles have been responsible for this problem because even non-blindfolded users reported this problem.

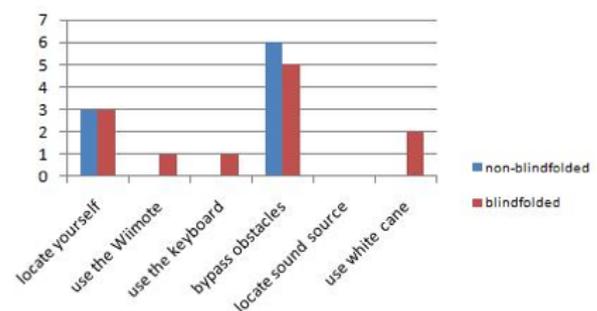


Figure 7: Problems indicated by users

Difficulties in locating him or herself in the environment were marked by 50% of subjects, half of the subjects blindfolded and half of the subjects non-blindfolded. This difficulty is understandable coming from the blindfolded participants (non-blind people

have more difficulty to maintain a mental image of a non-visual environment), but the same is not true for non-blindfolded users. We believe that a user group experienced in more realistic three-dimensional environments (rich in textures and light/shadow effects) may have encountered difficulties in this simplified environment (a prototype and without elaborate graphics). A possible explanation for this result is the similarity on the appearance of the visual elements of the game. All elements are represented as boxes, all of them with the same texture. Perhaps, by individualizing the elements of the environment with several different textures for the boxes, the users will have more facility to construct the mental map of the environment.

We also noticed that two new categories have been raised as particular difficulties: lack of realism to observe the environment, and difficulty to recognize the size of the boxes to avoid them when there is no visualization. Each one received an indication.

We analyzed the frequency of the difficulties that participants faced in using the software. We consider eight categories of problems (problems in moving, problems to avoid obstacles, problems in locating the sound source, problems caused by ambient sounds of the game, vibration control confounded the user, software errors, controls are very confusing, and fatigue caused by Wiimote usage) and four frequencies of occurrence of problems: did not affect me, a little frequent, frequent and very frequent. So, we assigned a number of points for each frequency: zero, one, two and four points respectively. The following results (Figure 8) represent the sum of points for each category of all participants.

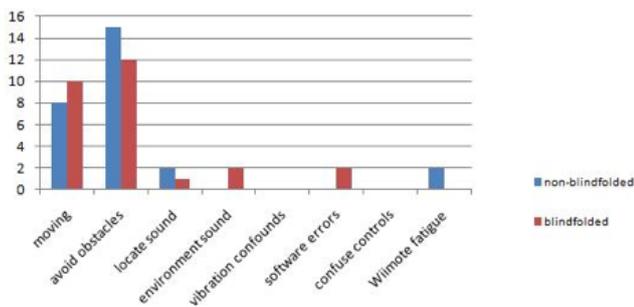


Figure 8: Frequency score of problems indicated by users

The two high scored issues were the difficulty to avoid obstacles (a total of 27 points from both blindfolded and non-blindfolded) and difficulty in moving (a total of 18 points). Confusion with controls and confounding Wiimote vibration received no indications.

The general difficulty experienced by the players was summarized in Figure 9. The blindfolded subjects have focused on evaluating the game as medium or hard, while the group with visualization has considered it easy.

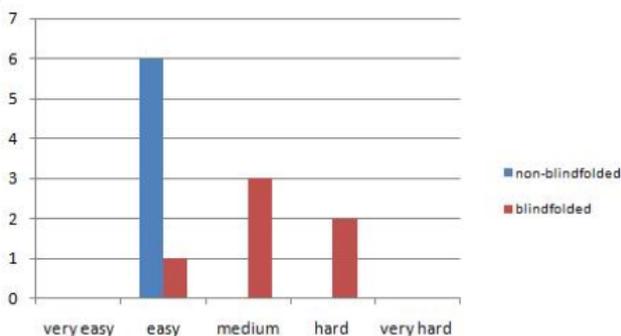


Figure 9: Evaluation of difficulty

Considering the usefulness of the *virtual white cane* to detect obstacles near, 66.7% of the users believed to be a little useful. Of X SBGames - Salvador - BA, November 7th - 9th, 2011

course, all non-blindfolded participants pointed that seeing the obstacles was more effective than using the white cane, so the subjects who considered it useful were those blindfolded.

With similar results, 66.7% of the users who used the Wiimote controller to perform the experiment told that the vibration aid them during the game. Among the reasons to consider this a relevant feature, they told, "It was faster to know I knocked something, even with sound" and "It confirms the graphical and auditory information". More than one user who marked the controller vibration as irrelevant justified that not even noticed the vibration during the game.

We find an unexpected level of frustration while using the software: 83.3% of users reported having experienced it. The most frequent reasons (presented in different ways for more than a half of the participants who reported feeling frustrated) were problems with the collision avoidance system. Some phrases make it clear: "The collision detection seems weird", "In a moment, collided with a box. I turn to left and I kept knocking when I went forward" and "I was stuck between the boxes".

At last in the evaluation of the questionnaires, we asked if they had thought the game was fun. 83.3% of participants thought the game was fun and explained as positive that the game trains skills used infrequently, presents a challenge to the user, and requires and exercises concentration.

Next, we show the user suggestions and behaviors that emerged during the test and we think to be relevant to this study.

We noticed that the main strategy used by blindfolded participants to achieve a good level of evasion in the presence of many obstacles was to move away as far as possible from the set of barriers, positioning toward the target and walking in a straight path. We believe that this may have been a result of problems in the collision system and other approaches should emerge as a new mechanic to be implemented.

Other speeches that corroborate with the idea of a problem in the obstacles avoidance system are "I'm stuck! I'm stuck!", "It seems that the box is around me", "I do not know if it's a big box or several side by side boxes", "Its confuse! First it seems like a wall of boxes, then seems that I was among them, and now it seems I'm in a labyrinth" and "I'm feeling so far and so close [from the crow]".

Some registered phrases from the think-aloud protocol clearly demonstrate the difficulty of the blindfolded volunteers to maintain a reliable mental map from the auditory experience in the environment: "It is difficult to remember everything you knock" and "I hit a box. Then I hit another. When I hit the third, I forget where the first has been". It is likely that this behavior is different for blind users because they have other mental structures to organize the placement of non-visual obstacles.

Suggestions also emerged spontaneously during the test and they are being evaluated for the refined version of the prototype. These include the use of an obstacle description mechanism, the implementation of a feedback system indicating how much the user has rotated the character, and alternatives for bypassing obstacles, e.g., jump a box.

Another important set of information is the log of interactions which results are discussed below.

Perhaps one of the most relevant data of our research is that the target box was found by all users in 100% of cases in the first four stages and 90% of cases in the fifth step (Figure 10). This confirms that the implemented resources of sound and haptic feedback were sufficient in almost all levels, even blindfolded sighted users might locate themselves, bypass obstacles (with greater or lesser difficulty) and find the target sound source. This indicates a strong tendency of blind participants also get succeed in completing the challenges posed by the game.

The average time (in seconds) to find the target has increased as well as the complexity of the environment, but in step two to step three (Figure 11). We believe that it has occurred because of the

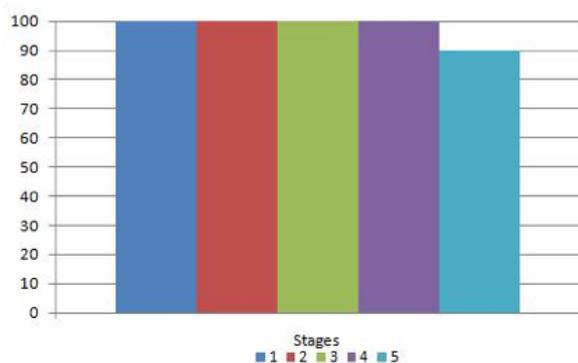


Figure 10: Average success rate

difficulty of both steps (which are very similar as described in Section 4.2) and because of the natural knowledge transfer from one environment to another.

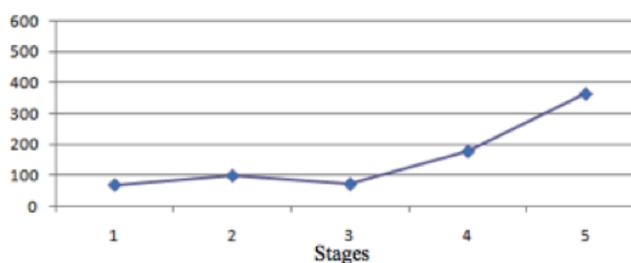


Figure 11: Average time to find the target (in seconds)

We also emphasize that the average time to locate the target using the Wiimote controller was six times smaller than the average time using the keyboard in stages one, three and five. Statistical significance (based, for such research, in the application of two-sampled independent paired Student's t test with non-homogeneous variance) of the data, however, was inconclusive in most cases. This suggests that although time increasing has been detected, the results should be refined by means of study in a larger population. The only exception was the comparison between the times of the blindfolded and non-blindfolded users in the fifth stage of the test (significance of 0.0574 showed – very close to 5% chance of acceptance).

The average number of movements made to find the target also increased through the stages (Figure 12). Here the same oscillation occurred in stages two and three was observed, enforcing our hypothesis of similar complexity and learning transfer.

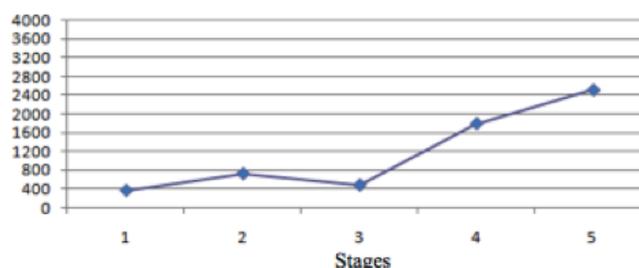


Figure 12: Average movement rate to find the target

The average amount of movement had no significant relationship in the use of Wiimote or keyboard, although the amount of movements has been substantially greater in the final stages to blindfolded participants.

The usage of virtual white cane feature suffered large oscillation in the stages of the game (Figure 13). No relationships were found to justify such behavior. However, it was apparent that the blindfolded volunteers more often used this function at all stages of the test.

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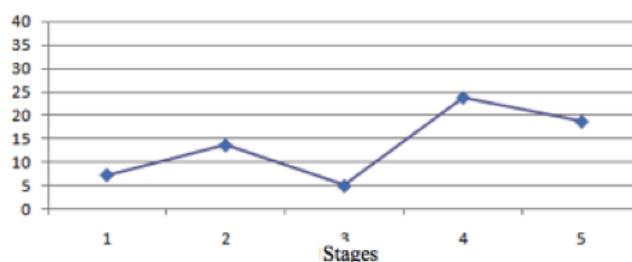


Figure 13: Average virtual white cane feature usage

The average number of collisions and the average number of collisions with the same obstacle (Figure 14 and Figure 15) show that more complex stages (four and five) present a substantial increase in collisions commonplace. While the first three stages tended to zero collisions for all cases, there was statistical significance in the last two stages when compared blindfolded and non-blindfolded users. Blindfolded subjects had – on average – 30 times more collisions and 10 times more collisions with the same obstacle according to a significance of 0.002 and 0.042, respectively.

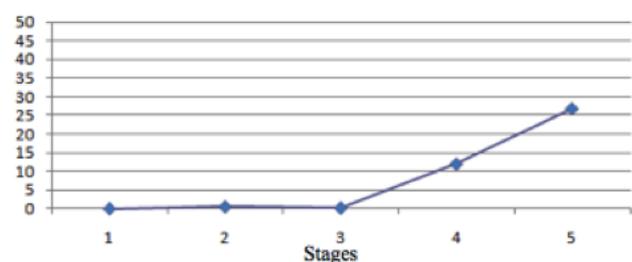


Figure 14: Average amount of collisions

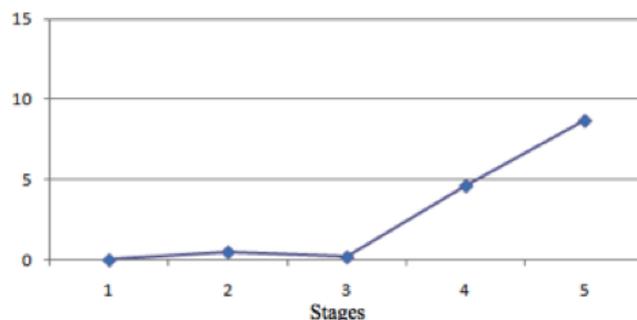


Figure 15: Average amount of collisions with the same box

These high rates of collisions with an obstacle confirm the existence of problems in collision avoidance system developed in this prototype.

6 Conclusions

From the analysis of this prototype, we have aimed to find the problems and limitations of the proposed approach and evaluate alternatives to correct them. Although we have been unable to recruit blind participants in early stages of this research, comparisons between blindfolded and non-blindfolded users showed to be sufficient to identify the most critical problems of usability and the main user behavior during gaming.

Difficulties with the collision system and the obstacle avoidance were significant, although they have not been presented as barriers that prevented the participants to complete successfully the challenges. This demonstrates that the use of 3D sound and the chosen modalities of interaction (with keyboard or Wiimote) are appropriated to explore the proposed environment and to complete the tasks.

Of course, there are unstudied limitations and potentials in regard to blind users. In addition, the prototype should be extended so deaf users can also play, because the optimal gaming experience should be as inclusive as possible.

The next steps of this work are to include blind participants in the usability testing, extend the user interface for deaf and people with mental disabilities, correct the identified issues, evaluate the compatibility with many modalities of assistive technologies, analyze the behavior and the experience of players with disabilities (especially blind people), and propose an intermediate layer that can be used in a set of commercial games (mostly first-person shooter games).

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References

- ALLMAN, T., DHILLON, R. K., LANDAU, M. A., AND KURNIAWAN, S. H. 2009. Rock vibe: Rock band; computer games for people with no or limited vision. In *Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility*, ACM, New York, NY, USA, Assets '09, 51–58.
- ARCHAMBAULT, D., AND OLIVIER, D. 2005. How to make games for visually impaired children. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology*, ACM, New York, NY, USA, ACE '05, 450–453.
- ATKINSON, M. T., GUCUKOGLU, S., MACHIN, C. H. C., AND LAWRENCE, A. E. 2006. Making the mainstream accessible: re-defining the game. In *Proceedings of the 2006 ACM SIGGRAPH symposium on Videogames*, ACM, New York, NY, USA, Sandbox '06, 21–28.
- BUAUD, A., ARCHAMBAULT, D., AND ROUSSEL, B. 2003. Ergonomic evaluation of computer games for visually impaired children. *Universal Access in HCI 4*, 1265–1269.
- BUREAU, U. C. 2005. *American with Disabilities*. www.census.gov/prod/2008pubs/p70-117.pdf.
- CASTELLS, M., 2003. A galáxia da internet: reflexões sobre a internet, os negócios e a sociedade. Rio de Janeiro: Jorge Zahar.
- ERICSSON, K., AND SIMON, H. 1993. *Protocol Analysis: verbal reports as data*. MIT Press, Boston.
- FILARDI, A. L., AND TRAINA, A. J. M. 2008. Montando questionários para medir a satisfação do usuário: avaliação de interface de um sistema que utiliza técnicas de recuperação de imagens por conteúdo. In *Proceedings of the VIII Brazilian Symposium on Human Factors in Computing Systems*, Sociedade Brasileira de Computação, Porto Alegre, Brazil, Brazil, IHC '08, 176–185.
- FRIBERG, J., AND GÄRDENFORS, D. 2004. Audio games: new perspectives on game audio. In *Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology*, ACM, New York, NY, USA, ACE '04, 148–154.
- GRIFFITHS, M. 2002. Educational benefits of videogames. *Educational and Health 20*, 3, 47–51.
- IBGE. 2000. *Censo Demográfico*. www.ibge.gov.br/home/estatistica/populacao/censo2000/populacao/deficiencia_Censo2000.pdf.
- MARCONI, M., AND LAKATOS, E. 2001. *Técnicas de Pesquisa: planejamento e execução de pesquisas; amostragens e técnicas de pesquisa; elaboração, análise e interpretação de dados*. Editora Atlas, São Paulo.
- MILLER, D., PARECKI, A., AND DOUGLAS, S. A. 2007. Finger dance: a sound game for blind people. In *Proceedings of the 9th international ACM SIGACCESS conference on Computers and accessibility*, ACM, New York, NY, USA, Assets '07, 253–254.
- PREECE, J., ROGERS, Y., AND SHARP, H. 2002. *Interaction Design: beyond human-computer interaction*. John Wiley & Sons, Chichester, New York.
- RUBIN, J. 1994. *Handbook of Usability Testing: how to plan, design and conduct effective tests*. John Wiley & Sons, Chichester, New York.
- SANTAROSA, L., CONFORTO, D., PASSERINO, L., ESTABEL, L., CARNEIRO, M., AND GELLER, M. 2010. *Tecnologias Digitais Acessíveis*. JSM Comunicação, Porto Alegre.
- TENG, C.-I. 2008. Personality differences between online game players and nonplayers in a student sample. *Cyberpsychol Behav 11*, 2, 232–4.
- TREWIN, S., LAFF, M., HANSON, V., AND CAVENDER, A. 2009. Exploring visual and motor accessibility in navigating a virtual world. *ACM Trans. Access. Comput.* 2 (June), 11:1–11:35.
- VYGOTSKY, L. 1997. Fundamentos da defectologia. In *Obras escogidas V*. Visor, Madrid.
- WOOD, R., GRIFFITHS, M., CHAPPELL, D., AND DAVIES, M. 2004. Educational benefits of videogames the structural characteristics of video games: a psycho-structural analysis. *Cyberpsychology and behavior: the impact of the Internet, multimedia and virtual reality on behavior and society 7*, 1–10.
- YUAN, B., AND FOLMER, E. 2008. Blind hero: enabling guitar hero for the visually impaired. In *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility*, ACM, New York, NY, USA, Assets '08, 169–176.