Oxford Handbooks Online

Music for Cochlear Implants

Stefan Helmreich

The Oxford Handbook of Timbre
Edited by Emily Dolan and Alexander Rehding

Subject: Music, Sound Studies Online Publication Date: May 2018
DOI: 10.1093/oxfordhb/9780190637224.013.12

Abstract and Keywords

This paper examines compositions and performances created by scientists and musicians who seek to make music for cochlear implants, surgically implanted assistive medical technologies used by many hard-of-hearing and deaf people. The implant employs a microphone to capture an audio signal, which is then divided into frequency bands and transmitted to a receiver emplaced in a recipient's skull, behind the ear. The implant provides poor reproduction of those timbral features of sound central to many normative experiences and expectations of music. Compositions and performances for implant users seek either (1) to improve the way the implant processes frequency, (2) to create music that works well with an implant's available frequency profile, or (3) to access the implant directly, crafting music specially tailored for the implant through the device's signal relays. Critically assaying such projects, this paper reevaluates and recontextualizes what can count as timbre in diverse deaf and hearing worlds.

Keywords: cochlear implants, timbre, deaf music, dis/ability, signal transduction, vibration, ASL

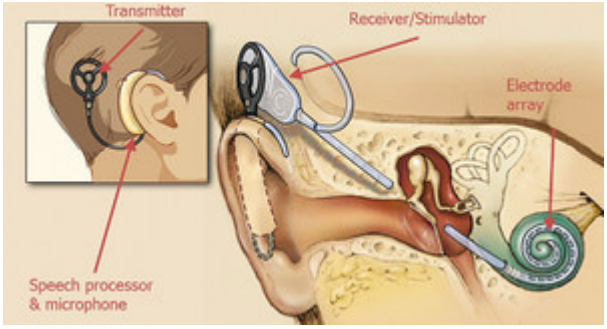
Biomedical researchers investigating the physiology and neurology of deafness have sometimes wondered what they might do to bring deaf persons closer to hearing persons' experiences of listening to music, with music in such inquiries defined as a genre of *sound*—and sound characterized as a sensation that materializes in the ear as a consequence of the vibration, in the 20 to 20,000 hertz range, of a solid, liquid, or gas medium. Of increasing interest to such researchers in recent years has been the technology of the cochlear implant, an increasingly prevalent medical technology taken up by many hard-of-hearing and deaf people (324,000 worldwide as of 2012[1]). Unlike a hearing aid, which more-or-less amplifies sound as it arrives at the ear, a cochlear implant bypasses the outer and middle ear, aiming more directly to stimulate, through electromagnetic transduction, the auditory nerve system. The device employs a small microphone to capture an audio signal, which is then divided into different frequency

bands and transmitted to a small receiver surgically implanted into a recipient's skull, just behind the ear. That receiver transduces the signals through an array of electrodes (usually twenty-two in number) that have been wound through the cochlea, a spiraling and labyrinthine cavity in the inner ear (see Figure 1). Once stimulated, the auditory nerves in the cochlea relay their activation to the brain, causing a kind of hearing (or "hearing," if one holds fast to common definitions that require sound to travel through the external and middle ear [the auricle and tympanum] in order to be heard).

An important qualification—and one that will become pivotal as this paper unfolds—is that the précis, just above, largely repeats a normative and audist (hearing-centered) and oralist (spoken language-centered) biomedical account. The experience and meaning of the cochlear implant varies for those people who use it (as well as for those who elect not to or who cannot afford it), with necessary effects on how music is apprehended and approached. Zooming out to the wider realm of deaf identity and community, Jessica Holmes offers the reminder that

> deaf people do not form a single, homogeneous social group. Rather, d/Deaf people relate to "deafness" in vastly different ways: deafness entails a combination of individual audiological characteristics, linguistic preferences, identity politics, and in some cases technological constraints — what amount to an idiosyncratic set of variables that shape musical experiences in profound ways.[2]

Some segment of cochlear implant users may even refuse the notion that the devices help them "hear," resisting having their experience assimilated to dominant audist or oralist categories, claiming, rather, that the devices provide spatial, social, and infrastructural information.[3] Such users may be unmoved by an appeal to them to access "music"—or may favor definitions of music (as visual rhythm, as very low-frequency vibration) that do not depend upon sounds. Such a position may align with the view, held by some sign language users, that the implant represents a threat to the integrity and vitality of sign, a manual language considered the keystone of Deaf culture; in respect to such politics, Deaf has sometimes been spelled with a capital D to denote a cultural rather than a bodily condition, marked with a lowercase d.[4] Such claims seek to distance d/Deafness from disability, though this can be a move that sometimes further reifies dichotomous, exclusionary categories of ability[5]—an implication that has many deaf studies now moving away from the d/D distinction, arguing also that it reifies ideal types and, transposed to non-Euro–American settings, is ethnocentric.[6] What these varied positions entail for what will count as "music" and "timbre" is multiple, a point to which I will return. For now, let me go back to the biomedical starting point offered by those doctors, composers, musicians, and users who would seek to tune cochlear implants to the sound of music.



Click to view larger

Figure 1. Diagram of a cochlear implant. (Morgan Leahy, "I Woke Up One Morning to Find I Was Deaf," *The Tab*, 2016)

A cochlear implant features software that parcels incoming audio signals into frequency bands, a parceling that has historically been formatted to optimize those spectral features associated with speech in non-tonal languages (e.g. English and not, say, Mandarin); the software packages inside implants are sometimes shorthanded as *speech processors*. The cochlear implant has therefore not been so friendly, it has been frequently noted, to the more complex spectral profiles—and *timbre* is central here—of canonical musical materials. The electrodes in cochlear implants are keyed to very specific bandwidths, about 180 Hz to 8000 Hz; their narrowness within each band, and the low number of bands, has rendered traditional musical experience a quite different thing for so-called normally hearing persons and cochlear-implanted persons. A simulation of a cochlear implant-mediated musical audition of Beethoven's Kreutzer Sonata[7] invites comparison to an original audio recording. For through-the-ear hearing persons, the simulation drops out important timbral information.[8]

The makers of newer cochlear implants hope to leverage a wider range of frequency bands into the brain, and the hope is that this might permit more finely textured apprehensions of sound. In some cases—as with work by otolaryngologists at the University of Washington[9]—new kinds of signal processing algorithms built into implants aim to fine-tune perception of harmonics, with, researchers report, enhanced perception for implantees of pitch and timbre. Harmonics, vibrations whose frequencies are integer multiples of a fundamental frequency, are kinds of *partials*—which were, as Emily Dolan reminds us, the holy grail of timbre for nineteenth-century physician and physicist Hermann von Helmholtz.

Projects of cochlear implant improvement that aspire to capture complex musical texture are largely ameliorative, aiming to tweak or modify implant technology so that it might more faithfully relay timbral textures, qualities held by many hearing persons to be essential to experiencing music as sound.[10] Such schemes of technical improvement are only one sort. I wish also to train my attention here on other cochlear implant-centered musical endeavors, ones that seek less to assimilate the experiences of people with cochlear implants to those of people with so-called normal hearing and aim, rather, to create new kinds of music, music specially designed to tune to the implant and its users.

As a quick example of an ameliorative project, though, take the work of the Dutch composer Kyteman, commissioned by Vodafone in 2014 to transform a popular song for the implant. Kyteman was given the task of customizing a musical piece for the cochlear

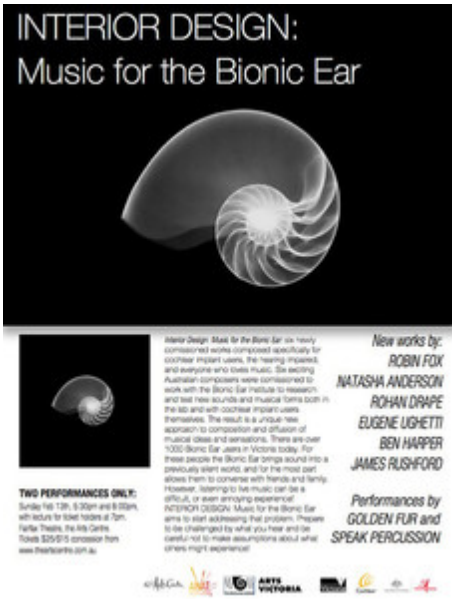
implant experience of Dutch nineteen-year-old Vera van Dijk.[11] To do so, Kyteman pitched down and frequency-focused a contemporary piece of pop music by Sam Smith—and, if one watches the video in which Vera van Dijk experiences the piece, it is full of visual rhetorics of her experiencing a revelation, of being brought from the world of the "disabled" into the world of "normal" people.

Beyond ameliorative projects like this one (which might even be called *compensatory*, to draw attention to their ableist outlines), however, there also exist enterprises that propose to craft new musical experiences tailored specifically to the affordances of cochlear implants. Such projects range across a continuum—from the gently experimental to the laboratory grade electro-cyborgian-techno-musicy. So, while some composer-performers seek to play with the pitch and timbre of musical performances so that they might be friendlier to the frequency filters of cochlear implants, other composer-performers seek to create compositions that interface more directly with the exact technological specifications of these devices, even offering new scales and tunings that they imagine might work best in this direct to auditory-cortex world. How timbre figures into such undertakings is very much under construction. Let me mark out some data points along this continuum.

Take those works assembled by auditory scientist Waldo Nogueira Vazquez, who in early 2015, through the German Hearing Center in Hanover, staged a concert entitled "Music for Cochlear Implants." This event saw lots of wild and wooly experiments in how one might tailor performance to the imagined auditory universe of the implanted. One performance-composition in particular was notable for its free improvisational style, extended techniques, and its attempt to capitalize on the usually-out-of-attention materiality of an instrument. "Slicing (for accordion and fixed sounds)," by Pablo Carrascosa, asks an accordion player to hit and caress an accordion, attending less to its possible keyboard sounds than to the sound of scratching and scraping its infrastructural components—bellows, grille, and buttons, with the implicit claim being that this percussive sound might be aesthetically intriguing for people listening with/through/via the narrow bands of an implant. To my own through-the-auricle hearing ears, it almost sounds like a performance of the vocodered Kreutzer Sonata.[12] The aesthetic is futurist, non-traditional, almost as though the vanguard character of the music is meant to match the futuristic device that many judge the implant to be.

The next point on my continuum is perhaps more interesting, moving away from the one-to-one translations of Kyteman, away from the impressionistic meeting-the-implant halfway experimentalism of Carrascosa, and toward attempts to create a music composed rather exactly for the 22-electrode form of the implant, almost as though the music is meant to be piped straight into the brain, "stimulating the audio nerve directly,"[13] to lift a line from a 2006 song by the late hyperdub poet Spaceape. Take, then, Australian audiovisual composer Robin Fox, who in 2009 collaborated with people at the Bionic Ear Institute in Melbourne to create a musical piece crafted with the technical specifications of the cochlear implant built right into an electronic music apparatus. Fox put his plan this way: "The logical thing to do would be to try and compose music that would attack

this piece of hardware, that would try and break down the limitations that the hardware presented by restructuring the music rather than restructuring the hardware." [14] The piece that Fox ended up with was a kind of electronic music for an electronic device and its attached person. As seen in Figure 2, Fox's piece was part of a larger concert, "INTERIOR DESIGN: Music for the Bionic Ear,"[15] with five other composers working at related adaptations of their practice to the implant.



Click to view larger

Figure 2. Flyer for INTERIOR DESIGN: Music for the Bionic Ear performance.

Reproduced with permission.

Timbre is in modification in Fox's practices, something worried about, compressed, imagined in a human-machine register. Listen, also, to Ben Harper, another person composing for cochlear implants, and who also presented at "INTERIOR DESIGN: Music for the Bionic Ear." Harper offered that implants might demand new musical scales:

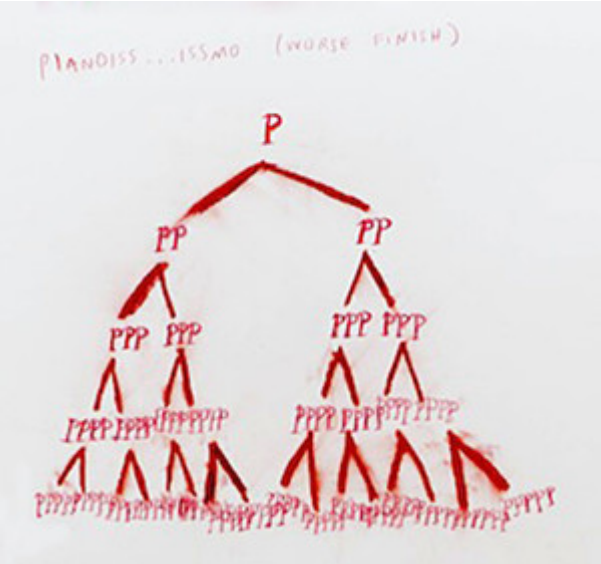
> It seemed a natural choice to write a piece of music tuned to a scale which is better suited to the structure of a cochlear implant than those of conventional instruments. The scale used in this piece has 16 tones, instead of the usual 12 tones in standard western tuning. These tones are made up of pitches based on overtones of a fundamental frequency of 250 Hz, the central frequency of the lowest-tuned electrode.[16]

Here, traditions of microtonal music are adapted for the specifications of an electronic device that carves the vibrational world into a very particular set of intervals. Such pieces might be understood as examples of "deaf futurist" music—a term coined by Mara Mills, which she uses to name some deaf persons' celebrations of their implants as technologies that might broker new and potentially liberatory human–machine amalgams and interfaces.[17] These are all also species of what Douglas Kahn in *Earth Sound Earth Signal* has called the *aelectrosonic*[18]—with acoustic vibration, of the sort one might imagine with the Aeolian harp, or, more precisely for my interests here, with the cilia (the hairs vibrating in the cochlea) fused with the electric, plugged in. Timbre not only goes electric, but also goes electrophysiological.

A key feature of all these projects is that they all summon up a certain technophily, a love of technological intervention and aesthetics. It is also the case—as far as I can tell—that these are projects fronted primarily by hearing persons. The one example I can find of a performer (and poet) with a cochlear implant is of Josephine Dickenson, who in her 2014 essay, "The Cochlear Switch," suggests that her individual experience of adapting to a high-frequency bias implant has led her newly to listen to and enjoy birdsong as well as such sounds as the dripping of a tap. She also reports that she has come to know her piano—which she experiences at once through her implant, through the instrument's physical vibrations, and through her memories (she was once hearing)—as a meeting point between her "'inner' sense and the 'outer world.'"[19] Hers is a non-universalizing claim about how implant technology may (or may not) broker the making and experiencing of music.

One should also not forget that there are deaf musics[20] and also recall that there are scholars[21] working in and around deaf studies who contest sono-centered definitions of music, pointing to the possibility of apprehending *rhythm* in written poetry and sign language and of apprehending *vibration* through the non-cochlear hearing that can permit the sensing of low frequency vibration.[22] There are also musics indigenous to non-cochlear implanted deaf communities.

What "timbre" might be in those musics could be a quite different thing—in, for example, the work of deaf sound artist Christine Sun Kim, whose diagrammatic contributions to MoMA's *Soundings* exhibit in 2013 (see Figure 3) shift the matter of sound and music into the visual, perhaps making "literal" notions of timbre as color and texture.[23] Her "Pianoiss … issmo" asks those people who encounter this pastel, pencil, and paper work to consider how the musical-notation command to play softly—*piano*, when multiply compounded as *pianissimo* and then *pianissimoissimo*—suggests that silence is an ever-deferred destination. "Sound" heading toward "silence" always has a texture.



Click to view larger

Figure 3. Christine Sun Kim, Pianoiss … issmo (Worse Finish) 38.5 x 50" (hxw), pastel and pencil on paper, 2012.

Reproduced with permission of Christine Sun Kim.

Kim's "Muffled Club Music" (2016), another pastel, pencil, and paper work that plays with conventions of notation, represents the vibration of distant electronic music with smudged quarter notes; smudge, here, becomes timbre. In another, performance piece, called *Face Opera II* (2013), "visual-spatial cues alone can constitute music"[24] and in this composition, "Deaf performers … 'sing' using a series of coordinated silent ASL facial expressions."[25] Timbre, here, is visual, tactile, revealing that timbre is a compound sensation. As Holmes suggests, "deafness highlights the contextual interdependence of the senses as they govern musical experiences: vision, touch, and hearing are merely idealized types; rarely do they operate in isolation."[26] As might now be apparent, this is also the case for persons who hear, a sensory mode similarly various in its embodiments.

Timbre, tuned into and out of through the technology and aesthetics of cochlear implants, becomes quite explicitly available to examination/audition. Efforts to listen to, through, with, and against music with (and without) the cochlear implant make it clear that timbre is always a relational category, a phenomenological effect, a technocultural artifact, an intersensory apprehension. More, understanding the artifactuality of timbre presses us up against the limits of what might count as music, as sound, and, indeed, as the very phenomenology of electroacoustic relationality itself.

Acknowledgments

I would like to thank Emily Dolan and Alex Rehding for inviting this contribution. I also thank the other participants in the "Making Sense of Timbre" exploratory workshop at the Radcliffe Institute, out of which this paper grew. Thanks, too, to Michele Friedner, Mara Mills, David Novak, Heather Paxson, and Ben Tausig for comments on earlier versions of this text.

Bibliography

Auditory Neuroscience. "What Do Cochlear Implants Sound Like?" 2013. **http://auditoryneuroscience.com/prosthetics/music** (accessed January 26, 2018).

Bionic Ear Institute. *Interior Design: Music for the Bionic Ear*. Program guide, Melbourne: Bionic Ear Institute, 2009.

Burial. "Spaceape." On *Burial*. Hyperdub CD 0001. 2006. Compact disc.

Chorost, Michael. "My Bionic Quest for Bolero." *Wired* 13, no. 11 (2005): 144–159.

Crider, Summer. “Re-Defining Music Through a Deaf Lens.” Paper presented at “Waves and Signs,” a conference and workshop on low-frequency vibration with a performance and dance party, MIT Center for Advanced Visual Studies, Cambridge, MA, cosponsored with Gallaudet University, April 24–25, 2009.

Dickenson, Josephine. “The Cochlear Switch.” *Aeon*. August 8, 2014. **https://aeon.co/essays/a-deaf-musician-and-poet-receives-a-cochlear-implant**.

Dolan, Emily I. *The Orchestral Revolution: Haydn and the Technologies of Timbre*. Cambridge: Cambridge University Press, 2013.

Edwards, Rebecca A. R. *Words Made Flesh: Nineteenth-Century Deaf Education and the Growth of Deaf Culture*. New York: New York University Press, 2012.

Friedner, Michele, and Stefan Helmreich. “Sound Studies Meets Deaf Studies.” *The Senses & Society* 7, no. 1 (2012): 72–86.

Hamilton, Jon. “Deaf Jam: Experiencing Music Through a Cochlear Implant.” *National Public Radio*. Morning Edition, May 18, 2015. **http://www.npr.org/sections/health-shots/2015/05/18/406838781/deaf-jam-experiencing-music-through-a-cochlear-implant**.

Harper, Ben. “Music for the Bionic Ear.” **Cookylamoo.com**. 2011. **http://www.cookylamoo.com/music/bionic_ear.shtml**.

Holmes, Jessica. “Expert Listening Beyond the Limits of Hearing: Music and Deafness.” *Journal of the American Musicological Society* 70, no. 1 (2017): 171–220.

Jones, Jeannette DiBernardo. “Imagined Hearing: Music-Making in Deaf Culture.” In *Oxford Handbook of Music and Disability Studies*, ed. Blake Howe, Stephanie Jensen-Moulton, Neil Lerner, and Joseph Straus, 54–72. Oxford: Oxford University Press, 2015.

Kahn, Douglas. *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts*. Berkeley and Los Angeles: University of California Press, 2013.

Kim-Cohen, Seth. *In the Blink of an Ear: Toward a Non-Cochlear Sonic Art*. London: Bloomsbury Academic, 2009.

Kolb, Rachel. “Sensations of Sound: On Deafness and Music.” *New York Times*, Opinion, November 3, 2017. **https://www.nytimes.com/2017/11/03/opinion/cochlear-implant-sound-music.html**.

Kusters, Annelies, Maartje De Meulder, and Dai O’Brien, eds. “ Innovations in Deaf Studies: Mapping the Field.” In *Innovations in Deaf Studies: The Role of Deaf Scholars*. Edited by Annelies Kusters, Maartje De Meulder, and Dai O’Brien, 1–56. Oxford: Oxford University Press, 2017.

Leahy, Morgan. “I Woke Up One Morning to Find I Was Deaf.” *The Tab*. 2016. **http://thetab.com/us/emory/2016/05/03/deaf-3264**.

Maler, Anabel. “Musical Expression Among Deaf and Hearing Song Signers.” In *Oxford Handbook of Music and Disability Studies*. Edited by Blake Howe, Stephanie Jensen-Moulton, Neil Lerner, and Joseph Straus, 73–91. Oxford: Oxford University Press, 2015.

Mills, Mara. “Do Signals Have Politics? Inscribing Abilities in Cochlear Implants,” In *Oxford Handbook of Sound Studies*. Edited by Trevor Pinch and Karin Bijsterveld, 320–346. Oxford: Oxford University Press, 2011.

National Institute on Deafness and Other Communication Disorders. “Cochlear Implants.” *NIH Publication* No. 11-4798, January 11, 2013.

Packard, Cassie. “Deaf Artist Christine Sun Kim Is Reinventing Sound.” *Vice*, April 4, 2015. **http://www.vice.com/read/gifted-dynamic-and-deaf-rising-star-christine-sun-kim-creates-art-that-reinvents-sound-679**.

STVdiochannel. “Synapse: Robin Fox and the Bionic Ear.” Posted January 23, 2012. **https://www.youtube.com/watch?v=HLX-rPsphV8**.

Vasquez, Waldo Noguerra. “Slicing.” Posted May 6, 2015. **https://www.youtube.com/watch?v=R9fhlDgdjH8** (accessed January 26, 2018).

Wollaston, Victoria. “The Music for DEAF People: Musician Composes Song at a Specific Frequency so Cochlear Implants Can Pick Up the Melody.” *The Mail Online*, September 4, 2014. **http://www.dailymail.co.uk/sciencetech/article-2743263/The-music-DEAF-people-Musician-composes-song-specific-frequency-cochlear-implants-pick-melody.html**.

Xing Li, Kaibao Nie, Nikita S. Imennov, Jay T. Rubinstein, and Les E. Atlas. “Improved Perception of Music with a Harmonic Based Algorithm for Cochlear Implants,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 21, no. 4 (2013): 684–694.

Notes:

([1]) National Institute on Deafness and Other Communication Disorders, “Cochlear Implants,” *NIH Publication* No. 11-4798, January 11, 2013.

([2]) Jessica Holmes, “Expert Listening beyond the Limits of Hearing: Music and Deafness,” *Journal of the American Musicological Society* 70, no. 1 (2017): 175.

([3]) Personal communication with Michele Friedner and Stephanie Lloyd.

([4]) Rebecca A. R. Edwards, *Words Made Flesh: Nineteenth-Century Deaf Education and the Growth of Deaf Culture* (New York: New York University Press, 2012).

([5]) Holmes, “Expert Listening Beyond the Limits of Hearing,” 179.

([6]) Annelies Kusters, Maartje De Meulder, and Dai O’Brien, eds., “Innovations in Deaf Studies: Mapping the Field,” In *Innovations in Deaf Studies: The Role of Deaf Scholars*, ed. Annelies Kusters, Maartje De Meulder, and Dai O’Brien, 1–56 (Oxford: Oxford University Press, 2017) 13–14.

([7]) Auditory Neuroscience. “What do cochlear implants sound like?” 2013.

([8]) Jon Hamilton, “Deaf Jam: Experiencing Music through a Cochlear Implant,” *National Public Radio*, Morning Edition, May 18, 2015.

([9]) Li Xing, Kaibao Nie, Nikita S. Imennov, Jay T. Rubinstein, and Les E. Atlas, “Improved Perception of Music with a Harmonic Based Algorithm for Cochlear Implants,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 21, no. 4 (2013): 684–694.

([10]) See the program for the Music and Cochlear Implants Symposium, held at Denmark’s Eriksholm Research Centre, October 2016, for a sense of the state-of-the-art technical discussion around these matters, http://implantsandmusic.net.

([11]) Victoria Wollaston, “The Music for DEAF People: Musician Composes Song at a Specific Frequency so Cochlear Implants Can Pick Up the Melody,” *The Mail Online*, September 4, 2014.

([12]) Waldo Noguerra Vasquez, “Slicing,” *YouTube video*, 6:47, Posted May 6, 2015.

([13]) Burial, “Spaceape,” *On Burial*. Hyperdub CD 0001. 2006. Compact disc.

([14]) STVdiochannel. “Synapse: Robin Fox and the Bionic Ear.” Posted January 23, 2012. Watch from 4:00–6:00.

([15]) Bionic Ear Institute. *Interior Design: Music for the Bionic Ear* (Program guide, Melbourne: Bionic Ear Institute, 2009).

([16]) Ben Harper, “Music for the Bionic Ear,” Cookylamoo.com. 2011.

([17]) See Mara Mills, “Do Signals Have Politics? Inscribing Abilities in Cochlear Implants,” In *Oxford Handbook of Sound Studies*, ed. Trevor Pinch and Karin Bijsterveld, 320–346 (Oxford: Oxford University Press, 2011) and Michael Chorost, “My Bionic Quest for Bolero,” *Wired* 13, no. 11 (2005): 144–159.

([18]) Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts* (Berkeley and Los Angeles: University of California Press, 2013).

([19]) Josephine Dickenson, “The Cochlear Switch,” *Aeon*, August 8, 2014.

([20]) Jeannette DiBernardo Jones, “Imagined Hearing: Music-Making in Deaf Culture.” In *Oxford Handbook of Music and Disability Studies*, ed. Blake Howe, Stephanie Jensen-Moulton, Neil Lerner, and Joseph Straus, 54–72 (Oxford: Oxford University Press, 2015).

([21]) See Summer Crider, “Re-Defining Music Through a Deaf Lens,” paper presented at “Waves and Signs,” a conference and workshop on low-frequency vibration with a performance and dance party, MIT Center for Advanced Visual Studies, Cambridge, MA, co-sponsored with Gallaudet University, April 24–25, 2009; and Anabel Maler, “Musical Expression Among Deaf and Hearing Song Signers.” In *Oxford Handbook of Music and Disability Studies*, ed. Blake Howe, Stephanie Jensen-Moulton, Neil Lerner, and Joseph Straus, 73–91 (Oxford: Oxford University Press, 2015).

([22]) See Seth Kim-Cohen, *In the Blink of an Ear: Toward a Non-Cochlear Sonic Art* (London: Bloomsbury Academic, 2009) and Michele Friedner and Stefan Helmreich, “Sound Studies Meets Deaf Studies.” *The Senses & Society* 7, no. 1 (2012): 72–86. For a personal account by an implant user who often prefers non-cochlear vibration as well as the visual experience of lyrics rendered into sign, see Rachel Kolb, “Sensations of Sound: On Deafness and Music,” *New York Times*, Opinion, November 3, 2017.

([23]) Cassie Packard, “Deaf Artist Christine Sun Kim Is Reinventing Sound,” Vice, April 4, 2015.

([24]) Holmes, “Expert Listening Beyond the Limits of Hearing,” 195.

([25]) Ibid., 196.

([26]) Ibid., 212.

Stefan Helmreich

Anthropology Program, Massachusetts Institute of Technology