Perception of multi-varied sound patterns of sonified representations of complex systems by people who are blind

O Lahav[1], J Kittany[1], S T Levy[2], M Furst[3]

[1]School of Education, Tel Aviv University, ISRAEL

[2]Faculty of Education, University of Haifa, ISRAEL

[3]Faculty of Engineering, Tel Aviv University, ISRAEL

lahavo@post.tau.ac.il

ABSTRACT

Listening to Complexity is a long-term research project, which addresses a central need among people who are blind: providing equal access to the science classroom, by allowing them to explore computer models, independently collect data, adapt and control their learning process. The innovative and low-cost learning system that is used in this project is based on the principle of perceptual compensation via technologies, by harnessing the auditory mode to transmit dynamic and spatial complex information, due to its unique affordances with respect to vision. Sonification of variables and events in an agent-based NetLogo computer model is used to convey information regarding both individual gas particles and system-wide phenomena, using alerts, object and status indicators, data representation and spatial audio displays. The paper describes two experiments: (1) Auditory perception of varying types of auditory representations, spatial trajectories of a modeled object's motion, relative intensity, and frequency; and (2) Auditory perception of complex sound patterns – exploring detection and recognition of multiple sound channels at different complexity levels of sound patterns. The research would serve to improve our understanding of the auditory processes by which perception of sound patterns takes place and transforms into a conceptual model. The long-term practical benefits of this research are likely to have an impact on science, technology, engineering and mathematics education for students who are blind.

1. INTRODUCTION

1.1 Science Education for Students who are Blind

The project addresses a central need among students who are blind: accessing information in exploratory learning of science. Students who are blind have been integrated into public schools for more than 60 years and are required to complete the same curriculum and assessments as sighted students. However, they are prevented from access to firsthand information, as many science education resources are based on the visual channel (Beck-Winchatz and Riccobono, 2008). In the past 40 years several manuals have been written on how to teach science to students who are blind and visually impaired (Hadary and Cohen, 1978; Kumar et al, 2001; Willoughby and Duffy, 1989). However, research into their application and impact on learning is sparse (Zaborowski, 2006). Few learning environments based on assistive technologies have been created to support science learning, such as the use of a force-feedback mouse to learn physics (Farrell et al, 2001; Wies et al, 2001).

1.2 Auditory Information Technologies for People who are Blind

The learning process of people who are blind is based on gathering information through perceptual and conceptual tools (Passini and Proulx, 1988). At the perceptual level, the shortage in visual information is compensated for by other senses such as the haptic, auditory and olfactory senses. Similar to other supportive environments, the Listening to Complexity (L2C) system is based on the principle of perceptual compensation via technologies (Lahav and Levy, 2010). L2C harnesses the auditory mode to transmit dynamic complex information. The choice of an auditory display results from three considerations: (a) the auditory mode transmits information that changes both in space and time, similar to the visual mode and different from the haptic mode; (b) the auditory mode easily interfaces with large bandwidths at fine frequency-discrimination and intensity-discrimination thresholds (Capelle et al, 1998); (c) the auditory system is used to dealing with complex and rapidly changing sound patterns (Hirsh, 1988). In fact, it has been found that individuals who are blind can recognize 2D shapes through audition that activates the right dorsal extrastriate visual cortex (Collignon et al,

2007). Sonification is the presentation of information using non-speech sound (Kramer, 1994).

Over the years, it was found that congenitally blind subjects were able to recognize auditory coded visual patterns related to hand movement (Arno et al, 2001). Subjects not only memorized simple associations between sounds and patterns; but they also learned the relationship between the auditory code and spatial attributes of the patterns. Research into the impact of different components of sound on auditory perception has shown that increasing the number of channels beyond three causes degradation in comprehension (Stifelman, 1994) and that a greater frequency separation between sound streams results in better stream segregation (Bregman, 1990). In the current project, we go beyond these studies in several ways. On one hand, we use sound to represent a dynamic rather than a static array. Moreover, the referents of the dynamic representation are multiple and operate at two system levels. Finally, we test how systematic variation of several different sound pattern features impacts detection and recognition of multiple channels, extending research into auditory perception. Few systems were developed to support Science, Technology, Engineering and Mathematics (STEM) education among students who are blind, such as the Talking Tactile Tablets (Landau et al, 2003) based on audio and 2D tactile materials, supporting interaction with 2D images for learning mathematical and science diagrams. The Line Graphs technology is based on auditory and haptic feedback and is geared to learning mathematics (Ramloll et al, 2000). The reported studies continue research into auditory compensation for visual information among students who are blind and extend it to both perception of dynamic and complex displays and learning about dynamic complex systems. The two experiments tackle a major challenge and require a leap above the current state-of-the-art in several research disciplines such as Computer Science, Learning Sciences, Auditory perception, and Human-Machine Interaction. We seek a deeper understanding of the neuroscientist Bach-y-Rita's phrase on brain plasticity: 'We see with the brain, not the eyes' (1972). To reach this overall goal we focus on two main experiments:

1. Auditory perception of varying types of auditory representations, the spatial trajectory of a modeled object's motion, relative intensity and frequency of sound.
2. Auditory perception of complex sound patterns, varying the number of sound streams, identity of the sonification components, their number, relative intensity and frequency.

2. METHODS

2.1   Sample Selection

The study included ten participants selected through snowball sampling for both experiments. A severe limitation is the small number of blind students in the proposed age bracket in Israel, resulting in a relatively small sample. They were chosen based on six criteria: at least 15 years old; comfort in use of computers; not multi-handicapped; normal hearing; total blindness; and onset of blindness at least two years prior to the experimental period. The participants' age range was 15-36, an average of 24 years old, five participants were female, eight were congenitally blind, five participants had residual vision but none used this in their everyday life. All the participants are proficient computer users, all learned STEM in their preliminary and high schools. All participants were with normal hearing, four participants played a musical instrument and one was member in a choir. The researchers obtained a sample of ten students, with similar proportions in terms of gender, age, and musical knowledge. The consenting guardians were made fully aware of the research framework and the specific experiments.

2.2   Variables

Nine Independent variables were defined, first three variables are connected to the research participants: age of onset of blindness; gender; and musical background. The next three variables are related to Experiment One: sonification type (musical instruments, inanimate objects' sounds, man-made sounds, and animal's sounds); spatial trajectory of the modeled object's motion; and sound frequency. The last three variables are associated with Experiment Two: sound intensity (loudness); Complexity of sound pattern (event frequency and complexity); and number and type of sound streams. Three dependent variables are defined: Preferences among sonified representations (Rating of the pleasantness of the sound, Most disliked (1); Dislike (2); Neutral (3); Like (4); and Most liked (5)); response time; and error rate in sound pattern recognition

2.3   Research instruments

This research included four implementation tools, and four data collection tools. The four implementation tools were the following: (i) Research apparatus - the recorded sounds were played through an Excel file running under Windows 7 on a personal computer equipped with stereo headphones (Sennheiser, HD580). All the sounds were played in 50% of the PC volume capability; (ii) Set of sound patterns Experiment One: a set of 31 sound patterns, developed with experts of dynamic sound patterns: object-object collision (7), object-wall collision (7),

speed was represented in three different ways – dashed speed represented speed by creating sound at regular distance intervals resulting in more frequent sound when the object was faster (4), sound pitch-as-speed, with pitch height representing speed (4), pitch space speed represented is base on the stereo sound (right left) and intensity (loud-close, soft –far) according to the speed and the particle's location in the space (4), each of these representations with varied frequency (5). All the sounds were based on earcon (associative auditory feedback used to represent an event), or created by the computer's MIDI musical instruments, or recordings of inanimate objects' interactions and man-made sounds, or animal sounds. For example: object-object collisions were represented with the a hand clap; air bubbles passing through water; glass tapping on glass; metal tapping on metal; billiard ball hit by the cue. We examined these sounds at five different frequencies: 500; 1000; 2000; 4000; and 5000. This set of sounds meets requirements regarding frequency range (500-5,000 Hz) and loudness (75dB) with respect to sensitivity of the human auditory system, duration (200 millisecond), wave structure, 16 bit per sample, and stereo stream; (iii) Sound tests for Experiment One: all the 31 sound patterns were tested twice by using different recorded scenarios in two different tests: comparison tests (e.g., which sound is preferred to represent speed? Sound A vs. Sound B) and scale - preferences among sonified representations (Most disliked (1); Dislike (2); Neutral (3); Like (4); and Most liked (5); and (iv) Sound tests for Experiment Two: based on results from Experiment One five sound representations were chosen for Experiment Two. 36 combinations of these five sounds were created, meeting the requirements regarding frequency range (4,000 Hz) and with respect to loudness sensitivity of the human auditory system (75dB), duration (30 second), wave structure, and stereo stream. In addition to the above, four tools was developed for the collection of quantitative and qualitative data: (i) Background questionnaire (15 items): personal information, science education, computer technology use, musical background, and information about hearing ability; (ii) Research protocol: two research protocols were developed, one for each experiment. These were structured as described in the procedure section hence. The Research protocol for Experiment One included five parts: explanation about the research; researcher demonstration; practice and training by the participant; experiment (part 1); intermission; experiment (part 2). The research protocol for Experiment Two also included five parts: explanation about the research; researcher demonstration; practice and training by the participant; experiment (part 1); intermission; and experiment (part 2); (iii) Observations: participants' behaviors were video-recorded (Experiment Two only); and (iv) Excel file structuring and accessing the design of the sounds in the research protocol.

2.4 Data Analysis

To evaluate the participants' performance in the two experiments, the results were coded directly by the researcher into an Excel file. These results were analyzed using quantitative software (Excel) to determine the relative preferences regarding sounds for each referent.

2.5 Procedure

All participants were examined individually in their home. In the first session the participants completed consent forms and a background questionnaire. Next, they were tested with Experiment One. After six months they were tested with Experiment Two. Each experiment included five parts: a short verbal explanation about the experimental process; researcher demonstration; practice and training by the participant; experiment part 1 (20 minutes); intermission (30 minutes); and experiment part 2 (20 minutes). Each of these protocols was conducted twice, 1 to 2 weeks apart.

3. DISCUSSION

In the described experiments ten participants took part in two experiments: Experiment One, auditory perception in which auditory representations were varied along various dimensions and Experiment Two, auditory perception of complex sound patterns, recognition of the sonified referents. The results of these experiments have important implications for continued research, and impact learning of people who are blind learning via sonified learning materials. Some of the Experiment One results highlight the importance of sonifying with sounds that are semantically related to the referent. For example, billiard ball collisions were preferred for sonifying object-object collisions (two billiard ball (same material) collide with each other) with respect to glass tapping on glass. The Navajo drum-beat was preferred for representing the object-wall collisions (an object (one material) collides with a wall (leather drum-head)). The participants didn't select animal or digital sounds and preferred recorded real life objects with related meanings. Also, as a speed representation, most of the participants selected the dashed sound, for which frequency of the dashes corresponds to the speed, and not the pitch-space sound that requires additional cognitive processing for aligning the representation (pitch) with the referent (speed). The 2x2 methodology, using the two sessions (data collection sessions) with two tests (comparison and scale tests) aided the researchers in reliably determining the selected sounds. By the time of the conference, the results from the second experiment will be analyzed and presented and further statistics analyzing of the first experiment will be added (such as t-test, χ^2, and cross tabs). Finally, we test how systematic

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014

339

variation of several different sound pattern features (type, number of audio streams, correctness of sound pattern recognition, and auditory perception tools) impacts detection and recognition of multiple channels, extending research into auditory perception, furthering support of the learning process of people who are blind that is based on auditory feedback.

4. REFERENCES

Arno, P, Streel, E, Wanet-Defalque, MC, Sanabria-Bohorquez, S, and Veraart, C, (2001), Auditory substitution of vision: Pattern recognition by the blind, *Applied Cognitive Psychology, 15* 509-519.

Bach-y-Rita, P, (1972), *Brain mechanisms in sensory substitution*, New York: Academic Press.

Beck-Winchatz, B, and Riccobono, MA, (2008), Advancing participation of blind students in science, technology, engineering, and math, *Advances in Space Research, 42,* 1855-1858.

Bregman, A.S, (1990), *Auditory Scene Analysis: The Perceptual Organization of Sound,* MIT Press.

Capelle, C, Trullemans, C, Arno, P, and Veraart, C, (1998), A real-time experimental prototype for enhancement of vision rehabilitation using auditory substituation, *IEEE Trans Biomed Eng, 45*, 1279-1293.

Collignon, O, Lassonde, M, Lepore, F, Bastien, D, and Veraart, C, (2007), Functional Cerebral Reorganization for Auditory Spatial Processing and Auditory Substitution of Vision in Early Blind Subjects, *Cerebral Cortex, 17*, 457—465.

Farrell, B, Baldyga, DD, and Erlandson, R, (2001), Force feedback mouse used for a physics experiment, *NSF 2001 report: Engineering Senior Design Projects to Aid Persons with Disabilities*, Chapter 21, Wayne State University 308-309, Retrieved July 27, 2010, from http://nsf-pad.bme.uconn.edu/2001/ Wayne%20State%20University.pdf

Hadary, D, and Cohen, S, (1978), *Laboratory science and art for blind, deaf and emotionally disturbed children,* Baltimore, MD: University Park Press.

Hirsh, IJ, (1988), Auditory perception and speech, in Handbook of Experimental Psychology Eds R C Atkinson, R J Hernstein, G Lindzey, RD Luce (New York: John Wiley), pp 377 – 408.

Kramer, G, (1994), An Introduction to auditory display, In: Kramer, G, (Ed.), Auditory Display: Sonification, Audification, and Auditory Interfaces, Santa Fe Institute Studies in the Sciences of Complexity, Proceedings vol. XVIII. Reading, MA: Addison-Wesley.

Kumar, D, Ramassamy, R, and Stefanich, G, (2001), Science for students with visual impairments: Teaching suggestions and policy implications for secondary learners, *Electronic Journal of Science Education, 5(3),* 1-9, Retrieved July 27, 2010, from http://wolfweb.unr.edu/homepage/crowther/ejse/kumar2etal.html

Lahav, O, and Levy, ST, (2010), Listening to Complexity: Blind people's learning about gas particles through a sonified model, Presented at ICDVRAT (International Conference Series on Disability, Virtual Reality and Associated Technologies) 2010, Vina del Mar/Valparaiso, Chile, August 31st-September 2nd, 2010.

Landau, S, Russell, M, Erin, J, and Gourgey, K, (2003), Use of the Talking Tactile Tablet in mathematics tests, *Journal for Visual Impairment and Blindness*, 97 (2), 85-96.

Passini, R, and Proulx, G, (1988), Wayfinding without vision: An experiment with congenitally blind people, *Environment and Behavior, 20,* 227-252.

Ramloll Y, Brewster, R, and Burton, D, (2000), Constructing Sonified Haptic Line Graphs for the Blind Student: First Steps, Proceedings of *ASSETS'00*, November 13-15, 2000, Arlington, Virginia.

Stifelman, LJ, (1994), The Cocktail Party Effect in Auditory Interfaces: A Study of Simultaneous Presentation, Technical Report, MIT Media Lab.

Wies, EF, Gardner, JA, O'Modhrain, M.S, Hasser, CJ, and Bulatov, VL, (2001), Web-based touch display for accessible science education, In S Brewster and R Murray-Smith (Eds.), Proceedings of *Haptic HCI 2000*, *LNCS 2058,* 52-60.

Willoughby, D, and Duffy, S, (1989), *Handbook for itinerant and resource teachers of blind and visually impaired students*, Baltimore, MD: National Federation of the Blind.

Zaborowski, B, (2006), *Research issues from the consumer perspective* [Message 1], Retrieved July 27, 2010, http://ecampus.pco.edu/webapps/portal/frameset.jsp?tab=course&url=%2Fbin%2Fvommon%2Fcourse.pl%3 Fcourse_id%3D_355_1