3D AUDIO AND HAPTIC INTERFACES FOR TRAINING THE SPATIAL ACOUSTIC RESOLUTION IN VIRTUAL AUDITORY ENVIRONMENTS

Oana Bălan, Alin Moldoveanu, Florica Moldoveanu

University POLITEHNICA of Bucharest,
Faculty of Automatic Control and Computers,
060042, Bucharest, Romania
oanab_2005@yahoo.com

ABSTRACT

In order to design an effective audio-based assistive device, we have to consider the users' sound localization performance and spatial auditory resolution. As most of the virtual auditory displays employ 3D binaural sounds synthesized from non-individualized Head Related Transfer Functions (HRTF) which offer an ambiguous spatial auditory perception, we identified the need of training the visually impaired subjects' sound localization abilities through a perceptual feedback based learning approach. This research is oriented towards the study of binaural sounds, audio games and virtual auditory displays as rehabilitative tools for the visually impaired people. In particular, we are focused on developing effective methods for training the sound localization accuracy and spatial auditory perception of the blind people, based on perceptual feedback training and multimodal sensorial interaction.

1. INTRODUCTION

Training plays an important role in improving the sound localization abilities of the blind listeners. The subjects who received intensive auditory training were able to better process the spatial information and to assess the visual principles of navigation and orientation [1], [2], [3].

We performed two experiments with the sighted and visually impaired people in order to study and compare the level of spatial auditory performance they can achieve as a result of training. The theoretical and practical results obtained in our research will be used for creating an effective strategy aimed at improving the sound localization accuracy of the visually impaired people and for designing 3D audio games that are targeted for both the blind community and for the sighted players.

2. THE SOUND LOCALIZATION EXPERIMENTS

2.1. Overview

9 sighted and 9 visually impaired people took part in our experiments. We obtained written consent from each person before participating in this research.

The target sounds consisted of a combination of continuous Gaussian white and pink noises that were perceived simultaneously, in varying proportions, according to the direction of the sound source in space [4]. We designed a method aimed at reducing the high rates of front-back confusions in virtual auditory environments that is based on the spectral coloration of the sound.

Another sound cue that we used was a repetitive (with short breaks) "ding" type signal. Both the white-pink noise combination signals and the "ding" sounds were convolved in real-time with the generic HRTFs from the CSound HRTF database [5]. All the 3D sounds have been generated in the horizontal plane, with 0 degrees elevation in the vertical plane.

2.2. The pre-test and post-test sessions

In the pre-test session of the experiments, we tested the sound localization accuracy and navigational skills of our subjects by using a virtual auditory application called Binaural Navigation Test. The Binaural Navigation Test is a graphical interface that requires the subjects to move freely (using the mouse cursor movement as the main method of interaction) from the starting position (randomly generated on the margin of a circle of 150 pixels radius) to the sound target (located in the center of the circle). Each block of trials consisted of 20 rounds (for the rounds numbered from 1 to 5 and from 11 to 15 we used the combination of white and pink noise and for the rounds numbered from 6 to 10 and from 16 to 20 we employed the "ding" sound as the main auditory navigation cue). The sound localization approach was based on 3D binaural sounds that have been delivered to the listeners through stereophonic headphones and on the inverse proportional sound intensity encoding of distance (as the listeners got nearer to the sound source, the sound intensity increased and as they got farther, the perceived amplitude decreased until total silence).

2.3. The training session

The training session offered multimodal perceptual feedback (auditory, haptic and visual – for the subjects with a higher percent of residual vision) about the correct direction of the sound source in the horizontal plane. The training session had the following three modules:

a). A free listening module in which the subjects were required to move the mouse cursor inside a circle and could hear at the same time the sound that corresponded to the pointed direction *(available in both experiments).*

b). A sound discrimination procedure with increasing levels of difficulty, with four virtual sources in the first round and eight in the second round, for both types of sounds. In the first round, the four sound sources have been randomly disposed in space (in each of the four quadrants of the auditory space – upper-right, bottom-right, bottom-left and upper-left). In the second round, the number of targets extended to eight (two sound sources in each quadrant). The auditory targets have been encoded as small circles of 5 pixels radius. The listeners were sequentially presented the 3D binaural sounds corresponding to the virtual sound targets and asked to indicate the perceived direction by clicking on the small circles assigned to each of them. When the listeners succeeded to identify the correct location of the sound sources, the small circles disappeared, reducing thus the searching range for the next targets *(available in the experiment with sighted subjects).*

c). A set of sound localization trials, in which the subjects were required to listen to various 3D binaural sounds and to point inside a circle the perceived direction of the incoming stimuli. Each block of trials consisted of 10 consecutive rounds, having as target stimuli the white-pink noise combination and 10 rounds in which the main auditory cue was the "ding" sound. The users were asked to listen carefully to the target sounds in order to recognize their spectral characteristics (especially in the case of the white/pink noise) and directionality and consequently click inside the circle to indicate their perceived location. The users were offered instant audio-visual feedback - the correct direction of sound was pointed on the screen (colored in green), together with the subject's choice (colored in red). In order to recalibrate the hearing and visual senses, the subjects were offered auditory feedback, as they could hear the target sound again in the headphones *(available in the experiment with sighted subjects).*

d). A sound localization session in which the subjects were required to listen to different sound stimuli (corresponding to the directions 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 and 330 degrees) and to indicate their apparent direction using the conventional hour hand of the clock (for example, 12 o'clock for 0 degrees to the front, 3 o'clock for 90 degrees to the right or 6 o'clock for 180 degrees to the back). After the subjects indicated the response, they were offered perceptual feedback about the correct direction of the sound. Thus, they felt a series of vibrations on the haptic belt they were required to wear on the head, corresponding to the direction of the 3D binaural sound that has been emulated over the headphones. The subjects who had some degree of residual vision received simultaneous visual feedback - the correct direction of the sound source was presented graphically on the screen (colored in green), at the same time with the listener's choice (colored in red). Auditory feedback has been provided in order to build an effective association between the 3D sounds and their direction. Each block of trials consisted of 12 rounds that used the white/pink noise and another 12 rounds that used the "ding" sound as the main auditory stimulus *(available in the experiment with visually impaired subjects*).

3. RESULTS

The results of our experiments demonstrated a rapid adjustment of the auditory system to the perception of 3D sounds synthesized from non-individualized HRTFs. We reported significant improvements in the sound localization accuracy and general spatial auditory resolution of our subjects, which is reflected in a lower rate of front-back confusions and in a decrease in the angular localization error. The perceptual learning process that took place during the training session enabled the subjects to focus on the spectral characteristics of the sound and to associate the perceived acoustic stimuli with their corresponding direction in space that was provided through haptic/visual feedback. The adaptation and recalibration process was rapid, demonstrating that other cognitive mechanisms, such as attention and focus have been used during perceptual learning. The improvements are more significant for the white-pink noise combination, due to their wider spectral profile and higher level of externalization. Nonetheless, we have demonstrated that other types of sounds (with a narrower spectral profile, such as the "ding" sound) can be localized effectively and present a significant potential for sound localization enhancement as a result of perceptual feedback based training.

4. CONCLUSIONS

Our studies demonstrated that both the visually impaired and sighted individuals are able to adapt to altered hearing conditions, such as the use of 3D sounds generated from non-individualized HRTFs in virtual auditory environments. They improved their spatial auditory resolution, sound localization accuracy, orientation and mobility skills and directional decision-making abilities. In conclusion, the proposed approach can be considered a useful training and rehabilitation tool for the future development of audio-only games or for the design of an assistive device for the blind people. Our research will continue by designing a navigational audio game, using the same sonification method as in the previous applications. The results that will be obtained will be integrated into a training procedure aimed to help the visually impaired people learn how to use a sensory substitution device.

5. ACKNOWLEDGMENT

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132395. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 643636 "Sound of Vision".

6. REFERENCES

[1] O. Bălan, A. Moldoveanu, F. Moldoveanu, M.I. Dascălu, "Navigational 3D Audio-Based Game - Training Towards Rich Auditory Spatial Representation of the Environment", *Proceedings of the 18th International Conference on System Theory, Control and Computing*, Sinaia, Romania, October 17-19, 2014, pp. 688-693.

[2] O. Bălan, A.Moldoveanu, F. Moldoveanu, I.Negoi, "The Role of Perceptual Feedback Training on Sound Localization Accuracy in Audio Experiments", *Proceedings of The 11th International Scientific Conference eLearning and software for Education*, Bucharest, April 23-24, 2015

[3] C. Mendonça, "A review on auditory space adaptations to altered head-related cues", *Front Neurosci*., vol. 219, no. 8, 2014

[4] Á. Csapó, Gy. Wersényi, Overview of auditory representations in human-machine interfaces, Journal ACM Computing Surveys (CSUR), Vol.46, No.2., Nov. 2013

[5] Csound, 2015. Available at: http://www.csounds.com