Sonification of Spatial Information: Audio-Tactile Exploration Strategies by Normal and Blind Subjects

Marta Olivetti Belardinelli[1,2], Stefano Federici[2,3], Franco Delogu[1], and Massimiliano Palmiero[2]

[1] Department of Psychology, 'Sapienza' University of Rome, Rome, IT
[2] ECONA, Interuniversity Centre for Research on Cognitive Processing in Natural and Artificial Systems, IT
[3] Department of Human and Educational Sciences, University of Perugia, Perugia, IT
marta.olivetti@uniroma1.it

Abstract. On the basis of a meta-analysis of existing literature about sonification technologies, new experimental results on audio-tactile exploration strategies of georeferenced sonificated data by sighted and blind subjects are presented, discussing: technology suitability, subjects' performances, accessibility and usability in the user/technology interaction.

Keywords: sonification, blindness, mental mapping, audio-tactile exploration strategies.

1 Three Orders of Problems in the Cognitive Research on Sonification

In recent years researchers have been increasingly attracted by the possibility of conveying spatial information through non-visual sensory channels. In particular, the sonification technology that implements non-speech audio information to represent data allows "the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication and interpretation" [1].

Three orders of problems are tied to the substitution of the auditory sensory channel to the visual one: 1) from an *objective point of view*, the capacity of the acoustic mean to convey information similar to the visual one has to be proven; 2) from a *subjective point of view* one may wonder if the potential information represents also a real one; 3) from the point *of view of the interaction* user/environment the problems regard the effective possibility for the user to explore and navigate a non-visual representation of space.

Taking into account the objective point of view, several parameters of the sound (timbre, frequency and intensity) may be combined in a meaningful percept in order to make sonification feasible to a large variety of fields, as well as to segregate or group multiple simultaneous sources, even minimizing the working load.

Spatial information by means of acoustic messages can be provided with speech, music and environmental sounds. In all cases a learning or training phase is therefore mandatory for the sonification to be effective.

C. Stephanidis (Ed.): Universal Access in HCI, Part II, HCII 2009, LNCS 5615, pp. 557–563, 2009.

The objective point of view about sonification redirects therefore the researchers' interest to a subjective perspective related to the allocation of attentional resources in auditory and visual spatial perception. In fact, it is questionable whether the representation of space is directly tied to the visual experience or rather it is an a-modal one either collecting information from different senses or forming equivalent representations from different sensory channel inputs. If spatial representations generated by different sensory modalities besides vision are functionally equivalent to the visual representation of space [4] blind people should be potentially able to gather functionally equivalent spatial mapping using tactile, auditory and kinaesthetic information, contending by this way with the absolute necessity of visual experience for spatial understanding [34]. On the other side the subjective perspective cannot be separated from the interactive one, according to which the central focus of investigation is shifted toward the possibility of space exploration and navigation and to the distinction between egocentric and allocentric space, founded on to two different frames of reference: the egocentric frame of reference and the allocentric one.

2 Coding and Processing Strategies of Non-visual Spatial Information

When exploring the near-space, people with little or no visual experience generally prefer to code spatial relations by reference to their own body co-ordinates [26]. Following this view blind and sighted individuals should perform similarly in tasks requiring an egocentric reference [19], although a recent investigation on the systematic distortions in blind haptic exploration put in evidence a shift from an egocentric to an allocentric representation when a delayed or a verbal response is required [32].

The auditory coding aimed to supply a mental representation of space [20], [28] was not extensively investigated, due to the peculiarity of auditory processing at the sensory, neural and cognitive levels (once more the subjective perspective) and, perhaps much more, to the technical contingencies in developing fit softwares for new communication modalities or augmented communication (objective perspective).

From the subjective perspective experimental results seem to converge into the idea that a combination of sound and touch will work better than a single modality in non-visual displaying of spatial information [40]. Already in 1984 Wikens [35] verified that sound can enhance a visual or haptic display. More recently Ramloll, Yu, Riedel, and Brewster [33] found that a combination of touch and sound will provide the optimal technology to read line graphs. A combination of haptic and auditory information is used in *iSonic*, a new sonification tool developed at the University of Maryland to facilitate the exploration of georeferenced information [37], [38], [39].

3 Sonification as a Means for Communicating Spatial Information

Taking into specific account the objective perspective the first systems were loudspeakers-based systems, simulating sound sources from different locations [12], [16] that may be used solely in indoor environments, with parameters such as distance, resolution, etc. already fixed.

Much more possibilities are offered by bat-like sonar systems relying on distance cues to analyze the auditory scene and to generate acoustical spatial maps by means of ultrasounds [17], [18], or musical scale [15], although some difficulties to judge the height of obstacles have been reported [7], [25].

The most of the sonification tools implement Head Related Transfer Function (HRTF). These systems particularly rely on binaural cues and pinna filtering to analyze the auditory scene. Individualization of the HRTF system is also possible, especially when sound elevation is needed [5]. However the HRTF systems allow blind users only to localize objects which are in a limited perimeter within which they move around.

4 Sonification and the Blinds: Is Technology Really Assistive?

One of the most important trends in sonification applications regards sensory substitution and sensory integration for visually impaired people, although most research on sonification for blind people, being authored by computer scientists and not by psychologists, scarcely consider both the subjective perspective and the interactive one, very often using unsatisfactory definitions of accessibility and usability. Moreover most experiments are carried only with sighted blindfolded subjects.

Very few systems, attempted to relate sonification to vision as in Meijer's software [23]: here visual information is analyzed by a software that sweeps the images with a vertical scan line. However, it was proved that continuous scanning of the environment from left to right may confuse the user and requires considerable concentration even if after an intensive training neural plasticity from hearing to vision may occur with the activation of the lateral-occipital tactile-visual area in sighted subjects [3], as well as in a congenitally and a late blind subject [24].

In a recent Conference Ag Asri Ag [1] presented a HCI Sonification Application Model for usability inspection, based on the Toolkit Technology for Interactive Sonification by Pauletto & Hunt [29], without giving information about subjects and results. Similar shortages of information can also be found in Candey et al. [6].

Auditory information, either verbal or musical, was added in some studies to other sensory information to enhance performances [21], [30], [31], [11], [13], nervertheless, none of these studies assessed the accessibility and usability of the tested devices on blind users.

A slight different situation characterizes the research on exploration and navigation of sonificated spatial representations, that demonstrated on blind users the capacity to identify mathematical concepts [22], simple 2-D graphical shapes[2] and table data location and acquistation [33]. Everinova showed that directional-predictive sounds are reliable and effective in guiding blind's exploratory behaviour [10], and Heuten et al. [14] assessed on blind users the accessibility of a new sonification interface to explore city maps.

In the above cited *iSonic* the software accessibility was tested before on blindfolded sighted subjects [9], then comparing blindfolded, congenitally and acquired blinds [27], [8] and finally with an intensive use of the software by subjects totally blind since long time [36].

5 Audio-Tactile Exploration Strategies: Comparing Normal and Blind Subjects

In *iSonic* different musical instruments indicate different map features and exploring contexts, while different pitches indicate different levels of a given geopolitical variable (e.g. unemployment, or crime rate statistics). Map exploration may be performed using two different navigation tools: a computer keyboard or a touch-pad. Recently Delogu et al. [39] demonstrated that congenitally blind, acquired blind and blindfolded people did not significantly differ in good recognition performances by means of both interfaces. These results confirm the suitability of the acoustic mean to convey spatial information (objective point of view).

In the following we will try to clarify if sighted blindfolded, congenitally blind, and acquired blind subjects: 1) perform differently in the recognition of sonificated maps (subjective point of view) and 2) deploy different strategies and modalities into the audio-haptic exploration of sonificated maps (interactive point of view).

In the first experiment 20 blind participants (10 early and 10 late) and 16 sighted blindfolded subjects explored three sonified auditory maps representing patterns of unemployment rates in U.S.A. 4 plastic tactile maps for each task were used in the recognition phase, one target (corresponding to the sonificated one) and three distractors.

After the auditory exploration of each one of the maps (either by means of the keyboard or the touch-pad), subjects performed a tactile recognition of the navigated map among three distractors. The analyses showed that in all tasks the target tactile map was well recognised and that congenitally blind, acquired blind and sighted blindfolded subjects do not differ in detecting targets in all tasks. No differences among the groups were found in relation to *exploration exhaustiveness, preferred direction* toward the right, and *direction change* generally coinciding with the variations in sound. Viceversa as regards the *displacement velocity* index, the congenitally blind subjects perform quite the double amount of steps with respect to both late blind and sighted subjects. In the final questionnaire blind subjects answered very differently from the sighted ones, judging the proofs more simple and the stereo-panning more important in orienting exploration.

To further investigate these differences the above described paradigm was repeated with 20 new blind subjects. After each task they were requested to reproduce the sonificated map by inserting plastic nails in a punched board to delimitate the map external borders, and three more kinds of nails, of different sizes, to indicate the employment rates. This way, we obtained a quantitative and tangible external representation of subjects' mental map. The analysis shows that the reproductions of the sonificated maps explored by touchpad users are much more accurate in terms of boundaries and inner details than the ones made by keyboard users. Moreover the reproduction through keyboard navigation shows a systematic reproduction error in the bottom left corner, probably due to the left/right direction of the sweeping.

To conclude our results indicate: 1) Sonification integrated with tactile exploration may be a suitable tool for transmitting spatial geographical information (*objective perspective*). 2) The equivalent recognition performances of sighted, acquired blind and congenitally blind subjects is in accordance with the hypothesis of a possible equivalence of different sensory channels in transmitting spatial information, consistently with the hypothesis of an a-modal representation of space results (*subjective* *perspective*). 3) As for the *interactive perspective*, the higher speed of congenitally blind as well as the better information reproduction after touch-pad navigation, provide interesting insights about multimodal integration in space navigation.

References

1. Ag Asri Ag, I.: Task analysis for sonification applications usability evaluation. In: Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility. ACM, Portland (2006)
2. Alty, J.L., Rigas, D.: Communicating graphical information to blind users using music: the role of context. In: ACM CHI, pp. 574–581. ACM Press/Addison-Wesley Publishing Co, New York (1998)
3. Amedi, A., Stern, W.M., Camprodon, J.A., Bermpohl, F., Merabet, L., Rotman, S., Hemond, C., Meijer, P., Pascual-Leone, A.: Shape conveyed by visualto-auditory sensory substitution activates the lateral occipital complex. Nat. Neurosci. 10(6), 687–689 (2007)
4. Avraamides, M., Loomis, J., Klatzky, R.L., Golledge, R.G.: Functional equivalence of spatial representations derived from vision and language: Evidence from allocentric judgments. J. Exp. Psychol. Learn. 30, 801–814 (2004)
5. Berman, L., Danicic, S., Gallagher, K., Gold, N.: The Sound of Software: Using Sonification to Aid Comprehension. In: 14th IEEE International Conference on Program Comprehension, ICPC, IEEEXPLORE (2006)
6. Candey, R.M., Schertenleib, A.M., Diaz Merced, W.L.: Sonify sonification tool for space physics. In: ICAD, pp. 289–290 (2006)
7. Davies, T.C., Patla, A.E.: Obstacle Avoidance Strategies Using a Sonic Pathfinder. In: Canadian Society of Biomechanics, Halifax, Nova Scotia (2004)
8. Delogu, F., Federici, S., Olivetti Belardinelli, M.: La rappresentazione di mappe sonificate in soggetti ciechi: modalità e strategie di esplorazione audio-tattile. In 14th AIP (2008)
9. Delogu, F., Olivetti Belardinelli, M., Palmiero, M., Pasqualotto, E., Zhao, H., Plaisant, C., Federici, S.: Interactive sonification for blind people exploration of geo-referenced data: comparison between a keyboard-exploration and a haptic-exploration interfaces. In: Cogn. Process. 7 (suppl. 1), pp. 178–179 (2006)
10. Evreinova, T., Vesterinen, L., Evreinov, G., Raisamo, R.: Exploration of directional-predictive sounds for nonvisual interaction with graphs. Knowl. Inf. Syst. 13(2), 221–241 (2007)
11. Garcia-Ruiz, M.A., Arthur, E., Aquino-Santos, R., Vargas Martin, M., Mendoza-Quezada, R.: Using Sonification to Teach Network Intrusion Detection: A Preliminary Usability Study. In: World Conference on Educational Multimedia, Hypermedia and Telecommunications, pp. 849–857. AACE, Cheasepeake (2007)
12. Golledge, R.G., Loomis, J.M., Klatzky, R.L., Flury, A., Yang, X.L.: Designing a personal guidance system to aid navigation without sight: progress on the GIS component. Int. J. Geo. Inf. Sci. 5(4), 373–395 (1991)
13. Guizatdinova, I., Guo, Z.: Sonification of Facial Expressions. University of Tampere, New Interaction Techniques Finland (2003)
14. Heuten, W., Wichmann, D., Boll, S.: Interactive 3D Sonification for the Exploration of City Maps. In: NordiCHI, pp. 155–164 (2006)
15. Heyes, T.: Sonic Pathfinder. Electr. & Wireless World 90, 26–29 (1984)

16. Kawai, Y., Kobayashi, M., Minagawa, H., Miyakawa, M., Tomita, F.: A Support System for Visually Impaired Persons Using Three-Dimensional Virtual Sound. In: ICCHP 2000, pp. 327–334 (2000)
17. Kay, L.: Auditory perception of objects by blind persons, using a bioacoustic high resolution sonar. J. Acoustical Soc. Am. 107, 3266–3275 (2000)
18. Kay, L.: Bioacoustic spatial perception by humans: a controlled laboratory measurement of spatial resolution without distal cues. J. Acoustical Soc. Am. 109, 803–808 (2001)
19. Klatzky, R.L., Golledge, R.G., Loomis, J.M., Cicinelli, J.G., Pellegrino, J.W.: Performance of blind and sighted persons on spatial tasks. J. Visual. Impair. Blin. 89, 70–82 (1995)
20. Lakatos, S.: Recognition of complex auditory-spatial patterns. Perception 22(3), 363–374 (1993)
21. Maffiolo, V., Chateau, N., Mersiol, M.: The impact of the sonification of a vocal server on its usability and its user-frendliness. In: ICAD, pp. 130–134. Published by Advanced Telecommunications Research Institute (ATR), Kyoto (2002)
22. Mansur, D.L., Blattner, M., Joy, K.: Sound-Graphs: A numerical data analysis method for the blind. J. of Med. Sys. 9, 163–174 (1985)
23. Meijer, P.B.: An experimental system for auditory image representations. IEEE Trans. Biomed. Eng. 39, 112–121 (1992)
24. Merabet, L., Pogge, D., Stern, W., Bhatt, E., Hemond, C., Maguire, S., Meijer, P., Pascual-Leone, A.: Activation of visual cortex using crossmodal retinotopic Mapping. In: 14th HBM, the Annual Meeting of the Organization for Human Brain Mapping, Melburne, Australia (2008)
25. Milios, E., et al.: Sonification of range information for 3-D space perception. IEEE Trans. Neural Sys. Rehab. and Eng. 11(4), 416–421 (2003)
26. Millar, S.: Understanding and representing space: theory and evidence from studies with blind and sighted children. Oxford University Press, Oxford (1994)
27. Olivetti Belardinelli, M., Delogu, F., Palmiero, M., Federici, S., Pasqualotto, E., Zaho, H., Plaisant, C.: Interactive sonification of geographical maps: a behavioural study with blind subjects. In: 15th ESCOP (2007)
28. Parente, P., Bishop, G.: BATS: the blind audio tactile mapping system. In: ACM Annual Southeast Regional Conference (2003)
29. Pauletto, S., Hunt, A.: A Toolkit for Interactive Sonification. In: ICAD (2004)
30. Pfeiffer, D.G., Maffiolo, V., Chateau, N., Mersiol, M.: Listen and Learn: an Investigation of Sonification as an Instructional Variable to Improve Understanding of Complex Environments. Comput. Hum. Behav. 28(2), 475–485 (2008)
31. Poguntke, M., Ellis, K.: Auditory attention control for human-computer interaction. In: Human System Interactions IEEEXPLORE, pp. 231–236 (2008)
32. Postma, A., Zuidhoek, S., Noordzij, M.L., Kappers, A.M.L.: Keep an eye on your hands: on the role of visual mechanisms in processing of haptic space. Cogn. Process. 9(1), 6–68 (2008)
33. Ramloll, R., Yu, W., Riedel, B., Brewster, S.A.: Using non-speech sounds to improve access to 2D tabular numerical information for visually impaired users. In: Annual conference of British Computer Society (BCS) IHM-HCI, pp. 515–530. Springer, Heidelberg (2001)
34. Ungar, S.: Cognitive mapping without visual experience. In: Kitchin, R., Freundschuh, S. (eds.) Cogntive Mapping: Past, Present and Future, pp. 221–248. Routledge, London (2000)
35. Wickens, C.D.: Processing resources in attention. In: Parasuraman, R., Davies, R. (eds.) Varieties of attention, pp. 63–101. Academic Press, New York (1984)

36. Zhao, H., Shneiderman, B., Plaisant, C.: Listening to Choropleth Maps: Interactive Sonification of Geo-referenced Data for Users with Vision Impairment. In: Lazar, J. (ed.) Universal Usability, pp. 141–174. John Wiley & Sons Ltd, Hoboken (2008)
37. Zhao, H., Plaisant, C., Shneiderman, B., Duraiswami, R.: Sonification of geo-referenced data for auditory information seeking: design principle and pilot study. In: ICAD (2004)
38. Zhao, H., Smith, B.K.,, Norman, K., Plaisant, C., Shneiderman, B.: Interactive Sonification of Choropleth Maps: Design and Evaluation. IEEE Multimedia 12(2), 26–35 (2005)
39. Zhao, H., Shneiderman, B., Plaisant, C.: Listening to Choropleth Maps: Interactive Sonification of Geo-referenced Data for Users with Vision Impairment. In: Lazar, J. (ed.) Universal Usability, pp. 141–174. John Wiley & Sons Ltd., Hoboken (2008)
40. Zuidhoek, S.: Representation of space based on haptic input. Febodruck, Utrecht (2005)