"What, for me, constitutes life in a sound?": Electronic Sounds as Lively and Differentiated Individuals

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Electronic sounds are commonly understood to be individual forms characterized by various dynamic qualities. Many of these qualities, such as duration, decay, and timbre, are associated in some way with properties of organic matter, living organisms, or social life.[1] Examples of these concepts abound in audio-technical discourse.[2] A recent book on the philosophy of sound suggests that "sounds themselves . . . are *particular individuals* that possess the audible qualities of pitch, timbre, and loudness. . . . They enjoy lifetimes and bear similarity and difference relations to each other based on the complexes of audible qualities they instantiate."[3] Textbooks on music production and acoustics often divide introductory chapters into subsections devoted to the constituent qualities said to make up an individual sound. Practitioners are taught to know sound, and its representation in electrical signals, by identifying these elements and the possibilities for their technologically controlled variation.[4] Musicians who work with electronic media follow this logic in their creative process when they isolate and sculpt individual sonic forms, treating each one as a distinct entity before combining it with other elements in a track or mix.[5] When and how did it become commonplace for musicians, audio practitioners, and philosophers of sound to think in these terms?

I trace these concepts to the late nineteenth and early twentieth centuries, a period of significant development in audio technologies and the consolidation of professional communities, such as the Acoustical Society of America, concerned with standardizing audio-technical knowledge.[6] This formative period in modern audio cultures was also a time in U.S. history in which momentous shifts engendered new patterns of encounter and politics of recognition around social and cultural differences. Such changes and movements took place in realms of industrialization and immigration, women's suffrage, reconstruction, and mass migrations of African Americans from the south to northern cities. Sounds and audio technologies are crucial sites of representa-

tion through which such historical shifts and associated cultural politics were imagined, expressed, and legitimated.

As David Suisman writes, "To think about music and sound historically . . . means recognizing that sound . . . is woven into a host of other social, political, and economic power relations. . . . [It] also means considering how aural phenomena and sensory experience in general may be historically constructed."[7] Sonic and social worlds are mutually constitutive. On the one hand, audio technologies are crystallizations of identity, subjectivity, and social difference. Lisa Gitelman has demonstrated that in early sound recordings, technical protocols of the new medium, like the hardness of recording surfaces and design of styli, were calibrated to accommodate the frequencies of women's voices.[8] Mara Mills's research documents what she calls "the resourcing of disability within technoscience," whereby experiments on deaf subjects were central to the design of numerous audio technologies and theories of telecommunication.[9] Moreover, I suggest that the practices and politics of social stratification, which grew alongside modern science and industrial capitalism, gathered currency in the ways that notions of differentiated embodiment came to reside in the forms of audio technologies and the terms used to describe them.

This essay explores how interrelations of the sonic and social unfolded through metaphoric understandings of electronic sounds as lively and differentiated individuals. I propose that the history of conceiving electronic sounds as individuals, and sorting them by perceived differences, intersects developments in scientific modernism in which bodies became similarly apprehended in terms of part-whole relations and associated aesthetic variations. This epistemological formation also took shape during the rise of industrial capitalism, in which the individual was increasingly seen as the fundamental unit of society, as a modern subject composed of quantifiable attributes legible through biopolitical measurements and controls. The metaphor of electronic sounds as differentiated individuals accompanied a logic of commodification in radio, phonograph, and telecommunication industries in early twentieth-century America, whereby the technological preparation of an individual unit of sound, music, or entertainment was seen to facilitate its widespread transmission and circulation.[10] It also influenced the design of modern synthesizers and other electronic musical instruments that generate or play back discrete sonic forms.[11]

To examine the history of electronic sounds as individuals, I focus on the work of the German physiologist and pioneering acoustics researcher Hermann von Helmholtz. Helmholtz's work was central to the emerging fields of

acoustics and electronic music composition in the United States in the early decades of the twentieth century. For one example, Dayton C. Miller, president of the Acoustical Society of America in the early 1930s, drew significantly on Helmholtz's research in his popular textbook on the "science of sound."[12] Miller and colleagues established a new social and professional network of composers, engineers, and hobbyists that consolidated common knowledge about electronic sound. They drew their ideas from the science of acoustics, modernist music, and a cultural enthusiasm for electricity and electronic devices.[13] During a period of American history in which markers of race, class, gender, and culture were visible and contested in emerging contexts of industrialization and urbanization, these surfacing communities of audio-technical practitioners learned to distinguish individual sounds through analogous representational signifiers of social stratification.

More than simply serving as technological delegates or extensions of embodied movements, electronic sounds came to be known and understood in analogous ways to modern bodies and subjects: as differentiated individuals in motion, marked and regulated by waveform representations of their extensions into space and variations over time. Waveform representations of sound, which grew from the intersections of acoustics and physiology research in the mid-nineteenth century, revealed scientific and cultural fascinations with the capacities and limitations of laboring bodies. The identification of electrical activity as an animating presence in diverse phenomena, from muscle movements to growing plants to new communication technologies, facilitated analogies among electronic sounds and lively bodies. As well, notions of sonic purity and timbral variation were newly expressed in the late nineteenth century through the figure of the sine wave and more complex curves that deviated from that ideal. Visual representations and technical language describing sound waveforms were characterized by signifiers of gender and racial difference, and of normativity and pathology.

Because the concept of electronic sounds as lively individuals continues to permeate audio-technical discourse, as the examples in my opening paragraph illustrate, this essay implicitly critiques knowledge in audio-technical cultures of the present as it inquires into sonic and social interrelationships of the past. As a feminist intervention in histories of sound and audio technologies, it aims to denaturalize common ideas in audio-technical discourse that are inherited by contemporary practitioners as neutral, epistemological "truths" and without history. I proceed by introducing the theoretical concepts of sonic worlds and technological worlding, to contextualize my critique of electronic sounds as a site of representation and cultural politics.

Worlds of Sound and Technological Worlding

To think of electronic sounds as individuals conjures, by extension, a whole world of sound populated by proliferating and overlapping sonic entities. In much the same way that the history of sound reproduction can be articulated to cultural desires for preservation (e.g., of the voice and the embalmed body beyond death, or of "dying cultures" threatened by genocidal extinction),[14] the history of electronically synthesized sound may be characterized by technoscientific dreams of genesis and creation.[15] An advertisement for the Micromoog synthesizer, one of the first portable electronic keyboard instruments widely available to musicians in the early 1970s, offered its users this possibility of creating "a world of sound in a nutshell." It promised to be a compact tool and creative companion for generating virtually any sound that could be desired.[16] A later generation of digital synthesizers, which incorporated microchips and sampling capabilities in their design, extended to musicians further possibilities for making "any sound you can imagine."[17] The evocative phrase of the Moog ad—"world of sound"—is more than marketing rhetoric; it is a useful way to describe an affective realm of music-making and audio-technical practice that integrates imaginary, embodied, and social modes of experience.

In a series of interviews I conducted with women who work creatively with electronic music and sound, the topic of synthesized sound elicited imaginative speculations on the interrelations of sounds, technologies, life, and liveliness. The composer Annea Lockwood described her work with synthesized sound in an early electronic music studio in Cologne in the 1960s: "The sounds which were assembled with all that care, all that mathematical interrelationship . . . struck me as not really being alive. . . . So then of course I had to ask myself: *What, for me, constitutes life in a sound?*" She left this as a rhetorical question but, in subsequent decades, some of her most prominent works featured recordings of rivers interspersed with interviews of people whose lives the river intersects. Lockwood implied that synthesized sound—which is generated electronically through techniques of analysis and recombination of a sound's constituent elements—lacks the kind of "life energy" that permeates flowing water and the cadences of human voices. By contrast, the composer Mira Calix claimed to be drawn equally to the expressive possibilities of analog synthesizers and wooden instruments because they seem to *share* lifelike qualities. For Calix, technologies made of analog circuits and wood both seem to fluctuate and breathe like "little creatures." The musician and instrument builder Jessica Rylan also identified similarities of analog electronics and "natural" phenomena; she uses analog circuits when designing her synthesizers because

they follow "very simple, natural laws, just like breaking a tree branch, or like water, or even like birds flying in a V." And the multimedia installation artist Christina Kubisch suggested that the sounds typically associated with natural environments, like those of rainforests and birds, can seem "less genuine" than the more familiar electrical hums and synthetic sounds in contemporary, industrialized contexts.[18]

These artists' observations intimate a theory of *technological worlding*, which encapsulates various ways that technologies affect and transform imaginary as well as material and social realms of experience. Worlding is a concept with Heideggerian roots; in "The Origin of the Work of Art," Martin Heidegger suggests that "to be a work [of art] means to set up a world," to reveal something "in the light of its being."[19] In this sense, "worlding" is to apprehend the waves of historical inheritance and possible futures of a given object, rather than to presume the possibility of fixed truths or accuracy in representation. "World is never an object that stands before us and can be seen," but is instead a process of the unfolding and unconcealing of meaning.[20] Donna Haraway's feminist theory of technoscientific figurations conjures the capacity of technologies to both hold and generate worlds. For Haraway, figurations are "performative images that can be inhabited." The chip, seed, or gene (and I would add electronic sounds to this litany) are "condensed maps of contestable worlds"—"dense nodes" of provisionally knotted social and historical relations that "explode into entire worlds of practice."[21] In and around such figurations, "social relationships include nonhumans as well as humans. . . . All that is unhuman is not un-kind, outside kinship, outside the orders of signification, excluded from trading in signs and wonders."[22] Technological worlding is a way to describe these encounters of humans, nonhumans, and environments.[23] The process of sound synthesis, which implies a holistic yet contingent configuration of parts, itself offers a metaphor for the making of worlds through nonnormative procreative contacts, generative syntheses, and emergent transformations of heterogeneous actors and elements.

Implicit in worlding is "a creation of strife; understanding worlding involves an analysis of that strife . . . seeing the historical, political, and economic dynamics of strife through its unconcealment."[24] So, one musician's liberating experience making a synthesized "world of sound," as suggested in the Micromoog advertisement, at the same time backgrounds other(s') worlds, such as those more immediately and adversely affected by the labor and toxic waste in electronics manufacturing and disposal.[25] Indeed, technological worlding often manifests fantasies of control, as in the "microworlds" constructed in the formal systems of computer cultures, which extend the promise of perfect technologi-

cal mastery within homosocial communities of young male programmers.[26]

This essay explores some of the "worlds of sound" that have been made in audio-technical discourse. The metaphor of electronic sounds as individuals constitutes one narrativizing strategy through which acousticians, musicians, and hobbyists have explained physical phenomena to themselves and others, and historicized their own work and social interactions. These practitioners' "world of sound" represents various and stratified social differences and often expresses desires for technological control. From another standpoint, Lockwood's query "What constitutes life in a sound?" can be read as a feminist question about technological worlding that calls out sound as a contestable world of representation and lived experience. What histories are present in the now-common conception of electronic sounds as differentiated individuals, and who are the (absented) others who inhabit this figuration?

My theorization of technological worlding and the creation of sonic worlds in audio-technical discourse resonates with studies of popular music, like Josh Kun's *Audiotopia*, which proposes that listening to music engenders a kind of imaginary space through which identity formations and cultural encounters unfold. In his discussion of music and race in America, Kun describes such an "auditory somewhere" as follows:

> Building my record collection was my way of building my own world, creating an alternate set of cultural spaces that, through the private act of listening, could deliver me to different places and different times and allow me to try out different versions of myself. . . . music had become my entryway into a boundless social world of difference and possibility.[27]

Kun examines how private and social aspects of musical experience and listening intersect, suggesting that "America" and its listening subjects are shaped through such spaces or "worlds" of sound. In complementary ways, media historians and science and technology scholars who study sound and musical instruments have explored various dimensions of technological design and interpretation, or definition and use. Such methods foreground the collective processes through which technologies are defined by a broad range of users over time, with different kinds of socially situated knowledges and practices.[28]

Building on the work of these scholars, this essay seeks to expose some of the epistemological scaffolding that supports the creative work that music makers and audio technologists do. It investigates technological conditions of possibility for *both* music production and consumption, by historicizing the processes by which sounds are technologically prepared to be sensed and experienced, and the resulting aesthetic contours of electronic soundscapes. We may not always *hear* these histories clearly in present circulations of

sound, largely because audio-technical discourse has long been the province of a limited group of experts. These experts are predominantly white, male, and middle-class engineers, composers, and hobbyists, which makes it all the more important to question how social differences may inflect discourses and technologies that are presented as neutral or universal.[29] In that historicizing any mode of sensory experience entails confronting interconnections among the senses;[30] I turn now to examine the strong attachments of visual cultures to sonic meanings.

Analogical Attachments: Visual Cultures and Sonic Meanings

Recent scholarship on histories of sound and the senses has demonstrated that in Western philosophy and cultures,

> sound itself [is] constantly subjugated to the primacy of the visual, associated with emotion and subjectivity as against the objectivity and rationality of vision, seen as somehow more "natural" and less constructed as a mode of communication—in essence, fundamentally secondary to our relationship to the world and to dominant ways of understanding it.[31]

In studying sound, "it is nearly impossible to escape the visual. Visual metaphors dominate our language."[32] The visual experience of seeing sound produced in musical performance has been integral to how performers and audiences alike determine the meanings of sound in society and culture: "For much of Western history, at the most fundamental levels of perception, the sound *is* the sight, and the sight *is* the sound."[33] Scientific techniques of visualizing sound, especially graphical methods used from the mid-nineteenth century forward, have also played a central role in constituting audio-technical knowledge.[34]

Visual representations and sonic meanings are articulated by metaphor and analogy. Metaphor is a communicative device that bridges the gap between expert and nonexpert communities by appealing to a broader cultural consensus of meaning than any particular scientific paradigm or theory.[35] Scientists also use metaphors and analogies to transfer knowledge across otherwise disparate fields, and this is especially fundamental to the fields of acoustics and electroacoustics. Analog devices—including some synthesizer instruments and computers—are so named because mathematical formulas and graphical representations facilitate analogies among mechanical, electrical, and acoustical systems.[36]

Scholars working in various disciplines in the humanities and social sciences have established that metaphors and analogies are constituent elements of scientific thought.[37] Analogies of race and gender played a significant role

in scientific determinations of human variation in the nineteenth century and enabled a host of hierarchized social categories in U.S. culture to be seen as manifestations of measurable corporeal differences.[38] In developmental biology, scientists' engagements of competing mechanist and organicist metaphors shaped a paradigm shift in understandings of embryonic form in the early twentieth century.[39] Cognitive scientists at midcentury, informed by cybernetic theories, developed metaphors of minds as computers, rendering them as problem-solving, symbol-processing systems.[40] What is clear among these few but diverse examples is that conceptions of bodily form, function, and differentiation have been a primary product of the operation of metaphors and analogies across a range of scientific and technological discourses.

It is my contention that audio-technical discourse is no exception, in that metaphors pertaining to sound mediate a host of analogies that give meaning to understandings of bodily forms and embodied relations. Histories of sound and audio technologies are inextricably entwined with histories of the body and classifications of bodies according to attributes.[41] For example, Helmholtz, writing in the 1880s as Charles Darwin's ideas circulated, adopted similar language to discuss variations in tone quality among "different individual instruments of the same species."[42] Given the common concerns for form in acoustics research and the life sciences over the nineteenth century, it is not surprising that the term *organology* has historically applied to the following three domains of inquiry: the comparative analysis of the organs of animals or plants; the theories common to nineteenth-century race science that differences in character correspond to structures in the human brain; and the study of the history of musical instruments.[43]

Electronically synthesized sounds, and the machines that produce them, have been shaped by analogies of hearing and vision. In the 1860s Helmholtz theorized that loudness, pitch, and timbre corresponded to the primary properties of color: brightness, hue, and saturation.[44] Friedrich Nietzsche, writing on the illusions of metaphor as Helmholtz's theories spread, critiqued such analogies of eye and ear: "A nerve-stimulus, first transcribed into an image! First metaphor! The image again copied to a sound! Second metaphor! And each time he [the creator of language] leaps completely out of one sphere right into the midst of an entirely different one."[45] Yet, like many metaphoric leaps with persuasive power, Helmholtz's ideas influenced subsequent generations of acousticians, synthesizer designers, and composers who continued to make sense of sound this way and adopt these fundamental properties as standard. His resolution of sound into basic elements, in connection with a logic of resolving complex waveforms into simpler sine waves, laid an epistemological foundation for

sound synthesis techniques. Any sound could be analyzed to its fundamental parameters and, at least in theory, synthesized from that information. The basic components of an analog synthesizer (oscillator, filter, and amplifier) inherit and correspond to Helmholtz's tripartite classification of sound (pitch, timbre, and loudness), which was based on analogies to properties of color.

Despite the centrality of visual representations and metaphors in constituting audio-technical knowledge, sound must not be ceded entirely to the realm of the visual, for it carries its own cultural associations as well as interconnections to multiple modes of sensory experience.[46] The senses of hearing and touch are profoundly interconnected, especially in experiences of lower frequencies when audible sound is felt throughout the body as tactile vibration.[47] Yet, given the strong attachments of vision and objectivity to systems of knowledge and power in the West,[48] it remains necessary to account for how techniques and cultures of visualization are historically and epistemologically inseparable from the construction of sonic meanings. Sounds circulate as material-semiotic figurations—vibrations and wave motions (which we apprehend as the natural or material), ever articulated to visual representations and narrative strategies (the cultural or semiotic). In that "the visual is the known—we have ways of dealing with it, talking about it and studying it" and "the auditory is the [relative] unknown, the unfamiliar, the new,"[49] the "world of sound" may present novel opportunities for feminist worlding—for tracking relations of humans and nonhumans, and of the social and technological, and imagining possibilities for more ethical encounters among them.

Electronic Sounds as Lively Individuals

The metaphor of sounds as individual entities is a relatively recent phenomenon, taking shape over roughly a century and culminating in U.S. audio cultures by the early twentieth century. Prior to 1800 natural philosophers and experimenters described sounds in general terms by comparing them with other moving bodies in the universe and other aspects of sensory experience.[50] During the nineteenth century and into the twentieth, new instruments of measurement and modern acoustic treatments made it increasingly possible to consider sounds, and components of sounds, in isolation and greater detail.[51] Such shifts in audio-technical discourse took place in the context of scientific modernism and the expansion of industrial capitalism. Political, economic, and scientific discourses in this period figured the individual as a fundamental unit of capitalist society, the organism as a fundamental unit in biology, the atom and its subatomic structures as foundational to physics, and the phoneme as a simple building block of language.[52]

Additionally, while the stethoscope, the X-ray, and techniques of psychoanalysis exposed new bodily interiors in medicine,[53] graphical methods in acoustics revealed an interior structure of sound—component parts such as frequency, loudness, and timbre, and within timbre, constituent partial or harmonic tones. As natural historians and phrenologists were concerned with analogies among organs of different species and relations of body parts to outward expressions of species identification or moral character,[54] relations of component parts of individual tones to sonic aesthetics came into similar focus. Sounds, like modern bodies and subjects, came to be understood as complex wholes distinguishable by individual variations and composed of fundamental parts that could be analyzed and controlled by specialized technologies and techniques. These differential variations were communicated by the shape of the waveform, which represented aesthetically desirable or undesirable characteristics as determined by acoustics researchers.

A waveform is a visual representation that delineates a varying physical quantity, and expresses the shape or manner of that variation over time. The term surfaced in the 1840s in descriptions of the motion of water. In subsequent decades, it came to signify variations of electrical signals over time, including patterns of electrical activity within living bodies.[55] Waveforms were produced by graphical inscription instruments, which were widely adopted across scientific disciplines in the middle decades of the nineteenth century and especially influential in acoustics and experimental physiology research.[56] These two fields were articulated and advanced together in Helmholtz's physiological theories of acoustics. Helmholtz's experiments relied on graphical methods, and he grounded his theories of the experience of musical aesthetics in anatomical form and function. Through the figure of the waveform, sounds acquired formal affinities to nineteenth-century representations of bodies in motion and bodily differentiation. Sounds took on analogous properties to organic processes like muscle contraction, respiration, circulation, and growth properties such as amplitude, duration, and periodicity.[57] By the late 1800s and early 1900s, acoustics textbooks were filled with analogies among all kinds of waveforms, from barometric pressure to the sound of an orchestra, all of which could be represented through the common language of the waveform.[58]

While the amplitude of a sound waveform marked changes in air pressure from particles' extension into space, its manner of extension was understood to vary over time. In this sense, the sound waveform encapsulated some of the contemporaneous ideas of individual variation introduced by Darwin's theory of evolution. In the seventeenth and eighteenth centuries, the Linnaeus classification system ordered nature by hierarchically organized types or essences.

Graphical inscription instruments, adopted across scientific fields as Darwin's writings circulated, provided visible evidence of individually varying physical characteristics among bodies of the same species and of individually varying sounds that, to the unmediated senses, might otherwise seem indistinguishable from each other.

The innovation of graphical inscription instruments, compared with earlier investigations in anatomy and physiology, was indeed to display physiological fluctuations over time. As one example, by the turn of the twentieth century, electrocardiographic waveforms presented the heart's electrical activity as, quite literally, signs of life. Medical experts could determine from the shape of waveforms whether electrical activities in the body were normal or pathological (as in cases of cardiac arrhythmia); moreover, an unvarying baseline (or flatline) symbolized life's absence. There are direct parallels between this representation of life and its absence, and sound and silence (figs. 1, 2). In both cases electrical activity functioned literally and symbolically as an animating and sustaining factor.[59] Electricity, which was naturalized by graphical methods as a sign of movement and life within living bodies, held the promise for technological control of amplitude, duration, and timbral variation of sound waveforms through the animating techniques of synthesis.

The discovery of electrical activity within living bodies was integral to developments in graphical methods and an important factor in forming analogies between electronic sounds and life processes. In the late 1700s the Italian physician and physicist Luigi Galvani had proclaimed electricity as a fundamental life force after discovering that the severed leg of a frog would kick as though alive when touched by an electric current.[60] This idea was elaborated on in the first half of the 1800s by several researchers who located the presence of a "resting current" or "action potential" in muscles.[61] Helmholtz developed an instrument called the myograph to graphically render nerve impulses and muscular expansion and contraction over time.[62] Around the same time, in *The Origin of Species* (1859), Darwin was especially intrigued by the case of electric fish, which use a specialized "electric organ" to generate electrical fields, thought to be applied toward a variety of communication and orientation purposes.[63] And, in the 1870s, the English physiologist John Scott Burdon-Sanderson, experimenting with Venus flytraps borrowed from Darwin, determined that electrical activity in moving plants was analogous to the expansion and contraction of muscles in humans and animals.[64] The presence of electrical activity among diverse forms of life naturalized the apparent liveliness of electronic sounds and the eventual associations of terms like *growth* and *decay* with their formal structure.[65]

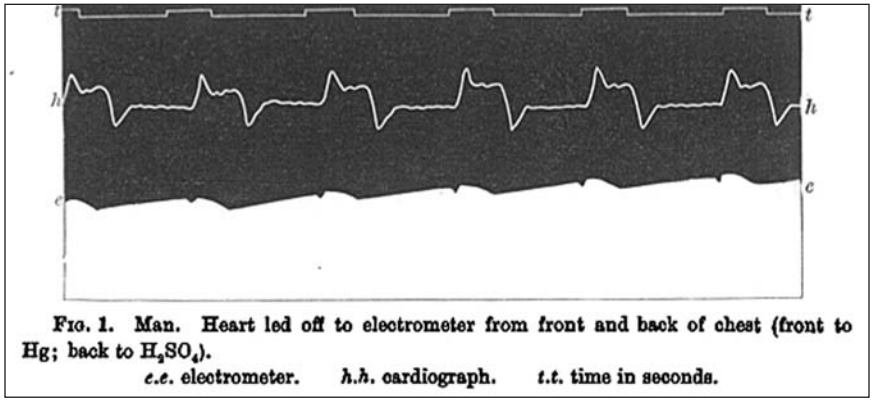

FIG. 1. Man. Heart led off to electrometer from front and back of chest (front to Hg; back to H_2SO_4).
e.e. electrometer. *h.h.* cardiograph. *t.t.* time in seconds.

Figure 1.
Augustus Waller's first published electrocardiogram, showing electrical activity in the heart of "man," in "A Demonstration on Man of Electromotive Changes Accompanying the Heart's Beat," *The Journal of Physiology* (1887), 17.

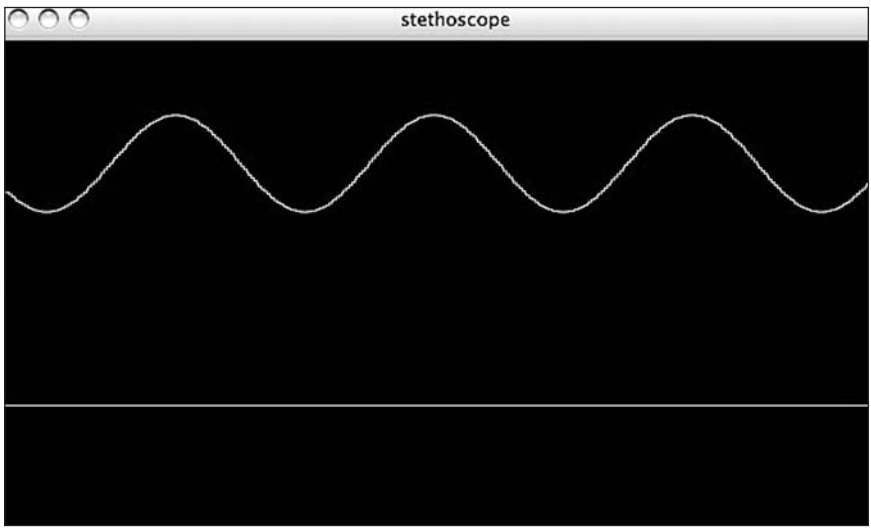

Figure 2.
A graphical representation of a sine wave oscillator (above) and silence (below), shown in the open-source software environment SuperCollider. Note that the tool in SuperCollider for displaying waveforms on currently monitored channels is named "stethoscope," like the analogous medical instrument for revealing the sounds of bodily interiors. Image courtesy of the author (2011); see also the SuperCollider Home Page (http://audiosynth.com/).

Waveform representations articulated electronic sounds to notions of ongoing life and life cycles by depicting successive patterns of periodic oscillations as renewable patterns of growth and decay. Electricity's capacity as a sustaining source of energy offset concerns about bodily fatigue, which graphical instruments sought to quantify. Over the latter half of the nineteenth century, "concepts of energy and fatigue reflected the paradox of social modernity, at once affirming the endless natural power available to human purpose while revealing an anxiety of limits—the fear that the body and psyche were circumscribed by fatigue and thus could not withstand the demands of modernity."[66] Fatigue was an obstacle for industrializing societies to overcome, and efficiency of laboring bodies was the target of Taylorism and other efforts at scientific management. Contemporaneous fascinations with the duration of electronic sounds can be understood in this cultural context. In audio-technical discourse, electricity represented a sustaining force that enabled the decay cycles of sounds to be followed by renewed growth. Unlike the human voice or breath, which was thought to naturally fade away, electricity seemed to offer the appealing potential to go on forever.[67] This alluring potential demanded new techniques for regulating the duration of electronically generated sounds, techniques which grew in conjunction with acoustics research around the turn of the twentieth century.[68] Over time, the technology of the amplitude envelope was developed and eventually standardized as a kind of container for individual sounds as they arose from, and fell back into, silence.[69] Through graphical methods in physiology and acoustics, curvy waveforms came to symbolize life and lively variation compared with the flatline of stillness, death, and silence. One particular curve—the sine wave—became associated with aesthetic purity, neutrality, and musical/cultural value.

Historicizing Timbre: The Sine Wave, Tonal Purity, and Variation

The waveform represented the technological possibility of isolating an individual sound amid the formless flux of a universe filled with otherwise indistinguishable sounds. Helmholtz called this environment the "atmospheric ocean," and the historian of acoustics and prominent Harvard University professor Frederick Hunt labeled it the "uneasy ocean of air."[70] This "uneasiness" of the acoustics researcher amid the waves marks an affective orientation to sound and audio technologies that, I argue, expresses a particularly gendered location. In audio-technical discourse, properties of sound waves have been aligned with the connotations of fluidity and excess that have been associated with female bodies throughout Western history and philosophy. Analogies between sound

and water waves in foundational acoustics texts articulated the physical behavior and experience of sound to the connotations of formlessness and unknowability that historically have been associated with female sexuality and corporeality, and to the horrors of submersion and dissolution that threaten the coherence and dominance of the male subject. Acoustics researchers often described their work with sound as a way to experience the pleasure and danger of navigating turbulent waves or seek their control from a distanced perspective.[71]

The development of waveform representations through nineteenth-century graphical methods presented the technological possibility of rendering individual waves legible through mediating instruments. Waveform representations also revealed how individual sounds differed from one another and thus enabled more detailed classifications of sounds according to aesthetic similarities and differences, much like the study and sorting of species, and of human bodies by racialized and other socially differentiated terms. The possibility of representing all sounds as waveforms opened up new possibilities for technological control, through which scientists and composers could confer aesthetic and cultural value on particular shapes of waveforms. As the historian of mathematics Charles Henry noted in 1885, if all of sensory experience could in principle be reduced to a waveform, artists could become "workers of the line," manipulating its shape to desired effects.[72]

Helmholtz's research on the relationship of waveforms to timbre (or tone quality) was one of his signal contributions to musical acoustics, and it opened up possibilities for understanding and manipulating timbre in detailed ways. Composers and instrument designers working in the United States in the first half of the twentieth century embraced the technological control of timbre as a hallmark of modern music composition.[73] Helmholtz extended earlier work by Joseph Fourier and Georg Ohm to argue that all complex tones could be resolved into simpler, sinusoidal components and resynthesized from that information.[74] Following this work, acoustics textbooks routinely described the sine wave as the "most pure tone"—"lacking body" or being "colorless," neutral, or without timbral character. The sine wave was hailed as a fundamental building block of musical tone and timbral variation, and counterposed to devalued dissonance and unpleasant noise. To recount a few representative claims: James Jeans, remarking on the "perfectly pure" tone of a tuning fork in a 1937 textbook on music and science, described a graphical representation of its vibration: "The extreme regularity of these waves is striking; they are all of precisely the same shape, so that their lengths are all exactly the same, and they recur at perfectly regular intervals. Indeed, it is this regularity which distinguishes music from mere noise."[75] Aden Evens, in his recent philosophical

exploration of sound, remarked: "An individual sine wave has a minimal timbre . . . [its sound] is thin, without texture, *a pure tone with no body behind it*."[76]

The sine wave is indeed a mathematical and technological ideal—the only "pure" waveform said to be lacking timbre—against which timbral variations are compared. The generation and control of timbral variation is a central contribution of synthesized sound to music production more generally in the twentieth century. I propose that cultural associations of timbre with a kind of devalued materiality of the body, evident in the marginalization of timbre in Western classical musical traditions,[77] were bolstered by Helmholtz's neoclassical aesthetics, through which the sine wave was figured as a pure form and said to be "without body." Notions of the sine wave as "pure" and "lacking body" were articulated to cultural valuations of whiteness and scientific objectivity, while timbral variation came to signify marked forms of material embodiment (e.g., raced, gendered, classed).

Helmholtz's taste in art, his gestures toward a theory of aesthetics, and his core scientific principles can all be described as neoclassical in that they tended to validate simplicity, order, harmony, and regularity. Helmholtz was a key figure in establishing a sonic epistemology that bridged ancient and modern themes, the kinds of transhistorical connections that characterized neoclassicist endeavors.[78] The sinusoidal form, as a smooth line and evenly proportioned twofold curve, is consistent with Helmholtz's neoclassical aesthetics and the desire for simplicity and order that manifested across his work and tastes. Such demarcations of the true, good, and beautiful at the nexus of capitalism, industrialization, and the foundation of Western modernity were built on racialized signs and associated claims to cultural value. As Paul Gilroy maintains, "Notions of the primitive and the civilized which had been integral to pre-modern understanding of 'ethnic' differences became fundamental cognitive and aesthetic markers in the processes which . . . [gave] way to the dislocating dazzle of 'whiteness.'"[79] Similarly, in her work on the color of stone in neoclassical sculpture, Charmaine Nelson has shown that the whiteness of marble was by no means neutral but a conscious rejection of pigment as dangerous and sensual by expatriate American artists in their sculptural representations of black female subjects.[80] Helmholtz was not as expressly engaged with representing racialized and sexualized subjects as visual artists were, although his discussions of tonality and harmony devalued non-Western musical traditions as primitive in ways consistent with dominant Western music discourses.[81] More significantly in terms of his lasting contributions to acoustics and synthesis history, his formulation of the sine wave as an ideal manifestation of harmony and order signified cultural markers of beauty and restraint associated in audio-technical discourse with whiteness and scientific objectivity.

In the imagination of Helmholtz and followers like the acoustician Dayton C. Miller, it seems the sine wave was a paragon of pure form, a model for other "simple" waveforms associated with the construction of tonal beauty, harmony, and musical pleasure that were articulated to notions of whiteness as a signifier of cultural value. One of Miller's exemplary "synthetic experiments" with his harmonic synthesizer, developed in 1914, was to use the machine to synthesize the curve of a white woman's portrait profile and to demonstrate its abstraction into a periodic waveform. He used the repetition of its "simple" curves to illustrate the principle that complex timbres are constructed of simpler forms, where "beauty of form may be likened to beauty of tone color, that is, to the beauty of a certain harmonious blending of sounds."[82] If the source for beauty of tone color was the simple form of the sine wave, analogized in these examples to the comparably perceived simplicity of a white woman's profile, it follows that timbral complexity and dissonance would correspond to alternately devalued and desired notions of deviation and excess, representable by more complex and asymmetrical waveforms and signifying racial difference.

Electronically produced timbral variations came to be celebrated in contrast to the idealized form of the sine wave, signifying the addition of stimulating sonic variations to the dullness of the "most pure tone." These are, for cultural theorists, familiar terms through which white supremacist discourses have framed cultural contacts with racialized otherness, where such contacts primarily enrich and transform white subjectivities and cultures, and sustain imperialist nostalgia.[83] Taking up this legacy critically, Afro-diasporic popular musicians, working in response to histories of slavery and colonialism, have often *claimed* sonic artifice—the creative manipulation of timbre with electronic synthesis and effects—as a way to expose the category of human (or, in this example, the disembodied ideal represented by the "pure" sine wave figure) as always already constructed, contingent, and never natural.[84] What I propose here is that Helmholtz's theories of tone and timbre, which were centrally taken up by acousticians across the United States, Canada, and Europe by the turn of the twentieth century and have remained influential, mark a significant historical moment when the aesthetics of electronic sounds came to be racialized through terms of modern science.

The sine wave can also be interpreted as an idealization of efficient motion and energy expended by the willfully controlled, laboring bodies of scientific researchers. Nineteenth-century biographies and autobiographies presented the role of scientists as one of diligence in effort, combined with restraint of the will to impose any hypotheses that would interfere with the objective rendering of nature's truths by graphical methods and instruments. Men of science

and their biographers compared work in the laboratory to labor in industrial factories. But, as a mark of their bourgeois class position or aspirations, they emphasized their superior discipline in exercising patience, vigilance, and self-restraint amid tireless, ongoing effort.[85] The smooth line of the sine wave perhaps remains legible and audible as "without a body" partly because it is an ideal shape that lacks the variability of actual bodies in motion. Instead, its form epitomizes nineteenth-century scientists' values of repetitive effort (ongoing cycles of a waveform) and willful restraint (smooth, precise curves with no excessive deviations).

The modern conception of electronic sounds as individuals with varying characteristics, classifiable by aesthetic properties, was thus co-emergent with scientific epistemologies used to produce cultural hierarchies of socially differentiated bodies, along modalities such as race, gender, and class. As the sine wave signified purity and order, aperiodic waveforms represented noise—increasingly a symbol of social and cultural transformations in the modern American city, a sign of urban congestion and disorder, and a target of progressive noise abatement campaigns by the early twentieth century.[86] The shape of sound waveforms, these examples suggest, is entwined with histories of scientific determinations of bodily difference and intersecting desires for social ordering and control.

Conclusion

The representational "space" of electronic sounds and signals was established over the course of nineteenth-century scientific research in Europe and the consolidation of acoustics as a professional field in the United States in the early twentieth century. It provided an imagined world for expressing identity and social stratification much as the Internet and other digital media do today. As political, economic, and scientific discourses over the nineteenth century increasingly centered on the organism as a fundamental unit in biology and the individual as a fundamental unit of capitalist society, sounds came into focus as discrete individuals with varying properties, in tandem with technologies for their electronic generation and control. In the context of various social and cultural shifts in America that generated new patterns of encounter around differences such as race, gender, and class, new communities of audio-technical experts learned to distinguish individual sounds through analogous representational signifiers. Properties of electronic sounds were articulated to ideas about social stratification: character, excess and constraint, purity and deviation. In her work on race and cyberspace, Lisa Nakamura has argued that the Internet

is a crucial site for representations of social difference through "digital signifying practices" that render aspects of identity and difference visible in particular ways.[87] Such critical interventions remain necessary to analog technocultures as well—the constellation of concepts, designs, and uses of analog technologies that prefigure and overlap contemporary digital cultures.

While there is a broad range of literature in sound and media studies about technologies of sound reproduction, there remains relatively little critical analysis of sound synthesis, the domain investigated in this essay. Much work on sound reproduction technologies has reframed a central theoretical concern in studies of film and photography: relations of original and copy, and the fidelity of reproductions to originals.[88] Synthesized sound, however, may direct our attention to other strands of cultural history that are imbricated in sonic worlds, such as discourses in life sciences concerned with relations of component organs and whole organisms, processing techniques in chemistry and food sciences, and popular notions of the synthetic as technologically constructed artifice. Synthesis may also be a useful model for feminist technological worlding: for thinking how individual entities of all sorts emerge out of contingent unions of partial elements, which are ever transformable through new arrangements and relations in worldly contexts.

Notes

Thanks to Jonathan Sterne, Carrie Rentschler, Darin Barney, Andra McCartney, Alanna Thain, Kim Sawchuk, the editors of this volume, and audiences at the Critical Theory Colloquium, University of Maryland, and the Maryland Institute for Technology in the Humanities Digital Dialogues series, for their conversations and feedback on versions of this essay.

1. One derivation of *timbre* is from meanings of *stamp* as a distinctive mark of individual character. *Oxford English Dictionary*, s.v. "timbre," http://dictionary.oed.com/entrance.dtl. Alexander J. Ellis, a translator of Hermann von Helmholtz's work into English, offers a wonderful etymology, rejecting the term *timbre* in favor of "quality of tone": "*Timbre*, properly a kettledrum, then a helmet, then the coat of arms surmounted with a helmet, then the official stamp bearing that coat of arms (now used in France for a postage label), and then the mark which declared a thing what it pretends to be . . . is . . . often mispronounced, and not worth preserving." Hermann von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, trans. A. J. Ellis, 2nd ed. (New York: Dover Publications, 1954), 24n. Ellis's wry and dismissive explanation illustrates well how the common terms we use to describe sounds often inherit winding and obscure paths of cultural history.
2. I use the term *audio-technical* to encompass a range of social actors and institutions invested in the technologically mediated production of knowledge about sound, distributed across such fields as music making and consumption, acoustics research and engineering, and electronics hobbyist cultures. Here *discourse* refers to "a way of knowledge, a background of assumptions and agreements about how reality is to be interpreted and expressed, supported by paradigmatic metaphors, techniques, and technologies." See Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass.: MIT Press, 1996), 34.

3. Casey O'Callaghan, *Sounds: A Philosophical Theory* (Oxford: Oxford University Press, 2007), 17.
4. David Miles Huber and Robert E. Runstein, *Modern Recording Techniques*, 5th ed. (Boston: Focal Press/Elsevier, 1997), 25–39; William Moylan, *The Art of Recording: Understanding and Crafting the Mix* (Boston: Focal Press, 2002), 161.
5. Isolating and mixing individual sonic elements reflect dominant techniques of Western and Eurological musical practices, those arguably bound most closely to the epistemological formations charted in this essay. These recording and editing techniques tend to fall short when documenting performances that foreground musical collectivity and dialogue, because they presume "that social interaction among the musicians is not a structural requirement of the performance." Beverley Diamond, "Media as Social Action: Native Americans in the Recording Studio," in *Wired for Sound*, ed. Paul Greene and Thomas Porcello (Middletown, Conn.: Wesleyan University Press, 2005), 124–25.
6. The Acoustical Society of America was organized in 1928, "institutionally recognizing the tremendous expansion of the field of acoustics . . . since the turn of the century." Its membership included physicists, musicians, psychologists, and others with interests at the intersections of music, sound, and science. See Emily Ann Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900–1933* (Cambridge, Mass.: MIT Press, 2002), 60, 105; see also Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham, N.C.: Duke University Press, 2003) on developments in sound reproduction technologies and modern listening techniques in this period.
7. David Suisman, "Introduction: Thinking Historically about Sound and Sense," in *Sound in the Age of Mechanical Reproduction*, ed. David Suisman and Susan Strasser (Philadelphia: University of Pennsylvania Press, 2010), 2–3.
8. Lisa Gitelman, *Always Already New: Media, History, and the Data of Culture* (Cambridge, Mass.: MIT Press, 2006), 14–15, 70.
9. Mara Mills, "Deaf Jam: From Inscription to Reproduction to Information," in "The Politics of Recorded Sound," ed. Gustavus Stadler, special issue, *Social Text* 102 (2010): 39.
10. Steve J. Wurtzler, *Electric Sounds: Technological Change and the Rise of Corporate Mass Media* (New York: Columbia University Press, 2009).
11. Trevor J. Pinch and Frank Trocco, *Analog Days: The Invention and Impact of the Moog Synthesizer* (Cambridge, Mass.: Harvard University Press, 2002), 53–69; Paul Théberge, *Any Sound You Can Imagine: Making Music/Consuming Technology* (Hanover, N.H.: Wesleyan University Press, 1997).
12. Dayton Clarence Miller, *The Science of Musical Sounds*, 2nd ed. (New York: Macmillan, 1937).
13. In her social history of electric communication technologies, Carolyn Marvin underscores the role of language in forming and perpetuating communities of technical experts in the late nineteenth century. She uses the term "textual communities" to describe groups of electrical experts that organized around authoritative texts and their accepted interpreters. This is a useful concept for understanding the rise of communities of audio-technical practitioners in the decades immediately following, for whom language and visual representations played key roles in forming accepted and common knowledge. See Carolyn Marvin, *When Old Technologies Were New: Thinking about Electric Communication in the Late Nineteenth Century* (New York: Oxford University Press, 1988), 12.
14. Sterne, *Audible Past*, 287–333.
15. This essay addresses logics of additive and subtractive synthesis that informed the design of most electronic musical instruments and synthesizers through the 1970s. Additive synthesis is based on the concept that a complex waveform can be approximated by the sum of many simple waveforms; it informs the design of instruments from pipe organs to the Telharmonium at the turn of the twentieth century, to the Hammond electronic organs popular in the mid-twentieth century. Subtractive synthesis techniques, which were popularized by Homer Dudley's vocoder system for synthesizing speech at the 1936 World's Fair and continued to inform the designs of many analog synthesizers through the 1970s and beyond, are based on a premise that a wide range of timbral variations can be achieved by the controlled removal or attenuation of harmonic frequencies from a basic waveform. A classic technique of subtractive synthesis involves the independent regulation of the pitch, volume, and timbre of a waveform, as controlled respectively by an oscillator, amplifier, and filter. Many other techniques for synthesizing sound have emerged, including physical modeling and granular synthesis, which represent rich areas for further research on the role of metaphors in constituting sonic epistemologies. See Curtis Roads, *The Computer Music Tutorial* (Cambridge, Mass.: MIT Press, 1996), 134, 163–65, 168–69, 197–98, 265–67.

16. "Micromoog Specification Sheet," 1975, David Kean files, Cantos Music Foundation, Calgary, Alb.
17. Théberge, *Any Sound You Can Imagine*.
18. Tara Rodgers, *Pink Noises: Women on Electronic Music and Sound* (Durham, N.C.: Duke University Press, 2010), 107, 117–18, 122, 131, 142.
19. Martin Heidegger, *Poetry, Language, Thought* (New York: Perennial Classics, 2001), 43, 35.
20. Ibid., 43.
21. Donna Jeanne Haraway, *Modest_Witness@Second_Millennium.Femaleman_Meets_Oncomouse: Feminism and Technoscience* (New York: Routledge, 1997), 11.
22. Ibid., 8.
23. Donna J. Haraway, "Foreword: Companion Species, Mis-recognition, and Queer Worlding," in *Queering the Non/Human*, ed. Noreen Giffney and Myra J. Hird (Burlington, Vt.: Ashgate, 2008), xxiii–xxvi.
24. Ranjana Khanna, *Dark Continents: Psychoanalysis and Colonialism* (Durham, N.C.: Duke University Press, 2003), 4–5; see also Gayatri Chakravorty Spivak, *A Critique of Postcolonial Reason: Toward a History of the Vanishing Present* (Cambridge, Mass.: Harvard University Press, 1999), 211–13.
25. Jonathan Sterne, "Out with the Trash: On the Future of New Media," in *Residual Media*, ed. Charles R. Acland (Minneapolis: University of Minnesota Press, 2007), 16–31; Rachel Grossman, "Women's Place in the Integrated Circuit," *Radical America* 14.1 (1980): 29–49; Annette Fuentes and Barbara Ehrenreich, *Women in the Global Economy* (Cambridge, Mass.: South End Press, 1983).
26. Sherry Turkle, "Computational Reticence: Why Women Fear the Intimate Machine," in *Technology and Women's Voices: Keeping in Touch*, ed. Cheris Kramarae (New York: Routledge, 1988), 42–43.
27. Josh Kun, *Audiotopia: Music, Race, and America* (Berkeley: University of California Press, 2005), 2.
28. Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch (Cambridge, Mass.: MIT Press, 1992), 40; Pinch and Trocco, *Analog Days*; Gitelman, *Always Already New*, 62; Steve Waksman, *Instruments of Desire: The Electric Guitar and the Shaping of Musical Experience* (Cambridge, Mass.: Harvard University Press, 2001).
29. Andra McCartney and Ellen Waterman, "Introduction: In and Out of the Sound Studio," *Intersections: Canadian Journal of Music* 26.2 (2006): 4; see also Ruth Oldenziel, *Making Technology Masculine: Men, Women, and Modern Machines in America, 1870–1945* (Amsterdam: Amsterdam University Press, 1999).
30. Suisman, "Introduction," 5.
31. Michelle Hilmes, "Is There a Field Called Sound Culture Studies? And Does It Matter?" *American Quarterly* 57.1 (2005): 249; Trevor Pinch and Karin Bijsterveld, "Sound Studies: New Technologies and Music," *Social Studies of Science* 34.5 (2004): 637; Sterne, *Audible Past*; Thompson, *Soundscape of Modernity*.
32. Pinch and Bijsterveld, "Sound Studies," 637.
33. Richard D. Leppert, *The Sight of Sound: Music, Representation, and the History of the Body* (Berkeley: University of California Press, 1993), xx.
34. Sterne, *Audible Past*, 45.
35. Nancy Leys Stepan, "Race and Gender: The Role of Analogy in Science," *Isis* 77.2 (1986): 271.
36. Harry Ferdinand Olson, *Dynamical Analogies*, 2nd ed. (Princeton, N.J.: Van Nostrand, 1958), iv; Derek Robinson, "Analog," in *Software Studies: A Lexicon*, ed. Matthew Fuller (Cambridge, Mass.: MIT Press, 2008), 22–23.
37. Stepan, "Race and Gender," 261; George Lakoff and Mark Johnson, *Metaphors We Live By* (Chicago: University of Chicago Press, 1980), 191–92, 195–97; Mary B. Hesse, *Models and Analogies in Science* (Notre Dame, Ind.: University of Notre Dame Press, 1966); Donna Jeanne Haraway, *Crystals, Fabrics, and Fields: Metaphors That Shape Embryos* (Berkeley, Calif.: North Atlantic Books, 2004); Andrew Ortony, *Metaphor and Thought* (Cambridge: Cambridge University Press, 1979); Edwards, *Closed World*.
38. Stepan, "Race and Gender," 267; Robyn Wiegman, *American Anatomies: Theorizing Race and Gender* (Durham, N.C.: Duke University Press, 1995), 32–33.
39. Haraway, *Crystals, Fabrics, and Fields*, 4–7.
40. Edwards, *Closed World*, 2.

41. Sterne, *Audible Past*, 12.
42. Helmholtz, *On the Sensations of Tone*, 19.
43. *Oxford English Dictionary*, s.v. "organology."
44. Timothy Lenoir, "Helmholtz and the Materialities of Communication," *Osiris* 9 (1994): 198–99; Helmholtz, *On the Sensations of Tone*, 18–19; John Durham Peters, "Helmholtz, Edison, and Sound History," in *Memory Bytes: History, Technology, and Digital Culture*, ed. Lauren Rabinovitz and Abraham Geil (Durham, N.C.: Duke University Press, 2004), 183.
45. Friedrich Wilhelm Nietzsche, "On Truth and Falsehood in an Extra-Moral Sense," in *The Complete Works of Friedrich Nietzsche*, ed. Oscar Levy (Edinburgh: T. N. Foulis, 1909), 180; see also Gayatri Chakravorty Spivak, preface to *Of Grammatology*, Jacques Derrida, trans. Gayatri Chakravorty Spivak (Baltimore, Md.: Johns Hopkins University Press, 1997), xxii.
46. Sterne, *Audible Past,* 14–19.
47. Andra McCartney, "Soundscape Works, Listening, and the Touch of Sound," in *Aural Cultures*, ed. Jim Drobnick (Toronto: XYZ Books, 2004), 179.
48. Donna J. Haraway, "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective," *Feminist Studies* 14.3 (1988): 581.
49. Pinch and Bijsterveld, "Sound Studies," 637.
50. Michael Spitzer, *Metaphor and Musical Thought* (Chicago: University of Chicago Press, 2004), 154–56.
51. Robert T. Beyer, *Sounds of Our Times: Two Hundred Years of Acoustics* (New York: AIP Press/Springer, 1999), 131–222; Thompson, *Soundscape of Modernity*, 61.
52. Michel Foucault, *An Introduction*, vol. 1 of *The History of Sexuality* (New York: Vintage Books, 1990), 139–43; Donna Jeanne Haraway, *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York: Routledge, 1991), 45; Robert M. Brain, "Representation on the Line: Graphic Recording Instruments and Scientific Modernism," in *From Energy to Information: Representation in Science and Technology, Art, and Literature*, ed. Bruce Clarke and Linda Dalrymple Henderson (Stanford, Calif.: Stanford University Press, 2002), 169.
53. Sterne, *Audible Past*, 122; Lisa Cartwright, *Screening the Body: Tracing Medicine's Visual Culture* (Minneapolis: University of Minnesota Press, 1995), 107–42.
54. Wiegman, *American Anatomies*, 31–33.
55. *Oxford English Dictionary*, s.v. "waveform."
56. Thomas L. Hankins and Robert J. Silverman, *Instruments and the Imagination* (Princeton, N.J.: Princeton University Press, 1995), 129.
57. *Oxford English Dictionary*, s.v. "amplitude."
58. James Hopwood Jeans, *Science and Music* (Cambridge: University Press, 1937), 11–12; Douglas Kahn, *Noise Water Meat: A History of Sound in the Arts* (Cambridge, Mass.: MIT Press, 1999), 78.
59. Georges Canguilhem, *The Normal and the Pathological* (New York: Zone Books, 1991), 43; W. Bruce Fye, "A History of the Origin, Evolution, and Impact of Electrocardiography," *American Journal of Cardiology* 73.13 (1994): 939–40. For a representation of silence and sound analogous to electrocardiographic patterns, see Jeans, *Science and Music*, 19.
60. Marvin, *When Old Technologies Were New*, 129.
61. Robert Frank, "The Telltale Heart: Physiological Instruments, Graphic Methods, and Clinical Hopes, 1854–1914," in *The Investigative Enterprise: Experimental Physiology in Nineteenth-Century Medicine*, ed. William Coleman and Frederic L. Holmes (Berkeley: University of California Press, 1988), 227; Fye, "History of the Origin, Evolution, and Impact of Electrocardiography," 938.
62. Brain, "Representation on the Line," 165.
63. Charles Darwin, *The Origin of Species* (London: Signet Classics, 2003), 178–79, 404–6.
64. Frank, "Telltale Heart," 231.
65. Harry F. Olson and Herbert Belar, "Electronic Music Synthesizer," *Journal of the Acoustic Society of America* 27.3 (1955): 596.
66. Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (Berkeley: University of California Press, 1990), 12.
67. Peters, "Helmholtz, Edison, and Sound History," 177; Thomas B. Holmes, *Electronic and Experimental Music: Pioneers in Technology and Composition*, 2nd ed. (New York: Routledge, 2002), 12.
68. Thompson, *Soundscape of Modernity*, 81–85, 173–78; Lord Rayleigh (John William Strutt), *The Theory of Sound*, 2nd ed., 2 vols. (New York: Dover Publications, 1945), 81, 137; J. A. Fleming, *The Principles of Electric Wave Telegraphy and Telephony*, 2nd ed. (London: Longmans, Green, 1910), 122.

69. Pinch and Trocco, *Analog Days*, 58–59.
70. Helmholtz, *On the Sensations of Tone*, 10; Frederick V. Hunt, *Origins in Acoustics: The Science of Sound from Antiquity to the Age of Newton* (New Haven, Conn.: Yale University Press, 1978), 1. These acousticians' characterizations of their "world of sound" were not unlike how Nietzsche characterized modernity itself: a "sea of forces flowing and rushing together." Quoted in Gillian Beer, *Open Fields: Science in Cultural Encounter* (New York: Oxford University Press, 1996), 313.
71. Elsewhere, I discuss this metaphor of electronic sounds as waves at length, working with Luce Irigaray's claim that in the Western philosophical tradition, feminized fluids are "a physical reality that continues to resist adequate symbolization and/or that signifies the powerlessness of logic to incorporate in its writing all the characteristic features of nature." See Luce Irigaray, "The 'Mechanics' of Fluids," in *This Sex Which Is Not One*, trans. Catherine Porter with Carolyn Burke (Ithaca, N.Y.: Cornell University Press, 1985), 106–7; and Tara Rodgers, "Toward a Feminist Epistemology of Sound: Refiguring Waves in Audio-Technical Discourse," in *Philosophy after Irigaray: Selected Papers from the Proceedings of the Luce Irigaray Conference*, ed. Mary Rawlinson, Danae Mcleod, and Sara McNamara (Albany: State University of New York Press, forthcoming).
72. Brain, "Representation on the Line," 170.
73. Carlos Chavez, *Toward a New Music: Music and Electricity*, trans. Herbert Weinstock (New York: W. W. Norton, 1937), 162; Peter Manning, *Electronic and Computer Music* (Oxford: Clarendon Press, 1985), 1, 12; Holmes, *Electronic and Experimental Music*, 75.
74. Helmholtz, *On the Sensations of Tone*, 21–36; Peters, "Helmholtz, Edison, and Sound History," 183–84; Lenoir, "Helmholtz and the Materialities of Communication," 197–205.
75. Jeans, *Science and Music*, 20.
76. Aden Evens, *Sound Ideas: Music, Machines, and Experience* (Minneapolis: University of Minnesota Press, 2005), 4; emphasis added.
77. Jeremy Gilbert and Ewan Pearson, *Discographies: Dance Music, Culture, and the Politics of Sound* (London: Routledge, 1999), 59–63.
78. Gary Hatfield, "Helmholtz and Classicism: The Science of Aesthetics and the Aesthetics of Science," in *Hermann Von Helmholtz and the Foundations of Nineteenth-Century Science*, ed. David Cahan (Berkeley: University of California Press, 1993), 556–67.
79. Paul Gilroy, *The Black Atlantic: Modernity and Double Consciousness* (Cambridge, Mass.: Harvard University Press, 1993), 8–9.
80. Charmaine Nelson, *The Color of Stone: Sculpting the Black Female Subject in Nineteenth-Century America* (Minneapolis: University of Minnesota Press, 2007).
81. Helmholtz, *On the Sensations of Tone*, 237; see also Jeans, *Science and Music*, 161.
82. Miller, *Science of Musical Sounds*, 119–20; Kahn, *Noise Water Meat*, 95–99.
83. bell hooks, "Eating the Other: Desire and Resistance," in *Media and Cultural Studies: Key Works*, ed. Meenakshi Gigi Durham and Douglas Kellner (Malden, Mass.: Blackwell, 2006), 366–80.
84. Alexander G. Weheliye, "'Feenin': Posthuman Voices in Contemporary Black Popular Music," *Social Text* 20.2 (2002): 21–47.
85. Lorraine Daston and Peter Galison, *Objectivity* (New York: Zone Books, 2007), 230–31.
86. Thompson, *Soundscape of Modernity*, 115–20.
87. Lisa Nakamura, *Digitizing Race: Visual Cultures of the Internet* (Minneapolis: University of Minnesota Press, 2008), 5.
88. Jonathan Sterne, "The Mp3 as Cultural Artifact," *New Media and Society* 8 (2006): 836–37; Gustavus Stadler, "Introduction: Breaking Sound Barriers," in "The Politics of Recorded Sound," ed. Gustavus Stadler, special issue, *Social Text* 102 (2010): 2; see also John Mowitt, "The Sound of Music in the Era of Its Electronic Reproducibility," in *Music and Society: The Politics of Composition, Performance, and Reception*, ed. Richard Leppert and Susan McClary (New York: Cambridge University Press, 1987), 173–97; Eric Rothenbuhler and John Durham Peters, "Defining Phonography: An Experiment in Theory," *Musical Quarterly* 81.2 (1997): 242–64.