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Sonification and Music, Music and Sonification

Paul Vickers

> Question: But, seriously, if this is what music is, I could write it as well as you.
>
> Answer: Have I said anything that would lead you to think I thought you were stupid?
>
> — John Cage in *Silence* (1961: 17)

Despite it being more than twenty years since the launch of an international conference series dedicated to its study, there is still much debate over what sonification really is, and especially as regards its relationship to music. A layman's definition of sonification might be that it is the use of non-speech audio to communicate data, the aural counterpart to visualization. Many researchers have claimed musicality for their sonifications, generally when using data-to-pitch mappings. In 2006 Bennett Hogg and I (Vickers and Hogg 2006) made a rather provocative assertion that bound music and sonification together (*q.v.*, and further developed in Vickers (2006)), not so much to claim an ontological truth but to foreground a debate that has simmered since the first International Conference on Auditory Display (ICAD) in 1992. Since then there has been an increasing number of musical and sonic art compositions driven by the data of natural phenomena, some of which are claimed by their authors to be sonifications. This chapter looks at some of the issues surrounding the relationship between sonification and music

and at developments that have the potential to draw sonification and the sonic arts into closer union.

Definitions

Sonification is commonly described as the use of non-speech sound to convey information, typically through the mapping of data and data relations to properties of an acoustic signal (Kramer *et al.* 1999). Where David Howes talks elsewhere in this volume of "hearing with our eyes" sonification, then, is about seeing with our ears.

The practice of converting data and data relations to audio signals has been ongoing for over thirty years and achieved recognition as a discipline in its own right with the inaugural International Conference on Auditory Display (ICAD) in 1992. Sonification draws in researchers from across discipline boundaries. Computer scientists use it to communicate information about running programs and processes, psychologists study it in relation to our ability to interpret it, statisticians use it for exploratory data analysis, earth scientists use a form of it for analyzing seismic data, neuroscientists interpret EEGs with it, sports scientists use it for training elite athletes, and developers of assistive technology use it to bring data to the visually impaired, to list just a few examples. For a good overview with representative examples from across the field, see *The Sonification Handbook* (Hermann, Hunt & Neuhoff 2011).

Despite a dedicated conference and a close-knit community of practice, the definition of sonification remains, as Alexandra Supper (2012: 92) discovered, something of an open question. There are several points of disagreement in the literature regarding what constitutes a sonification and the interested reader is directed to Supper's excellent treatment of the matter (Supper 2012).

One apposite point of debate regards the methodological nature of sonification. Over the years there have been many examples of data-driven music and sonic art (partly as a result of the ICAD meetings, several of which have included sonification concerts as part of the program), and some have found it difficult to distinguish between sonification and sonic art practice. To clarify the distinction, Thomas Hermann (2008) asserted that

sonification should be cast as scientific method and offered four necessary and sufficient conditions by which something could qualify as a sonification. However, Scot Gresham-Lancaster (2012) cautions against this way of thinking, calling it a grave mistake to frame sonification only in terms of scientific method. As Stephen Barrass and I (Barrass and Vickers 2011: 152) pointed out, the same technologies, tools, and techniques used to synthesize sounds from data are also used by computer musicians and sound artists. Barrass (2012b) argued that sonification is a design practice in which effective solutions to the problem of communicating data via sound are achieved through an iterative, heuristic process. For Barrass and Vickers (2011: 165):

> A definition of sonification focusing on usefulness and enjoyment reconfigures sonification from an instrument solely for scientific enquiry into a mass medium for an audience with expectations of a functional and aesthetically satisfying experience. A design-centered approach also moves sonification on from engineering theories of information transmission to social theories of cultural communication.

Even though there is debate around what sonification is and whether it is scientific method or a range of techniques that can be employed *within* a scientific method if so desired, there is more agreement about what sonification is not. Supper's interviews with researchers from across the range of sonification practice reveal that whatever else sonification might be, one thing it is certainly not is music (Supper 2012). And yet, sonification and music continue to wear each other's clothes as researchers publish papers describing their musical sonifications and composers present their sonification music.

Sonification as Music

The provocative statement referred to in the introduction was this (Vickers & Hogg 2006: 214):

(1) Sonification ⇔ Music

that is, sonification and music mutually imply each other. It arises from two simpler premises:

(2) Sonification ⇒ Music

and

(3) Music ⇒ Sonification

Proposition (2) is relatively easy to explain (though not uncontentiously so). It says that *if* something is a sonification *then* it is also music. There is much debate about what music is (captured nicely in John Cage's dialogue in *Silence*, part of which is quoted at the start of this chapter), and certainly sonification qualifies as "organized sounds framed by silence" (Judkins 2011: 14). Definition and taxonomy are still much discussed in the music/sound art/sonic arts world (worlds?). For instance, is music, as Simon Emmerson suggests, a subset of sonic art (Gibbs 2007: 64), or is sound art all music, as Leigh Landy suggests (Landy 2007: 8, 177)? It is, perhaps, for the musicologists to settle the ontological status of music. Instead, we can take the position that if one chooses to listen to something as music then it is music (a typecast that is explored more fully in Vickers & Hogg 2006). A common objection to this concerns the role of intention: if there was no compositional intent behind the sound then it is not music. (What was the compositional intent behind the music of the spheres?) David Worrall also observed that even when listened to as music sonifications "may provoke critical commentary about issues such as the appropriateness or formal incompleteness of the resulting sonic experience" (Worrall 2014: 53).

Proposition (3) stems from the observation that any piece of music is an auditory display that communicates the physical properties of the instruments, the emotional state and/or intention of the performer and, perhaps, the intentions of the composer too. Again, there are arguments against this being the case but the problems really begin when the two propositions are joined. If (2) and (3) are both true then the mutual implication in (1) obtains. The contention lies in what (1) says. The symbol ⇔ is read as *if-and-only-if*. That is, if, and only if, something is a sonification then it is music (and *vice versa*).

This was not a popular statement to make at ICAD and its full ramifications have yet to be explored. To be fair, its veracity is difficult to establish given the lack of agreement

over the definition of the words on both sides of the arrow. However, it does provide a useful nexus for discussion. The central point of our paper (Vickers and Hogg 2006) was to suggest an *aesthetic perspective space* in which practice in various schools of music composition might be used to improve the aesthetic design and interest of sonifications. As musical sonifications and data-driven compositions attest, sonification and music *are* related, even if they are at times uneasy bedfellows (see Andrea Polli elsewhere in this volume). But what is the extent of that relationship and how should it be managed and mediated? When can practice in one serve the needs of the other? As Grond and Hermann (2012: 214) put it: "what circumstances enable us to listen to sound as sonification?"

Music Composition and Sonification Design

Music and sonification have ostensibly different goals. The composer strives for aesthetic interest, that is, the results should be "aesthetically useful" (Wishart 1994: 4–5). In sonification, it is not aesthetic interest but successful signification of the data that is the goal. But are these goals mutually exclusive and, if not, how can practice in one field inform the other?

It has been demonstrated that structured tonal musical frameworks can be used for successful sonification (Alty & Vickers 1997). It also makes intuitive sense that sonification should employ representational schemes that leverage our innate ability to monitor the world aurally through continuous auditory streams, or soundscapes (e.g., as is becoming increasingly common in cosmology and astronomy). Both approaches have met with their own successes and failures. Bracketing the question of what path we ought to take as perhaps unanswerable (and certainly currently unanswered), how should sonification designers who wish their work to be more "musical" approach the task?

Realizing that sonifications that are difficult or fatiguing to listen to will be less successful, some valiant attempts have been made to incorporate some elements of composition into the sound mappings. As music is designed to engage and hold the

listener's interest, surely a sonification that is more musical will be better than one that is not? Unfortunately, sonifications purportedly designed to be musical are often still fatiguing or unengaging. Sometimes this is simply because the sonification is musically naive or simplistic (often consisting in simple data-to-MIDI-pitch mappings).

Conversely, the goal of communicating essential information can be masked in the effort to achieve a stronger musical expression. Grond and Hermann stressed that "the information content of a sonification needs to be found in the ear of the listener and not only in the signal into which the data are converted" (Grond & Hermann 2014: 43). Unfortunately, the drive to focus on the ear can sabotage the sonification's purpose. For example, Weinberg and Thatcher (2006: 11) attempted to create a sonification that both communicated clearly and provided a "compelling musical experience" but concluded that "the trade-off we came up with favoured aesthetics and music over science and education." Likewise, Barrett and Mair (2014: 12–13) found that a departure "from scientific accuracy had however already begun: musical abstractions were achieved … for musical rather than scientific goals."

Addressing this phenomenon, Filimowicz (2014) set up sonification as a two-dimensional space of dialectical tensions and proposes an aesthetic field in which sonification design is the struggle to find a balance between data-for-itself and the listener-for-itself on one axis and between the Peircean triad of rheme, dicisign, and argument (signs that represent objects in terms of quality, existence, and law or habit respectively) and the three parametric orders (data features, data structure, sound structure) on the other. Filimowicz cited Yolande Harris's *Satellite Sounders* as an example of a sonification that is both data centric and listener friendly and which keeps these dialectical tensions in balance.

Achieving this balance is even more difficult when one considers the reticence that can be displayed by composers to engage with sonification projects. Stallmann, Peres, and Kortum (2008) described a project that used musical composition to create sound cues that helped users of a telephone queueing system to maintain a sense of queue progress and to better predict when the call might come to an end. The result was an effective auditory display with the salient information carried melodically. Aesthetically it was

stronger as it more easily facilitated the sensuous perception (this is the root meaning of aesthetics after all) of the information. However, during her presentation at ICAD 2008, Camille Peres indicated that the collaborating composer expressed caution at being associated with the music; it was not something he felt proud of or wished to have as part of his oeuvre. For him it was not, as Wishart put it "aesthetically interesting." Sonification is, if you like, the graphic design of art; the music was something to disown as if a down-at-heel Mozart had accepted cash to write an advertising jingle for the latest brand of Viennese *Sachertorte*. Composers aim for artistic credibility, after all.

Bovermann, Rohruber, and de Campo (2011: 240) highlighted the tension between achieving accurate data communication within a musical context. The use of traditional musical instrument timbres can lead to pitch differences sounding "wrong" as opposed to interesting. If a pitched musical framework is adopted whereby data points are quantized to chromatic intervals and a regular meter, then essential details may be lost and "potentially misleading artefacts" introduced and yet still with a result that does not resemble "worthwhile music."

Sonification and Electroacoustic Music

Much of the conversation around sonification and music is grounded in the electroacoustic tradition, with a special emphasis on Pierre Schaeffer's *quatres écoutes* (modes of listening) which lie at the center of recent discourse around how we listen to sonification (see, for example, Tuuri, Mustonen and Pirhonen 2007; Vickers 2012; Tuuri and Eerola 2012; Grond and Hermann 2014). However, the electroacoustic tradition brings its own challenges. Dunn (1999) reflected that his own electronic music was interesting only because it was experimental and had little to do with music as an aesthetic experience. What was missing, he says, were the underlying structure and cultural traditions that make music accessible. Much sonification sounds a lot like this "experimental music" and there is a lack of research to investigate how different underlying musical and aural frameworks affect the communicative abilities of sonification.

We are very practical at monitoring the world around us with our ears. We establish expectations and anticipations for the normal state of our local soundscape and are skilled at recognizing anomalous sounds or changes in existing sounds that signify salient events. Managing expectation and anticipation is one of the skills a good composer must possess. Robert Jourdain put it this way:

> When we expect something, we await its exact replication. And so, if you know a song by heart, you expect its exact notes. On the other hand, you can anticipate even music you have never heard before by counting on it to follow rules of musical structure and style. Expectation is specific, it coincides with *episodic memory*… Anticipation is general and coincides with *semantic memory*. The more daring music is, the harder it is to anticipate and the more you need to hear it several times before you can properly expect its twists and turns. (Jourdain 1997: 246)

Shannon's (1948) information theory is a way of valorizing the information content of a signal. For sonification the goal is to maximize the information transfer while minimizing the noise (a high signal-to-noise ratio). However, for composers, music that contains high information and low redundancy cannot be accommodated into musical schemata (Snyder 2001: 235). Dunn's experience with attempting to sonify tide table data bears this out: "the data were seemingly too random to give the resulting music a sense of structure, deep or otherwise" (Dunn and Clark 1999: 27). In other words, the high Shannon information content of the data led to a sonification that was difficult to accommodate in a standard musical schema. Music that is expected, then, has a low Shannon information content, whilst music that cannot be anticipated easily has a much higher information content.

Watkins and Dyson (1985) demonstrated that melodies following the rules of Western tonal music are easier to learn, organize cognitively, and discriminate than control tone sequences of similar complexity. This suggests that the cognitive organizational overhead associated with atonal systems makes them less well suited as carriers of program

information (Vickers 2004). However, this does not take account of electroacoustic music which, whilst often lacking discernible melodies and harmonic structures, is still much easier to organize and decompose cognitively than atonal pieces (Vickers 2005).

Sonification and Composition

Artists are increasingly appropriating the term sonification for works that lie at the other end of the intentional spectrum. Jøran Rudi, echoing Vickers and Hogg, said that sound art should "be understood as a sonification of artistic ideas, or sonic representations of the same" (Rudi 2009: 1). This is sonification as mimesis or, as Robert Johnstone (2013: 192) put it, "artistic sonification," where mimesis is taken to be the relating of a sign to its referent object (Iosafat 2009: 49). There is an established history of composers using computational and algorithmic procedures as compositional aids, from Cage's aleatoric pieces to the generative works of Brian Eno. Given its data-to-sound nature it is unsurprising that composers and sound artists have turned to sonification as a seed or driver for their work. Nevertheless, Schedel and Worrall caution that the use of sonification in music "inherits many of the concerns of procedural composition" (Schedel and Worrall 2014: 2). There is a view that such works might be better described as "data music."

If the goal of communicating data gets subverted in sonification projects, as noted above, composers engaging in sonification music will often lose sight of that goal altogether in pursuit of aesthetic interest. For example, the project to sonify solar wind data from NASA's ACE satellite (Alexander, Zurbuchen, Gilbert, Lepri and Raines 2010) was a collaboration between scientists and composer Robert Alexander. The musical piece that was showcased at ICAD 2010 (which can be found at http://www.robertalexandermusic.com/) though musically impressive, does not admit the sort of inspection of data that is the goal of sonification. Just as some sonification designers proclaim their works to be both informative and aesthetically interesting, so there is a tendency for some composers to use sonification as a label even though the music does not communicate information about the data. The upside of this is that such endeavors do, at least, expose sonification to new audiences (Ballora 2014: 38).

Sometimes there is even confusion about the status of a piece. Alvin Lucier's *Music for Solo Performer* (1965) is often wheeled out as an early example of sonification. In performances of the work Lucier had electrodes attached to his head which were sensitive to alpha waves. Lucier's role was to relax and generate alpha waves which were picked up by the sensors which sent impulses along wires connected to loud speakers which, in turn, caused instruments to which they were connected to emit sound. An assistant used a mixing desk to select which instruments would be audible, thereby orchestrating the performance in real time. According to Straebel and Thoben (Straebel and Thoben 2014: 17) any perceived sonification is illusory, a result of "an intended theatrical effect". At best, the piece is, in Gresham-Lancaster's (2012) terminology, a second-order sonification, though it's really an example of signal-driven art.

A very interesting example of the porous boundary between sonification and music is the *Listening to the Mind Listening* concert which was part of the ICAD 2004 program (Barrass 2012a). The concert comprised performances of ten pieces that were all sonifications of the same EEG data set (they can be listened to at http://icad.org/websiteV2.0/Conferences/ICAD2004/concert.htm). What is striking is how some of the composers focused on the goal of letting the listener hear the brain activity (as represented by the EEG data) whilst others used the data more as a compositional seed. Some of the pieces were aesthetically interesting sonifications (musical sonifications), others were more sonification music. Barrass reflected on the reviewing process thus:

> An analysis showed that the overall impression of all reviewers correlated with their rating on the sub-scale of aesthetic appreciation. However, there were distinct patterns in the way reviewers with different expertise interpreted the other scales. For concert-goers, aesthetic appreciation was correlated with musical accessibility, while composers did not link these two aspects at all. For sonification researchers, their aesthetic appreciation was correlated with their rating of the mapping from data into sound. (Barrass 2012a: 281-282)

Each piece included a detailed description of the sonification approach taken by the composer. Barrass observed that "practices that are sophisticated in one domain are not necessarily sophisticated in the other, and *vice versa*, indicating the value of a multidisciplinary approach to sonification" (282).

Future Directions

An ever-present tension exists between compositional strategies on the one hand and the information transfer and signification goals of sonification on the other. There is a growing focus on the links between sonification design, practice, and listening strategies and established musical paradigms. The influence of electroacoustic thinking is particularly strong and it will be instructive to follow the progression of musical thought to see how it might further influence sonification thinking especially if the view of sonification as a cultural practice bears fruit.

Interest in embodiment is also starting to impact on sonification research and practice. From Leman's embodied musical cognition (Leman 2008) to Hogg's "enactive consciousness" (Hogg 2011), embodiment offers new ways to explore how people interact with sonifications. Roddy and Furlong (2014) make a case for using embodied schemata in sonification design and, indeed, preliminary studies suggest this area has much potential (Diniz, Deweppe, Demey and Leman 2010; Maes, Leman and Lesaffre 2010; Worrall 2014). (See also Laura Maes and Marc Leman elsewhere in this volume.)

An account of embodiment contributes also to the way in which signification may take place in sonification. Here, the term signification is used in the Peircean sense (see Vickers, Faith and Rossiter 2013). The sonification forms a sign (*representamen* in Peirce's terminology) for some referent object (the data, or information about the data). The sign causes an *interpretant* (a mental evocation) to form in the mind of the listener which brings the listener into relation with the object. Similarly, the Schaefferian approach, according to Leman, is "an attempt to understand the notion of a musical object from an intentional perspective" (Leman 2008: 32). The musician

> …encodes gestures in sound, and the listener can decode particular aspects of them through corporeal imitation… a model of musical communication in which the encoding and decoding of biomechanical energy allows the communication of intentions. (Leman 2008: 159–160)

Here, the intentions are different from those of the sonification designer, but exploring how the former may assist practice in the latter needs to be studied further. As Barrass noted regarding *Listening to the Mind Listening*, there is value in a multidisciplinary approach, and this can work both ways: composers can help sonification designers, and sonification designers can help composers understand how data can be structured and mapped in interesting ways.

Because of the problems with creating "musical" sonifications, Bovermann *et al*. (2011: 240) advised creating opportunities for "practicing more open-minded listening which may be epistemically and aesthetically rewarding once one begins to read the sonification's details fluently." Musical listening is a skill that can be developed. Pop music is accessible in part because it seems to demand so little of us cognitively, it is anticipatory. At least initially it admits quick entry but rewards more systematic listening by revealing further structures, harmonic progressions, production techniques, and so on. Much "serious" music, however (in which more "difficult" artists such as Björk may be included) puts up a barrier admitting (rewarding) only those who are prepared to devote time and effort to listening to it and searching for what it has to say, eventually resulting in what Jourdain (1997) described as "ecstasy." So, do we want our sonifications to be pop music or, as Bovermann *et al*. suggest, should they demand a more disciplined approach to listening? The ongoing and developing discourse around sonification and musical listening (especially Schaefferian listening) promises to add much to the canon of sonification design.

Related Chapters

David Howes

Andrea Polli

Further Reading and Listening

Listening to the Mind Listening at

http://icad.org/websiteV2.0/Conferences/ICAD2004/concert.htm

Chris Chafe's Polar Tide, Oxygen Flute, and End of Winter. See http://chrischafe.net/

Bob L. Sturm's sonifications of Pacific Ocean buoy data, "Music from the Ocean", at http://ohmytracks.com/#/music/Bob+L.+Sturm

References

Alexander, R., T.H. Zurbuchen, J. Gilbert, S. Lepri and J. Raines (2010) "Sonification of ACE Level 2 Solar Wind Data," in E. Brazil (ed.) *16th International Conference on Auditory Display*, Washington, DC: ICAD, pp. 39–40.

Alty, J.L. and P. Vickers (1997) "The CAITLIN Auralization System: Hierarchical Leitmotif Design as a Clue to Program Comprehension," in J. A. Ballas and E. D. Mynatt (eds.) *ICAD '97 Fourth International Conference on Auditory Display*, Palo Alto: Xerox PARC, pp. 89–96.

Ballora, M. (2014) "Sonification, Science and Popular Music: In Search of the 'Wow'," *Organised Sound* 19(1), pp. 30–40.

Barrass, S. (2012a) "Sonifications for Concert and Live Performance," *AI and Society* 27(2), pp. 281–283.

——— (2012b) "The Aesthetic Turn in Sonification Towards a Social and Cultural Medium," *AI and Society* 27(2), pp. 177–181

Barrass, S. and P. Vickers (2011) "Sonification Design and Aesthetics," in T. Hermann, A. D. Hunt and J. Neuhoff (eds.) *The Sonification Handbook*, Berlin: Logos Verlag, pp. 145–172.

Barrett, N. and K. Mair (2014) "Aftershock: A Science–Art Collaboration Through Sonification," *Organised Sound* 19(1), pp. 4–16.

Bovermann, T., J. Rohruber and A. de Campo (2011) "Laboratory Methods for Experimental Sonification," in T. Hermann, A. D. Hunt, and J. Neuhoff (eds.) *The Sonification Handbook*. Berlin: Logos Verlag, pp. 237–272.

Cage, J. (1961) *Silence*, Middletown CT: Wesleyan University Press.

Diniz, N., A. Deweppe, M. Demey and M. Leman (2010) "A Framework for Music-Based Interactive Sonification," in E. Brazil (ed.) *16th International Conference on Auditory Display*, Washington, DC: ICAD, pp. 345–351.

Dunn, J. and M.A. Clark (1999) "'Life Music': The Sonification of Proteins," *Leonardo* 32(1), pp. 25–32.

Filimowicz, M. (2014) "Peircing Fritz and Snow: An Aesthetic Field for Sonified Data," *Organised Sound* 19(1), pp. 90–99.

Gibbs, T. (2007) *The Fundamentals of Sonic Art and Sound Design*, Lausanne: AVA Publishing.

Gresham-Lancaster, S. (2012) "Relationships of Sonification to Music and Sound Art," *AI and Society* 27(2), pp. 202–212

Grond, F. and T. Hermann (2012) "Aesthetic Strategies in Sonification," *AI and Society* 27(2), pp. 213–222.

——— (2014) "Interactive Sonification for Data Exploration: How Listening Modes and Display Purposes Define Design Guidelines," *Organised Sound* 19(1), pp. 41–51.

Hermann, T. (2008) "Taxonomy and Definitions for Sonification and Auditory Display," in B. Katz (ed.) *Proc. 14th Int. Conf. Auditory Display (ICAD 2008)*, Paris, France: ICAD.

Hermann, T., A.D. Hunt and J. Neuhoff (eds.) (2011) *The Sonification Handbook*, Berlin: Logos Verlag.

Hogg, B. (2011) "Enactive Consciousness, Intertextuality, and Musical Free Improvisation: Deconstructing Mythologies and Finding Connections," in D. Clarke

and E. Clarke (eds.) *Music and Consciousness: Philosophical, Psychological, and Cultural Perspectives*, Oxford University Press, pp. 79–94.

Iosafat, D. (2009) "On Sonification of Place: Psychosonography and Urban Portrait," *Organised Sound* 14(1), pp. 47–55.

Johnstone, R. (2013) "Creating a Coral Symphony: Sound Art and Sonification," etropic 12(2), pp. 191–196.

Jourdain, R. (1997) *Music, the Brain and Ecstasy: How Music Captures Our Imagination,* first edition, New York: William Morrow Co. Inc.

Judkins, J. (2011) "Silence, Sound, Noise, and Music," in T. Gracyk and A. Kania (eds.) *The Routledge Companion to Philosophy and Music*, Abingdon, Oxon: Routledge, pp. 14–23.

Kramer, G., B. Walker, T. Bonebright, P. Cook, J.H. Flowers, N. Miner and J. Neuhoff (1999) *Sonification Report: Status of the Field and Research Agenda*, ICAD/NSF.

Landy, L. (2007) *Understanding the Art of Sound Organization*, Cambridge, MA: MIT Press.

Leman, M. (2008) *Embodied Musical Cognition and Mediation Technology*, Cambridge, MA: MIT Press.

Lucier, A. (1965) "Music for Solo Performer."

Maes, P.-J., M. Leman and M. Lesaffre (2010) "A Model-Based Sonification System for Directional Movement Behavior," in *ISon 2010, 3rd Interactive Sonification Workshop*, KTH, Stockholm.

Roddy, S. and D. Furlong (2014) "Embodied Aesthetics in Auditory Display," *Organised Sound* 19(1), pp. 70–77.

Rudi, J. (2009) "Editorial," *Organised Sound* 14(1), pp. 1–2.

Schedel, M. and D.R. Worrall (2014) "Editorial," *Organised Sound* 19(1), pp. 1–3.

Shannon, C.E. (1948) "A Mathematical Theory of Communication," *The Bell System Technical Journal*, 27, pp. 379–423 and 623–656

Snyder, B. (2001) *Music and Memory: An Introduction*, Cambridge, MA: MIT Press.

Stallmann, K., S.C. Peres and P. Kortum (2008) "Auditory Stimulus Design: Musically Informed," in B. Katz (ed.) *Proc. 14th Int. Conf. Auditory Display (ICAD 2008)*, Paris, France: ICAD.

Straebel, V. and W. Thoben (2014) "Alvin Lucier's *Music for Solo Performer*: Experimental Music Beyond Sonification," *Organised Sound* 19(1), pp. 17–29.

Supper, A. (2012) "Lobbying for the Ear: the Public Fascination with and Academic Legitimacy of the Sonification of Scientific Data" (PhD thesis), University of Maastricht.

Tuuri, K. and T. Eerola (2012) "Formulating a Revised Taxonomy for Modes of Listening," *Journal of New Music Research* 41(2), pp. 137–152.

Tuuri, K., M.-S. Mustonen and A. Pirhonen (2007) "Same Sound – Different Meanings: A Novel Scheme for Modes of Listening," in H. Köhler (ed.) *Proceedings of Audio Mostly 2007 2nd Conference on Interaction with Sound*, Röntgenbau, Ilmenau, Germany: Fraunhofer Institute for Digital Media Technology, pp. 13–18.

Vickers, P. (2005) "Ars Informatica – Ars Electronica: Improving Sonification Aesthetics," in L. Ciolfi, M. Cooke, O. Bertelsen, and L. Bannon (eds.) *Understanding and Designing for Aesthetic Experience Workshop at HCI 2005 the 19th British HCI Group Annual Conference*, Edinburgh, Scotland.

——— (2004) "External Auditory Representations of Programs: Past, Present, and Future – an Aesthetic Perspective," in S. Barrass and P. Vickers (eds.) *ICAD 2004 – the Tenth Meeting of the International Conference on Auditory Display*, Sydney: ICAD.

——— (2006) "Lemma 4: Haptic Input + Auditory Display = Musical Instrument?" in D. McGookin and S. Brewster (eds.) *Haptic and Audio Interaction Design: First International Workshop, HAID 2006, Glasgow, UK, August 31 - September 1, 2006. Proceedings*, Lecture Notes in Computer Science, Springer-Verlag, pp. 56–67.

——— (2012) "Ways of Listening and Modes of Being: Electroacoustic Auditory Display," *Journal of Sonic Studies* 2(1), retrieved from http://journal.sonicstudies.org/vol02/nr01/a04.

Vickers, P. and B. Hogg (2006) "Sonification Abstraite/Sonification Concrète: An 'Aesthetic Perspective Space' for Classifying Auditory Displays in the Ars Musica Domain," in T. Stockman, L. V. Nickerson, C. Frauenberger, A. D. N. Edwards, and D. Brock (eds.) *ICAD 2006 - the 12th Meeting of the International Conference on Auditory Display*, London, pp. 210–216.

Vickers, P., J. Faith and N. Rossiter (2013) "Understanding Visualization: A Formal Approach Using Category Theory and Semiotics," *IEEE Transactions on Visualization and Computer Graphics* 19(6), pp. 1048–1061.

Watkins, A.J. and M.C. Dyson (1985) "On the Perceptual Organisation of Tone Sequences and Melodies," in P. Howell, I. Cross, and R. West (eds.) *Musical Structure and Cognition*, New York: Academic Press, pp. 71–119.

Weinberg, G. and T. Thatcher (2006) "Interactive Sonification: Aesthetics, Functionality and Performance," *Leonardo Music Journal* 16, pp. 9–12.

Wishart, T. (1994) *Audible Design: A Plain and Easy Introduction to Practical Sound Composition*, York UK: Orpheus the Pantomime.

Worrall, D. (2014) "Can Micro-Gestural Inflections Be Used to Improve the Soniculatory Effectiveness of Parameter Mapping Sonifications?" *Organised Sound* 19(1), pp. 52–59.