Works in Audio and Music Technology

edited by Axel Berndt

TUDpress
2015

Impressum / Bibliografische Informationen

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

ISBN 978-3-95908-021-7

Verlag der Wissenschaften GmbH
Bergstr. 70 | D-01069 Dresden
Tel.: +49 (351) 47 96 97 20 | Fax: +49 (351) 47 96 08 19
http://www.tudpress.de

Typeset by editor.
Printed in Germany.

Contributors

Nadia Al-Kassab
Leipzig, Germany

Axel Berndt
Detmold, Germany

Tilo Hähnel
Weimar, Germany

Robert Harald Lorenz
Dresden, Germany

Maxim Müller
Dresden, Germany

Felix Schönfeld
Dresden, Germany

Hendrik Schuster
Dresden, Germany

Reviewers

Georg Essl
University of Michigan, Ann Arbor, MI USA

Mark Grimshaw
Aalborg University, Aalborg, Denmark

Daniel Hug
University of Applied Sciences and Arts Northwestern Switzerland, Brugg-Windisch, Switzerland
Zurich University of the Arts, Zurich, Switzerland

Stefania Serafin
Aalborg University Copenhagen, Denmark

Proofreaders

Anne-Katrin Helmuth and Antje Schuster
Dresden, Germany

Contents

Foreword vii

Preface ix

1 Auditory Pointers 1

Robert Harald Lorenz, Hendrik Schuster

1.1 Auditory Display Essentials 1

1.2 Navigating with Sounds 5

1.3 Technical Design 9

1.4 Sound Design Study 13

1.5 Summary 22

2 TouchNoise: A Multitouch Noise Instrument 31

Nadia Al-Kassab, Axel Berndt

2.1 Introduction 31

2.2 Related Work 32

2.3 Concept & Development 35

2.4 Discussion 51

2.5 Summary 54

3 Interactive Ambient Music Generation **59**
Maxim Müller
3.1 Introduction . . . 59
3.2 Characteristics of Ambient . . . 60
3.3 Music Generation . . . 67
3.4 Related Works . . . 74
3.5 Interactive Ambient Music Generator . . . 75
3.6 The Player Module . . . 84
3.7 Discussion . . . 89
3.8 Conclusion and Future Perspectives . . . 91

4 Formalizing Expressive Music Performance Phenomena **97**
Axel Berndt
4.1 Introduction . . . 97
4.2 Performance Features and Analyses . . . 98
4.3 Timing . . . 104
4.4 Dynamics . . . 111
4.5 Articulation . . . 116
4.6 Some Remarks on Implementation . . . 119
4.7 General Discussion & Future Directions . . . 120
4.8 Summary . . . 123

5 Studying Music Performance and Perception via Interaction **129**
Axel Berndt, Tilo Hähnel
5.1 Introduction . . . 129
5.2 Inégalité and Performance Research . . . 131
5.3 Hypotheses . . . 135
5.4 Methodology . . . 135
5.5 Results . . . 142
5.6 General Discussion . . . 147
5.7 Summary . . . 149

6 Vocalmetrics: Music Visualization and Rating Techniques 155

Felix Schönfeld

6.1 Introduction 155

6.2 Related Work 156

6.3 Concept & Development 158

6.4 Discussion 166

6.5 Conclusions 168

Index 171

Robert Harald Lorenz, Hendrik Schuster Chapter 1

Auditory Pointers

Abstract Auditory displays, where the aim is to use the human auditory perception as an information channel, are utilized as navigation aids with increasing frequency. With their help it is not only possible to support but to extend their visual counterpart. This chapter investigates how sounds can be used to guide the listener and provide navigational cues in virtual, as well as in physical environments. We call such sounds *auditory pointers* in analogy to the concept of visual pointers. At first we will give a brief overview of different *sonification* techniques and we will review important articles dealing with navigation through sound. While previous work mainly focused on the spatial localization property of sounds, we would like to complement this by using properties of the sound itself. The distance and direction to a target point can be sonified with the help of volume level, timbre or reverb. Therefore, we introduce an exemplary implementation of respective sound synthesis techniques. In two experiments we investigated and compared the effectiveness of different properties. The findings reveal big differences between the sound parameters. Timbre, pitch and tempo proved to be very efficient in contrast to volume, reverb and stereo panning. Finally we suggest to scrutinize the design process of an auditory display right at the beginning and give advice for functional sound design. This chapter extends a previous publication by Lorenz, Berndt & Groh (2013) and compiles further findings by Lorenz (2013) and Schuster (2013).

1.1 Auditory Display Essentials

Sound, speech and music are elementary parts of multimedia. While we are very aware of our visual perception, the auditory elements are often perceived unconsciously. Accordingly, their impact and benefit are often underrated and remain unexhausted. Nevertheless, the sonic representation of data has a long tradition and its importance is well-known (Patterson 1982). As early as in the beginning of the 20th century people used sounds to perceive environmental information, for instance, with the help of a Geiger counter which maps the degree of radioactivity to a tone. Similar to visual displays auditory displays are able to provide perceptible information for the user of a system. Hence, audio can be used as an additional or solely representation of data which are either hard to gather visually or which resides in the myriad of input data undiscovered (Pettey, Bracken, Rubenking, Appley, Brown, Butler, Cline, Coralic, Hargiti & Liou 2008).

In modern media the visual channel is more and more exhausted. For example, while the use of smartphones and navigation systems increases, the size of their visual displays becomes distinctly smaller. In order to compensate the loss of the overview of all modes, conditions and relations abstract data are used for representation. Providing orientation in such circumstances is hardly possible by giving even more visual cues. This is where audio comes into play. While the verbal representation is inconvenient and improper in most cases because of its universal meaning, auditory displays are able to present multiple pieces of information in one acoustical event with the help of different sound attributes. But how do abstract data sound? How does the stock exchange price sound, or the weather of tomorrow or of the last years? How can tones be used to navigate a blind person securely through a city? These are typical questions in the field of auditory displays where the aim is to use the human auditory perception as an additional or exclusive information channel to *sonify* data, information and interactions.

Although sounds have been used for a long time for the interaction with computers, they are more or less pre-recorded or synthesized speech or simple, unalterable supervisory sounds. Although even mobile devices are capable to create sounds in realtime, the potential of modern hardware is not utilized to its full extent. Therefore, it is possible to not only play ready-made sounds but also generate them dynamically to adapt them to the particular situation and to use them as individual assistance for the user. Thus, the user performance can be improved and the mental workload can be reduced (Brewster, Raty & Kortekangas 1996, Walker & Lindsay 2003). However, there are not many guidelines describing which sounds and sound properties are appropriate to solve which kind of task. There is a large body of work about the impact of pitch, volume and the spatial placement. These works also investigate complex sounds, melodies and rhythms for particular applications and requirements. But the design process is strongly limited right from the beginning. Comparative surveys are performed with insufficient numbers of sound parameters. Hence, designers of auditory displays still have to make ad-hoc decisions for both, the processes of selection and the creation of sounds (Pirhonen, Murphy, McAllister & Yu 2006).

The scope and a brief overview over the main possibilities for creating auditory displays are presented below. However, this chapter is limited to non-speech methods, called *sonifications*. They are more flexible in terms of parameterization and thus, their application is more ubiquitous. Additionally, they are competing less with the natural language of humans. Kramer, Walker, Bonebright, Cook, Flowers, Miner & Neuhoff (2010) describe the concept of sonification as a transformation from the data domain to the audio domain as a means to enable communication or interpretation. Hermann (2008) refines the definition by indicating the transformation of complex data to sound as a systematic, objective and reproducible one. Furthermore, Peres, Best, Brock, Shinn-Cunningham, Frauenberger, Hermann, Neuhoff, Nickerson & Stockman (2008) differentiate the process for designing sonifications on three levels:

The interpretation level describes how a user interprets the sounds he hears and if it is an analogical or symbolic sonification based on his/her understanding of the context.

The level of interactivity explains the possibility for the user to interact with the sonification covering non-interactive to fully interactive design approaches.

Hybridness describes the underlying principles of sonification, more precisely, on what sonification is based, reaching from isolated techniques to a complex mixture of different techniques like Auditory Icons, Earcons and Parameter-Mapping Sonification (PMS), which will be described in detail subsequently.

A brief overview of the main sonification techniques to create auditory displays is given in the remainder of this section. The selection follows "The Sonification Handbook" by Hermann, Hunt & Neuhoff (2011), which provides more detailed introductions and discussions of each technique.

Audification has been used as a sonification technique for a long time. A popular example is the Geiger counter. This approach interprets the one- or two-dimensional data directly and interprets them as audio samples.

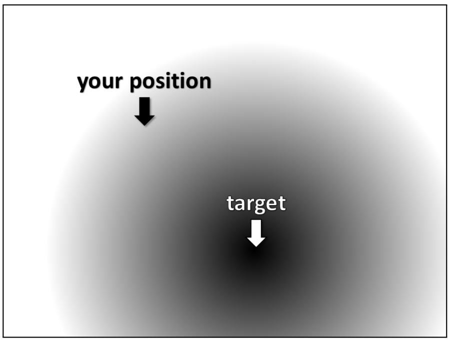
This is a reading sample!

1.3 Technical Design

An *auditory pointer* maps spatial parameters, like distance and direction, onto sonic parameters. Today, this is mainly done with the help of stereo effects, head related transfer functions (HRTF) or other sound spatialization techniques (Walker & Lindsay 2006*a*, Vazquez-Alvarez et al. 2011). However, these methods tend to be inadequate in many real-world scenarios. While stereo and surround panning are not feasible for, e.g., applications in noisy environments and on small speaker setups, sophisticated HRTFs have to be calculated individually for every person (Middlebrooks & Green 1991, Wenzel, Arruda, Kistler & Wightman 1993, Wightman & Kistler 1999). Besides the inconvenience of these methods, one main problem in the design process of auditory displays in general and auditory pointers in particular is the selection of the proper sound attributes or attribute combinations out of the vast number of possibilities. The mapping between spatiality and sound is very important for their viability. Different sound attributes can be used to give an impression of spatiality, e.g. timbre (Zhao et al. 2004). However, there are almost no guidelines available to support the designer in the design process at all.

Additionally, alternatives have to be investigated. Thereby, the comparability between the attributes is a major concern in order to summarize the findings and push their formalization into design guidelines. Few surveys fathomed the efficiency of navigational aids although many problems still remain (Walker & Lindsay 2006*b*). The results presented in this chapter attempt to provide a substantial contribution to close this gap. Therefore a software tool was implemented: a realtime synthesizer that is modulated by the distance between a mouse cursor and a virtual target point, both mapped onto the screen space of a 19 inch display. In the survey (section 1.4), the black screen did only show the mouse cursor but not the target point which the participants then had to find only via listening to the sound. The concept is generic and can also be transferred to other scenarios, e.g. to real-world navigation with a smartphone. Basically, it is a question of scale, whether it is a mouse pointer on a screen or a geo-referenced position in the real world. The distance calculations might then even be reduced to the horizontal axis where the target points into the direction to go. Abstract examples for application scenarios are illustrated by figures 1.1(a) and 1.1(b).

The sound parameters used here are volume, pitch, tempo, tremolo (low frequency amplitude modulation, LFO for short), reverberation time, volume envelope, stereo panning, and timbre (the mixing/lowpass filtering of harmonic



(a) Mapping of sound properties via a two-dimensional scalar field.

(b) Directional mapping of sound properties via a one-dimensional scalar field.

Figure 1.1: Abstract application scenarios. The shading maps onto sonic properties like pitch, timbre and volume.

partials and the so-called THX effect for inharmonic spectra). The THX effect derives from the well-known quality label of the Lucas' Films Company and is inspired by their first audiovisual logo, "wings", from 1983.[1] Our THX effect is not a reproduction of the original but synthesizes a timbre consisting of a fundamental frequency and a number of partials. The frequency of the partials is subject to a certain random offset that produces an inharmonic, dissonant sound. The offset gradually gets smaller, the closer the cursor gets to the target until all partials are in a harmonic ratio to the fundamental frequency. The whole sound synthesis patch is shown in figure 1.2 and detailed in the succeeding section.

1.3.1 Sound Synthesis

The sound of the auditory pointer is generated via additive sound synthesis. Up to ten sinusoids are added to produce the signal $s_v(t)$. Each of the partials has its frequency in Hertz, amplitude A_n and phase angle φ_n.

$$s_v(t) = V(\text{Fundamental}(t) + \text{Overtones}(t))$$

with

$$\text{Fundamental}(t) = A_1 \sin(2\pi f t + \varphi_1)$$
$$\text{Overtones}(t) = \sum_{n=2}^{10} A_n \sin\left((n + rand_n)\, 2\pi f t + \varphi_n\right)$$

[1] http://www.thx.com/consumer/movies/8492259/, last accessed: June 2015.

This is a reading sample!

values. There is, of course, a variety of further possible decay shape that are potentially interesting, like inverse shapes, logarithmic shapes, cascaded slopes, and more complex combinations of basic shapes. These will be subject to future investigations.

1.5 Summary

Sounds are already used in many ways as a unidirectional information channel, e.g. the beeping sounds of a microwave or the output of a Geiger counter. The disadvantage of many such auditory displays is the use of inflexible, static and, often, very simple sounds. A lot of untapped potential for human-computer interfaces lies in the use of adaptive and dynamic sounds. However, there are almost no guidelines or rules for creating appropriate, expressive sounds so that designers are often forced to make ad-hoc decisions and simplify the design process due to time constraints.

Auditory pointers are a typical example of such functional sounds that are already in use in a wide field of auditory displays. Their usefulness is well-known but the representation of objects or target positions in the environment solely with spatialized sound is not always feasible. Thus, the aim of the project presented here is to complement previous research through the investigation of certain sound properties apart from spatialized sound in order to give a proposition about their efficiency and functionality. A software tool was implemented that modulates up to ten parameters of the sound synthesis to indicate the distance and direction of a target.

In a study we investigated the ten properties, volume, pitch, tremolo and timbre in the study's first phase and envelope, reverb, tempo, stereo panning and the THX effect in the study's second phase. Additionally, an alteration of the decay graph was introduced that specifies the sound parameters' distance attenuation. Each of these parameters has been combined with four decay characteristics.

The findings suggest that there is a strong relation between the sound alteration used and the duration to find the target. Moreover the distance between the real target position and the clicked position, as well as the directional accuracy of the mouse path toward the target are strongly interconnected.

As can be seen from the results, the sound parameters tempo, pitch and timbre turned out to be the fittest concerning accuracy and duration. Furthermore the reverb effect was able to prove an average efficiency while the mental workload was low. Contrary to this, the stereo panning and the THX effect seem hardly suitable for navigation tasks. The THX effect that implemented a distance dependent degree of dissonance in a sound caused a very high degree of confusion and annoyance. The stereo panning can be used as an additional variable for different sound parameters and is able to produce positive effects under particular conditions like wearing headphones. The investigation of the transition steepness described by different decay graphs proved to be successful. It has been found that non-linear decay graphs yield significantly better results than linear decay graphs.

The findings indicate that the choice of the sound and the mapping of the distance are two essential aspects for the design of auditory navigation and orientation aids. Even the mental workload could be reduced by an informed and aware design process. Furthermore, aside from a spatial presentation of paths, other sound parameters could be used. The potential lies in the almost innumerable possible combinations of sounds and distance mappings. Timbre could, for instance, be used to find the target roughly in a wide surrounding and, for a precise determination of the target pitch can be used in combination with a larger exponent of the decay graph.

The findings provide important cues for functional sound design. They prove that it is possible to mark invisible or remote objects acoustically without the help of a visual representation and in this way guide the user.

Acknowledgement We would like to thank Romy Müller from the Engineering Psychology and Applied Cognitive Research Group at Technische Universität Dresden for her advise in the study preparation, her assistance in the evaluation and we like to thank all participants.

Bibliography

Brazil, E. & Fernström, M. (2011), Auditory Icons, *in* T. Hermann, A. Hunt & J. G. Neuhoff, eds, 'The Sonification Handbook', COST Office and Logos Verlag Berlin, Bielefeld, Germany, pp. 325–338.

Brewster, S. A., Raty, V.-P. & Kortekangas, A. (1996), Earcons as a Method of Providing Navigational Cues in a Menu Hierarchy, *in* M. A. Sasse, R. J. Cunningham & R. L. Winder, eds, 'Proc. of HCI '96', number XI *in* 'People and Computers', British Computer Society, Springer Verlag, London, UK, pp. 169–183.

Donker, H., Klante, P. & Gorny, P. (2002), The Design of Auditory User Interfaces for Blind Users, *in* 'Proc. of the Second Nordic Conference on Human-Computer Interaction (NordiCHI): Tradition and Transcendence', ACM SIGCHI, Aarhus, Denmark, pp. 149–156.

Eldridge, A. (2006), 'Issues in Auditory Display', *Artificial Life* **12**(2), 259–274.

Etter, R. & Specht, M. (2005), Melodious Walkabout: Implicit Navigation with Contextualized Personal Audio Contents, *in* 'PERVASIVE 2005: The 3rd Int. Conf. on Pervasive Computing', Ludwig-Maximilians-Universität München, Munich, Germany, pp. 43–49.

Gröhn, M., Lokki, T. & Takala, T. (2005*a*), 'Author's comments on Gröhn, Lokki, and Takala, ICAD 2003', *ACM Transactions on Applied Perception* **2**(4), 571–573.

Gröhn, M., Lokki, T. & Takala, T. (2005*b*), 'Comparison of Auditory, Visual, and Audiovisual Navigation in a 3D Space', *ACM Transactions on Applied Perception* **2**(4), 564–570.

Grond, F. & Berger, J. (2011), Parameter Mapping Sonification, *in* T. Hermann, A. Hunt & J. G. Neuhoff, eds, 'The Sonification Handbook', COST Office and Logos Verlag Berlin, Bielefeld, Germany, chapter 15, pp. 363–397.

Hermann, T. (2008), Taxonomy and Definitions for Sonification and Auditory Display, *in* 'Proc. of the 14th Int. Conf. on Auditory Display (ICAD)', IRCAM Centre Pompidou, Int. Community of Auditory Display, Paris, France.

Hermann, T., Hunt, A. & Neuhoff, J. G., eds (2011), *The Sonification Handbook*, COST Office and Logos Verlag Berlin, Bielefeld, Germany.

Klatzky, R. L., Marston, J. R., Giudice, N. A., Golledge, R. G. & Loomis, J. M. (2006), 'Cognitive Load of Navigating Without Vision When Guided by Virtual Sound Versus Spatial Language', *Journal of Experimental Psychology: Applied* **12**(4), 223–232.

Kramer, G., Walker, B., Bonebright, T., Cook, P., Flowers, J., Miner, N. & Neuhoff, J. (2010), Sonification report: Status of the field and research agenda, Technical Report 444, Faculty Publications, Department of Psychology, University of Nebraska–Lincoln, Lincoln, Nebraska, USA. Prepared for the National Science Foundation by members of the International Community for Auditory Display Editorial Committee and Co-Authors.

Lokki, T. & Gröhn, M. (2005), 'Navigation with Auditory Cues in a Virtual Environment', *IEEE MultiMedia* **12**(2), 80–86.

Lokki, T., Gröhn, M., Savioja, L. & Takala, T. (2000), A Case Study of Auditory Navigation in Virtual Acoustic Environments, *in* 'Proc. of the Int. Conf. Auditory Display (ICAD)', Georgia Institute of Technology, Int. Community of Auditory Display, Atlanta, Georgia, USA, pp. 145–150.

Loomis, J. M., Golledge, R. G. & Klatzky, R. L. (1998), 'Navigation System for the Blind: Auditory Display Modes and Guidance', *Presence: Teleoperators and Virtual Environments* **7**(2), 193–203.

Lorenz, R. H. (2013), Design auditorischer Zeiger: Eine Untersuchung zu den Auswirkungen ausgewaehlter Klangparameter auf die Effektivitaet eines akustischen Zeigers, Diploma thesis, Technische Universitaet Dresden, Faculty of Computer Science, Dresden, Germany.

Lorenz, R. H., Berndt, A. & Groh, R. (2013), Designing Auditory Pointers, *in* 'Audio Mostly 2013: 8th Conf. on Interaction with Sound—Sound for Information and Intuition', Interactive Institute/Sonic Studio Piteå, ACM, Piteå, Sweden.

McGookin, D. & Brewster, S. A. (2011), Earcons, *in* T. Hermann, A. Hunt & J. G. Neuhoff, eds, 'The Sonification Handbook', COST Office and Logos Verlag Berlin, Bielefeld, Germany, chapter 14, pp. 339–361.

Middlebrooks, J. C. & Green, D. M. (1991), 'Sound Localization by Human Listeners', *Annual Review of Psychology* **42**(1), 135–159.

Mowbray, G. H. (1953), 'Simultaneous vision and audition: The comprehension of prose passages with varying levels of difficulty', *Journal of Experimental Psychology* **46**(5), 365–372.

Patterson, R. D. (1982), *Guidelines for Auditory Warning Systems on Civil Aircraft*, Civil Aviation Authority, London, UK.

Peres, S. C., Best, V., Brock, D., Shinn-Cunningham, B. G., Frauenberger, C., Hermann, T., Neuhoff, J. G., Nickerson, L. V. & Stockman, T. (2008), Auditory interfaces, *in* P. Kortum, ed., 'HCI Beyond the GUI: Design for Haptic, Speech, Olfactory, and Other Nontraditional Interfaces', Morgan Kaufman Publishers, Elsevier, Burlington, MA, USA, chapter 5, pp. 147–195.

Pettey, G., Bracken, C. C., Rubenking, B., Appley, E., Brown, M., Butler, D., Cline, K., Coralic, Z., Hargiti, J. & Liou, H. (2008), No Vision is Complete without Sound: The Sonification of Telepresence, *in* A. Spagnolli & L. Gamberini, eds, 'Presence 2008: 11th Annual International Workshop on Presence', Int. Society for Presence Research, University of Padua/Human Technology Lab, CLUEP Cooperativa Libraria Universitaria Padova, Padua, Italy, pp. 38–45.

Pirhonen, A., Murphy, E., McAllister, G. & Yu, W. (2006), Non-Speech Sounds as Elements of a Use Scenario: A Semiotic Perspective, *in* 'Proc. of the Int. Conf. on Auditory Display (ICAD)', Int. Community of Auditory Display, London, UK, pp. 134–140.

Sanchez, J. (2010), Identifying and Communicating 2D Shapes using Auditory Feedback, *in* E. Brazil, ed., 'Proc. of the 16th Int. Conf. on Auditory Display (ICAD)', George Washington University, Int. Community of Auditory Display, Washington, DC, USA, pp. 89–95.

Schuster, H. (2013), Erweiterte Untersuchung zum Design auditorischer Zeiger, student research project, Technische Universitaet Dresden, Faculty of Computer Science, Dresden, Germany.

Tran, T. V., Letowski, T. & Abouchacra, K. S. (2000), 'Evaluation of acoustic beacon characteristics for navigation tasks', *Ergonomics* **43**(6), 807–827.

Vazquez-Alvarez, Y., Oakley, I. & Brewster, S. A. (2011), 'Auditory display design for exploration in mobile audio-augmented reality', *Personal and Ubiquitous Computing* **16**(8), 987–999.

Walker, B. N. & Lindsay, J. (2003), Effect of Beacon Sounds on Navigation Performance in a Virtual Reality Environment, *in* 'Proc. of the Int. Conf. on Auditory Display (ICAD)', Boston University, Int. Community of Auditory Display, Boston, MA, USA, pp. 204–207.

Walker, B. N. & Lindsay, J. (2006*a*), The Effect of a Speech Discrimination Task on Navigation in a Virtual Environment, *in* 'Proc. of the Human Factors and Ergonomics Society 50th Annual Meeting', SAGE, San Francisco, CA, USA, pp. 1538–1541.

Walker, B. N. & Lindsay, J. (2006*b*), Navigation Performance With a Virtual Auditory Display: Effects of Beacon Sound, Capture Radius, and Practice, *in* 'Proc. of the Human Factors and Ergonomics Society 50th Annual Meeting', SAGE, San Francisco, CA, USA, pp. 265–278.

Wenzel, E. M., Arruda, M., Kistler, D. J. & Wightman, F. L. (1993), 'Localization using nonindividualized head-related transfer functions', *The Journal of the Acoustical Society of America* **94**(1), 111–123.

White, G. R., Fitzpatrick, G. & McAllister, G. (2008), Toward Accessible 3D Virtual Environments for the Blind and Visually Impaired, *in* 'Proc. of the Int. Conf. on Digital Interactive Media in Entertainment and Arts (DIMEA)', ACM, Athens, Greece, pp. 134–141.

Wightman, F. L. & Kistler, D. J. (1999), 'Resolution of front-back ambiguity in spatial hearing by listener and source movement', *The Journal of the Acoustical Society of America* **105**(5), 2841–2853.

Wilson, J., Walker, B. N., Lindsay, J., Cambias, C. & Dellaert, F. (2007), SWAN: System for Wearable Audio Navigation, *in* '11th IEEE Int. Symposium on Wearable Computers', IEEE, Boston, MA, USA, pp. 91–98.

Zhao, H., Plaisant, C., Shneiderman, B. & Duraiswami, R. (2004), Sonification of Geo-Referenced Data for Auditory Information Seeking: Design Principle and Pilot Study, *in* S. Barrass & V. P., eds, 'Proc. of the 10th Int. Conf. on Auditory Display (ICAD)', Int. Community of Auditory Display, Sydney, Australia.