An orientation game with 3D spatialized audio for visually impaired children

Diogo Simões, Sofia Cavaco
CITI, Departamento de Informática
Faculdade de Ciências e Tecnologia
Universidade Nova de Lisboa
2829-516 Caparica, Portugal
d.simoes@campus.fct.unl.pt, scavaco@fct.unl.pt

ABSTRACT
In this article, we propose an educational mobile game designed to help visually impaired children to develop orientation skills. These skills are usually trained at orientation and mobility classes for special needs children. The proposed game can be played on touch screen mobile devices and can be used in class or after classes. It uses a child appropriate theme and it aims at training children to perform accurate sound localization, while distinguishing concepts like front/back, left/right, close/far, etc.

We have had very promising results from a preliminary test with blind and low vision students. Training these concepts on an entertaining environment can have very positive outcomes as it motivates children to spend more time training and at the same time allows children to forget that they need to train due to their special needs.

Author Keywords
Educational Game; Orientation and Mobility; Android Game; Visual Impairment

ACM Classification Keywords
H.5.1. Information Interfaces and Presentation (e.g. HCI): Multimedia Information Systems; H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces; K.4.2. Social Issues: Assistive technologies for persons with disabilities; K.3.1. Computers and Education: Computer-assisted instruction (CAI)

INTRODUCTION
Visual stimuli are very important in child development because they arouse the child's curiosity to further explore by listening, touching or tasting. Visual impairments deprive children to obtain such stimuli. Children who suffer from this condition need an adequate education, matching their special requirements. This means that visually impaired students may require materials in alternative formats, such as Braille or enlarged print, or adaptive equipment, such as magnification devices or accessible software. In addition to the specialized materials and the regular curriculum, blind students need to learn skills specific to their condition, such as Braille reading, using adaptive technology and orientation and mobility skills.

Orientation and mobility can be defined as the ability to move independently, safely and efficiently from one place to another. This often translates into the ability to independently cross streets, to use public transportation systems, to travel from home to work, etc. During their school time, visually impaired students need to develop the concepts and skills which make the aforementioned goals attainable in later life, thus making it possible to have an active and independent life.

Serious games can be an excellent tool to transmit knowledge and provide extra motivation, including training orientation skills. Nonetheless, only a few games have been proposed that are accessible to blind children. In order to be accessible to visually impaired children, games must use non-visual modalities. AudioDoom is an example of a game accessible to blind children [4]. This game uses 3D spatialized audio in an highly interactive acoustic environment to test the hypothesis that this type of environment can be used to stimulate and reinforce some abilities of blind children, such as spatial representation. *Código Pitágoras* is a game to help motivate blind students to learn and like mathematics [2]. All the features are complemented with audio and it uses 2D audio to guide blind students to travel in the games' maps.

Though not educational, AudioPuzzle and Terraformers are games accessible to blind children that are worth mentioning [1, 7]. AudioPuzzle consists of a musical puzzle in which the players use the Android's haptic screen to sort music pieces. Terraformers uses speech and 3D spatialized audio in several different features, such as in voiced hierarchical menus, and to simulate an acoustic compass and a sonar, among other features. This game shows that audio can effectively be used in many different forms to give information to blind users in alternative ways.

As for orientation and mobility games, also only a few games have been proposed in the literature. *Blindfarm* is an iOS game that uses both GPS and the compass sensor [5]. The purpose of this game is to help visually impaired children to

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learn paths they use in their daily life routines. For that, the game includes a feature that adults can use to mark a path by placing virtual animals in specific locations. Then the players have to follow the real path by listening to the vocalizations of the virtual animals in stereo sound. These sounds signal the direction towards which the child shall walk.

Another example was presented by Sánchez et al. in a project whose goal was to analyze the usability of an audio-haptic game and its influence in orientation and mobility skills [6]. This was a computer game in which the players had to navigate a virtual space while collecting objects as game goals. Although the virtual world was three-dimensional, the sound was not, which certainly limited the localization of the game sounds.

Both these games lacked the immersion needed to train certain orientation and mobility skills. None of them used three-dimensional sound, which is of great importance given the special condition of the target users. Also, the results presented by the authors were not conclusive and did not prove that their games were able to positively influence the children's orientation skills.

Here we propose an immersive audio game capable of implicitly teaching orientation skills to visually impaired students. The game uses 3D spatialized audio that is implemented with head-related transfer functions (HRTF). It gives children an opportunity to train their audio localization skills and other localization concepts like front/back, left/right, close/far, in an entertaining environment. Besides the main educational goals, the game's entertaining characteristics, help children to surpass self-confidence problems commonly felt by children with this type of disability.

In this paper we describe the game in detail, the design and development options, and the results of an early testing phase.

TECHNICAL DETAILS

The game was developed for the Android operating system, in Unity3D, which makes it very accessible to the general public. For convenience of the mobility teacher or parent it has an optional visual interface. As requirements it needs an Android device with a gyroscope sensor and a set of headphones. In order to process the sounds with HRTFs we integrated OpenAL[1] in Unity3D through a plug-in.

THE ORIENTATION AUDIO CHALLENGES

The proposed game consists of a set of three scored challenges designed to train orientation skills, such as performing accurate sound localization and other orientation concepts. The theme is attractive to a wide age range: it is about a scientist traveling in a space ship, who has to capture or photograph alive alien insects for posteriori analysis. The challenges consist of chasing a few types of insects or perform other tasks in the space ship.

Since the game is designed for blind and low vision users, there is no need to see the graphics to play. Sound (speech and 3D spacialized audio) and vibrations of the device are used to convey information to the users. The users interact with the game by touching the screen and moving the device. The players have to move in a virtual environment by turning the device towards the insects. They do not have to walk but they need to turn around holding the device with the screen facing their faces or chest. Information from the device's gyroscope is used to determine which direction the user is facing.

[1] http://openal.org/

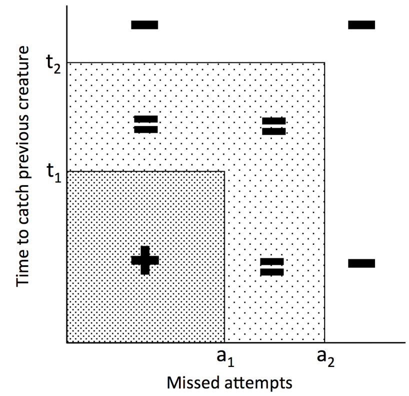

Figure 1. Adaptive difficulty rules.

In each of the three challenges, the player has to heavily use his/her hearing. The goal of the first challenge is to capture space roaches that escaped from a science laboratory. To achieve this, the player needs to detect the direction from which the creatures' sounds are coming from. These are static 3D spatialized sounds. If the player takes too long to capture the roach, the device vibrates and the roach disappears.

The second challenge is very similar to the first one, the only difference being that the creatures are alien bees that are flying around the player's position, while describing a sinusoidal motion (flying up and down). Again, 3D spatialized sound is used in this challenge.

Both these challenges have the option of being played with adaptive difficulty, that is, the difficulty can increase or decrease depending on the player's performance. This success-difficulty relation is depicted in figure 1 and follows the same difficulty-adaptation pattern as suggest in [3]. As it will be discussed in the next section, this feature was introduced only after the preliminary test had been performed. When the player is fast to capture the insects (i.e., he/she spends less than t_1 seconds) and does not miss many insects (less than a_1) the difficulty increases. The difficulty will remain the same if the player is fast but he/she misses more than a_1 insects, or if the player does not miss many insects but takes a bit longer to capture them (from t_1 to t_2 seconds). If the player takes to long to capture the insects or misses many of them, the difficulty will decrease.

The parameters t_1, t_2, a_1 and a_2 are easily reconfigured and have different values for the roaches challenge and the bees challenge (3, 6, 2, 4, respectively, for the roaches challenge, and 4, 7, 3 and 5, respectively, for the bees challenge).

In the third challenge, which we call the *Soundpath* challenge, the sounds have still another dimension: distance. In this challenge the player has to identify the direction from where the sound comes but also the distance of the sound source. The goal of this challenge is to navigate in a virtual room in search for objects that allow the player to complete simple tasks, like opening a door or activating a machine. In order to reach the objects, the player can walk in the virtual room. The interaction is very simple: the player can rotate the device like before and now he/she can also touch the screen to walk. In order to give players the notion of movement, when they choose the walking mode, the sound of footsteps is reproduced. In order to increase the difficulty of the challenge, some obstacles may be present in the room, requiring the player to identify and avoid them. The obstacles are sonified, so as to be identifiable in the environment just by sound.

This challenge has two distinct game modes: normal and puzzle. The normal mode consists of a fixed set of tasks, whose difficulty increases over progression. The puzzle mode requires some auditive memory from the player. When starting this mode, a sequence of sounds is reproduced and the player must then search the room for them, acquiring them in the correct order.

As mentioned before, the non-speech sounds used in the game are 3D spatialized sounds. We use HRTFs for this end. HRTF functions are used to reproduce the direction-dependent acoustic filtering of the sound waves caused by the head, torso, and pinnae. By having one HRTF function for each output signal, it is possible to reproduce a sound in a way that our brain can determine its location in both horizontal and vertical planes.

PRELIMINARY TESTS

We have run a preliminary test with visually impaired students in an inclusive school. The goal of the test was to ascertain how the students reacted to the game and if it had any compromising faults. Five students, two female and three male students with ages between 8 and 19 years old, participated in the test. All of them had severe visual impairments, two of them being legally blind.

During this test, the students tried the first version the game's three orientation challenges in a mobile phone and wearing headphones. Before starting the test, we explained them how to interact with the game. They were also told that they had to hold the phone in front of them and that to capture the insects they had to turn themselves along with the phone. Some of the students received some help on the first trials. After that, little or no instructions were given, except in cases of great difficulties.

The first conclusions of these tests were that, generally, all of the subjects enjoyed the game and had fun while playing it. The youngest one (an 8 year old blind girl) seemed to have a harder adaptation, possibly because she did not enjoy the game theme as much as the others. Noticeably, after inquiring the students their opinion about the game, they seemed interested in playing the full version of the game.

Another relevant conclusion concerned the motor coordination of the subjects. The game compelled them to rotate in their standing position, in order to rotate in the virtual environment. We observed that the blind participants tended to rotate the upper body, leaving their feet fixed on the ground. Low vision participants did not show this behavior as pronounced as blind participants. In discussion with a special education school teacher who accompanied the testing, we concluded that this behavior was probably caused by their lack of security regarding the surrounding environment. It was then acknowledged that the game could have a positive impact in such motor coordination details, which contributes to the students' orientation and mobility skills.

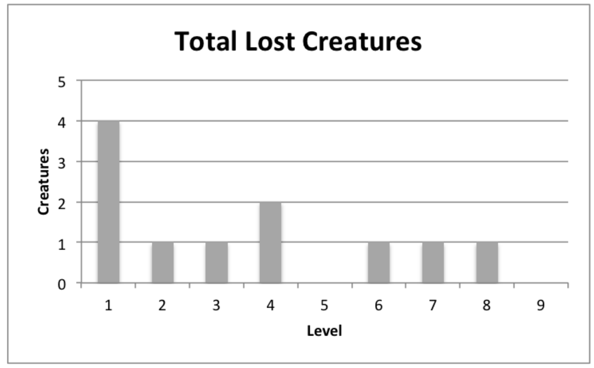

Figure 2. Total number of lost static roaches on the first orientation challenge. The ith bar indicates how many participants failed the ith roach.

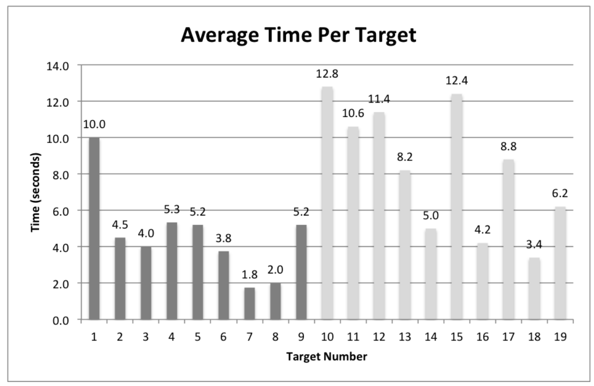

Figure 3. Average time spent to catch each insect on the first two challenges. The ith bar indicates the average time spent by all participants to catch the ith insect.

The three-dimensional sonification of the game was also implicitly tested and approved by all subjects. The first challenge, i.e. the challenge with the static roaches, proved that the sounds are easily located in the horizontal plane, whereas the second challenge, with the flying bees, proved that the movements of the sound source on both horizontal and vertical plane are also easily noticeable.

We observed that there was a learning pattern in the first two challenges (that is, the static roaches and the flying bees challenges). This can be confirmed by inspecting figures 2 and 3. Figure 2 contains information about the total number of lost roaches in the static roaches orientation challenge. Figure 3 shows the average time that the participants spent with each insect. The roaches challenge is represented by the dark grey bars, while the bees challenge is represented by the light gray ones. For example, the first bar in figure 2 shows that four of the five participants were not able to capture the first roach, that is, only one participant was able to capture the first static roach. The first dark gray bar in figure 3 shows that that participant took 10 seconds to catch the first static roach. The second insect had considerably better results. The second bar in figure 2 shows that only one participant missed the second roach, and the second bar in figure 3 shows that the other four participants took 4.5 seconds on average to catch the second roach. These two graphs show that while the first static roach was difficult to catch, the participants quickly adapted to the game and showed good performance from the second to the 9th roach.

Also worth noticing is the difficulty felt by the players in the bees challenge, compared to the roaches one. The light gray bars in figure 3 show the average time spent to catch the flying bees. Though the average times are higher for the bees than for the roaches, the graph shows that the players also adapted to this challenge as they spent less time to catch the last bees than the first few ones. Despite occasional longer times, all the participants had a considerably good performance, in a game beyond anything they had yet played.

Apart from some initial difficulties on learning how to to turn the body in the same direction as the phone, the subjects quickly learned how to play the game, having little difficulties after that. One of the test subjects adopted a technique that consisted on touching the screen repeatedly and quickly (even before he could hear the insect), in order to eventually hit the target. In response to this behavior, we improved the challenges, including a scoring system and an adaptive difficulty mechanism that do not favor this type of behavior.

The third challenge, i.e. the *Soundpath* challenge, had only two sound sources, one reproduced by Unity3D's audio engine and the other by using HRTFs. Here we wanted to understand if Unity3D's sounds were good enough or if we required a more complex technique to process the sounds.

The performance of the subjects and their comments about this challenge proved that Unity3D's audio engine is not adequate for this game, as it cannot produce real three-dimensional sound. This happens because Unity3D only panns the sound over the two output signals. Sound panning is clearly insufficient because it does not provide enough sound clues to determine if a sound is in front or behind the subject, the same happening to sounds on the vertical plane. The sounds processed with HRTFs, on the other hand, proved to be efficient.

CONCLUSION

Here we proposed an educational game specially designed for visually impaired children. The goal of this game is to help visually impaired children to improve their orientation skills, while having fun with something usually inaccessible to them. The game is played on a common smartphone and is characterized by its immersiveness and ease of use. This was possible by using HRTFs, which allowed us to create a realistic three-dimensional sound environment, through which the player can localize sounds in space.

The results of a preliminary test with visually impaired students showed that the students enjoyed the game and easily understood how to play it. We also observed the immediate impact of the game in the motor coordination of the participants when they needed to turn around but kept their feet static. This showed that access to these activities can have a positive impact in this type of motor coordination abilities.

Since the youngest participant, an 8 year old girl, seemed less interested in the game's theme, as future work, we will introduce the option of having a theme more adequate for younger girls. The tasks in the challenges will be essentially the same but with other sounds and another story. This can be done with little development effort, as all the game objects are easily configurable. Finally, in order to validate the game, we will also run a more formal user study with visually impaired children that will last for a few weeks.

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