1 Introduction

1.1 Profusions

Contemporary art is replete with works that explore the relationships between sound and space, with "space" understood in physical, sensorial, geographical, social, and political terms. Today I can plug my headphones into the façade of a building in Berlin to hear how its materiality, made audible through the use of seismic sensors embedded into the building's infrastructure, changes over time and in response to variations in atmospheric pressure, weather, and other environmental factors. In other words, I can listen to a building as it evolves over time and in relation to its surroundings. In suburban London I can visit a building whose spiraling form is inspired by the music of Erik Satie and the chance methods of John Cage. Electronic music, projected over loudspeakers, is played throughout the building. The music is created from sounds that were recorded during the making of the building itself: the sounds of breaking ground, of pouring concrete. This literal *musique concrète* is lush and surprisingly beautiful. And, it is impossible to say where music begins and architecture ends. In 2017 I could visit an acoustic refuge in a low-income neighborhood in Beirut. This temporary structure, erected in a parking lot close to a highway, used acoustic paneling to reduce environmental noise, but it also featured a quiet, meditative soundtrack composed of everyday city sounds. The designer wanted to draw attention to the uneven ways in which noise affects rich and poor inhabitants of the city—how a politics of noise shapes the city and differently impacts upon the lives of its residents.[1]

While these particular projects are formed at the intersection of music, art, architecture, and urban design, many others take the form of sound recordings, compositions, performances, films, installations, sculptures, radio works, websites, and much more. I can listen to a "sound essay" that makes audible the subterranean crypts, caverns, and cisterns of Cagliari by an artist who "spent weeks listening to the changing echoes while descending down into the dark and recording the city filtered through its cavities" (Lidén 2015). I can take a listening tour of Bonn, following a map of unique acoustic features of the city created by Bonn's "City Sound Artist" in 2010. Or, I can take an "electrical walk" in any number of cities while wearing specially designed headphones that make audible normally inaudible elements of the urban infrastructure. During my walk, what were formerly silent objects like surveillance cameras, ATMs, and transportation infrastructures beat and resonate with the pulses and tones of electromagnetic energy.[2]

In parallel to this proliferation of artworks that explore the relationships between sound and space, contemporary scholarship on sound is replete with spatial concepts—concepts that likewise traverse physical, sensorial, geographical, social, and political realms. It is common to read about "acoustic spaces," "soundscapes," "aural architectures," "auditory perspective," "acoustic communities," and "acoustic territories," to give only a few examples.[3] Such concepts have been defined and redefined, theorized and problematized. They are laden with meaning—and in some cases multiple and conflicting meanings—and they form, in a foundational sense, the ground of sound studies. As Andrew Eisenberg writes, "It is difficult to identify any work of sound studies that does *not* deal in some way with space" (Eisenberg 2015, 195).

Despite this striking "profusion of research" (Born 2013, 5)—what Georgina Born describes as "a veritable avalanche of scholarship devoted to the interconnections between sound and space" (5)—our historical understanding of how sound came to be understood as spatial nevertheless remains lacking. Today we take for granted that sound is spatial, and that hearing is spatial, too: that it is possible to hear where sounds come from and how far away or close they are. However, as recently as 1900, a popular scientific view held that sound itself could not relay "spatial attributes," and that the human ear had physiological limitations that prevented it from receiving spatial information. Many psychologists believed it was through reasoning, or else through visual or haptic sensations, that an "auditory space" was constructed (Pierce 1901). In order to explore such striking shifts in perspective, *Stereophonica* will trace a history of thought and practice related to acoustic and auditory spatiality as they emerge in connection to such fields as philosophy, physics, physiology, psychology, music, architecture, and urban studies. I track evolving ideas of acoustic and auditory spatiality (the spatiality of sound and hearing); and, equally, ideas that emerged in connection to particular *kinds* of spaces, acoustic and auditory technologies, musical and sonic cultures, experiences of hearing, and practices of listening. My discussion begins in the nineteenth century, a century that marks a "transition from sound and listening as non-spatial phenomena to fundamentally spatial phenomena" (Théberge, Devine, and Everrett 2015, 15). It extends to the present day, when artists seek to reconfigure entire cities through sound, and the concept of "sonic urbanism" circulates within and across the worlds of architecture, urban studies, and sound studies (Kafka, Lovell, and Shipwright 2019).

Rather than revisit recent academic debates on sound and space, which are deftly unpacked by Born and others, in this introductory chapter I look back to spatial conceptions of sound that circulated prior to the nineteenth century. This is in order to situate the discussion that follows within even longer trajectories of thought that continue to resonate in various scientific, musical, artistic, and intellectual traditions today. In the following passages I turn to three recurring figures of acoustic spatiality: (1) propagation, which pertains to the *inherent* ability of sound to pass through a medium and traverse space—an idea encapsulated by the common refrain "sound travels"; (2) reflection, whereby sound is understood in relation to its *interactions* with objects and environments; and (3) projection, which denotes the movement of sound across a distance, implies that something is done *to* sound, and is typically associated with some kind of technological mediation (e.g., sound projected via an apparatus, whether a loudspeaker, a trumpet, or a mouth). By showing how these figures emerged at the intersection of historically situated scientific, technological, philosophical, and musical cultures, this brief introduction serves as a microcosm of the book, which makes the case that a properly historicized account of the understanding of the relationships between sound and space can help us to better appreciate the myriad creative practices and theoretical discourses that give form and sense to those relationships today.

1.2 Propagations

By the nineteenth century there were already numerous treatises on the propagation of sound in the scientific literature. In "A Catalogue of Works Relating to Sound" (Peirce 1836), a bibliography that attempted to collect all known philosophical and scientific writings on sound to date,[4] we find an impressive list of titles on propagation arranged into six categories: Propagation of Sound in General (sixteen entries), Propagation of Sound in Air (forty-nine entries), Propagation of Sound in Gases and Vapors (ten entries), Propagation of Sound through Liquids (nine entries), Propagation of Sound in Solids and Mixed Media (twenty entries, including an essay on hearing by the teeth), and Mathematical Theory of Propagation of Sound (thirty-five entries, beginning with Newton's *Principia*).[5]

Theories on the propagation of sound were established through extensive and sometimes remarkable experiments that aimed to determine such factors as: the material nature of the propagation (did sound propagate as a wave? a pulse? as rays? particles? a combination of these?); its form (were the waves concentric? did the rays radiate outward from a source?); its speed (did sound propagate more quickly in air or water? was it the medium's density or its elasticity that determined how quickly sound propagated through it?); and the conditions required for propagation to occur (could sound propagate in *any* medium? could it propagate in a vacuum?).

While such questions may seem straightforward, the experimental methods they inspired were not. In 1808 the French physicist Jean-Baptiste Biot descended into the subterranean quarries of Paris, where he held conversations in hushed tones through empty cast-iron tubes that normally delivered water throughout the metropolis. He found that the quietest whispers could be clearly heard through an iron tube 3,120 feet long, while a pistol fired at one end of that tube could extinguish a candle at the other (see Tyndall 1867, 13). Thus, not only could sound propagate over long distances, its propagations could produce distinct effects—and not only sonic ones. Another experimenter required three auditors to strip naked and dive under water. While submerged, they listened as the experimenter yelled at them, discharged a pistol, and finally exploded a grenade, all in an attempt to better understand the propagation of sound in water (see Herschel 1830, 767). The German physicist and musician Ernst Chladni reported on experiments by the Danish scientists Johann David Herholdt and Carl Gottlob Rafn in which a 600-foot-long metal wire was stretched between a metal plate, suspended in air, and an auditor who held the wire between his teeth. In this precarious position the auditor heard not one but two distinct sounds whenever the plate was struck. He heard the first sound, which was conducted through the wire, almost instantaneously. The second sound, which was conducted through the air, arrived later (Herschel 1830, 772).

Theories of sound propagation informed, if not engendered, spatial conceptions of sound. If sound is imagined as a vibration (e.g., an oscillation) that propagates as a wave (e.g., an audible wave of pressure) then it is by definition spatial; and if it is imagined as propagating through air and other mediums, then through its propagations it is effectively "spatialized."[6] However, the ability of sound to propagate in, and just as important, *through*, any medium—whether air, solids, liquids, gases, or vapors—further conferred upon sound distinct powers, both real and imagined. The French naturalist Jean-Baptiste Lamarck, for example, was inspired to study the propagation of sound following an enormous explosion at the Grenelle gunpowder factory in Paris. On the morning of August 31, 1794, approximately sixty-five thousand pounds of gunpowder exploded in the factory, killing over a thousand workers (see figure 1.1). The explosion was so loud that it was reportedly heard at Fontainebleau, around seventy kilometers away. The air was very still that day, so much so that leaves on trees did not rustle. Even so, the sound of the explosion was so forceful that Lamarck believed it had caused distant windows to break, ceilings to crack, and even ice cubes inside people's homes to fracture.

Lamarck's views on sound contained what we now know to be fallacies. Shock waves, and not sound waves, would have caused the destruction that he and others witnessed that day; and sound is not an invisible fluid that "immerses" the listener, as he also proposed.[7] Still, these views spoke to the idea that sound, as something that could cross vast distances, breach any physical boundary, and permeate any medium, was possessed of great power, even great

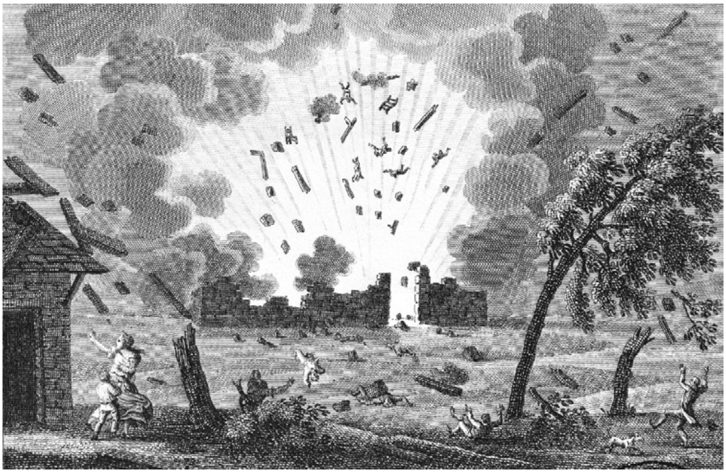

Figure 1.1
Copper engraving by François-Louis Couché depicting the explosion of the gunpowder factory at Grenelle on August 31, 1794.

powers of destruction, precisely because of its propensity to be reflected and its ability to propagate through space.

1.3 Reflections

At the same time, these propensities rendered sound mercurial: a wavering, trembling, quavering substance whose reflections and propagations could hardly be well controlled.[8] "Echo is a capricious being, whose caprices are not easily divined," wrote the Prussian astronomer and mathematician Rodolphe Radau (1870, 88). In *Wonders of Acoustics* (1870) Radau collected marvelous and sensational stories of sound, drawing from well-known historical sources like Athanasius Kircher's *Musurgia Universalis* (1650) and *Phonurgia Nova* (1673), as well as from the contemporary scientific literature, notably the writings of Ernst Chladni, Charles Wheatstone, and Hermann von Helmholtz, which I return to later. One story recounted the fate of an Englishman who had embarked on a doomed project to capture an echo. It was a cautionary tale:

> An Englishman, traveling in Italy, met with an echo so beautiful that he determined to buy it. It was produced by a detached house. This was taken down, carried to England, and reconstructed on one of his estates, exactly on its original plan—a place having been chosen for it at exactly the same distance from his dwelling as it stood, in Italy, from the place whence the echo was most distinctly heard. To test the echo he sent for a box of pistols, charged both the weapons, went to the window,

> and fired—no sound was returned; drawing the trigger of the second, he shot himself through the brain! It was never known what defect in the construction was the cause of this lamentable disappointment. (Radau 1870, 88)

The reader, of course, wondered if there was any defect at all in the construction of the house, or whether the defect lay in the crude project of trying to trap, indeed purchase, something as sublime and elusive as an echo—a figure that for many philosophers symbolized *that which can never be apprehended*, since an echo is always and only ever sensed through reflections. After all, the echo is not the voice, but the "image of the voice," as the French Minim friar and mathematician Marin Mersenne wrote in *Harmonie universelle* (Mersenne 1636, book 1, 51, my translation). Echo was a fugitive Nymph; the "daughter of the air"; a "vagabond" (54).

Echoes—a particular species of acoustic reflection wherein the reflected sound is delayed enough that it is perceived as a distinct sound—not only conjured ideas of sound's ephemerality and ineffability; they were also rich with spiritual and religious resonances. In *Sylva Sylvarum* (1627), a ten-volume study of the natural world by the English philosopher Francis Bacon, we find an intriguing passage in which Bacon recounts a spiritual encounter with an echo. Upon visiting Charenton-le-Pont, a town near Paris, Bacon stumbled upon a ruined chapel that produced fantastic "Super-Reflexions," what he called the echoes of echoes. The four walls of the chapel were still intact but its roof was completely missing. Speaking at one end of the chapel one afternoon, Bacon heard his voice returned to him thirteen times. He learned that others who had spoken in the same chapel in the evenings, when the air was thicker, could hear their voices returned to them up to sixteen times. The echoes, however, did not return all the words that had been spoken equally well. In particular they could hardly express the letter "s" (Bacon 1627, III.251, 58). Invited to do so by a man who believed that the echoes were the work of good spirits, Bacon called out the name "Satan." What the echoes returned was "*va t'en*," a French expression that roughly translates as "go away," or, in this context, "be done with you." This encapsulated Bacon's idea that echoes represented the "*Spiritual Essence*" of sounds (III.287, 62; emphasis in original).[9] For, if echoes did not have a spiritual basis, the words should all be returned alike and should not be so inexplicably, and so perfectly, transformed.

While accounts like Mersenne's and Bacon's might strike the modern reader as mannered, even sober accounts in eighteenth- and nineteenth-century mathematical treatises on acoustics often included passages on the phenomenal nature of remarkable echoes. Chladni cited an echo that was said to change the voice in different ways, another that could repeat a word forty times, and even one that could repeat the first verse of the *Aeneid* eight times (Chladni [1809] 2015, 158). He also recalled a church in which a hidden orchestra, seated behind boards in an alcove near the church's ceiling, produced music that was heard only through its reflections. Beautiful tones seemed to pour out from the top of a tableau that depicted angels announcing the birth of Christ (160).

Such rapturous echoes and acoustic reflections were a testament to the infinite variety of forms that sound could take when it came into contact with the world; and equally, to the infinite variety of ways in which sound could reshape the world in its "image." Although Mersenne never met the vagabond nymph, leaving the project to "another Pan," he took solace in knowing that echoes were "the Creator's way of giving language to the woods, to rivers and mountains," and thereby creating in nature a kind of "ravishing harmony" that all the great works of human invention tried to imitate (Mersenne 1636, book 1, 56; my translation).

The propagations and reflections of sound thus rendered it simultaneously powerful and fragile in the minds of philosophers and physicists. As energy or matter in motion, sound could move through a void, permeate a medium, and penetrate, corrupt, and even destroy objects. Its fluctuating movements, however, rendered it paradoxically unstable: vacillating, oscillating, undulating, fluttering, trembling, quavering. The propagations of sound thus complicated questions about its nature, distinguishing it as a phenomenon that could occupy and simultaneously transform a medium. Bacon distinguished visible from audible phenomena, for example, by suggesting that "*Visibles*" did not have the power to "mingle" in a medium like water or air, whereas "*Audibles*" did (Bacon 1627, III.224, 53; emphasis in original). In contrast to light, sound could *disturb* a medium and produce changes in it, even if those changes were minor or temporary. Indeed, sound was uniquely believed to possess the power to reconfigure the physical world, as well as spiritual and psychical worlds, through its spatial effects. To gain control over these effects, then, would be to gain control over these other domains as well.

1.4 Projections

The stories of the explosion at the gunpowder factory, the thwarted Englishman, and the chapel at Charenton-le-Pont variously describe the spatial effects of sound as mystifying, terrifying, and mesmerizing. Such effects were exploited to a spectacular degree by twentieth-century composers who used electroacoustic technologies to create "spatial music" that evoked these very same qualities. Spatial effects had certainly been heard in diverse musical traditions prior to the twentieth century. Well-known examples include the antiphonal singing of *cori spezzati* (spatially separated choirs) in Renaissance Venice, or the antiphony underlying African American musical traditions (Lornell 2012).[10] The mid-twentieth century was a turning point in this history, however, in that composers now had at their disposal electroacoustic technologies (such as multitrack sound recording and reproduction systems, discussed in chapter 4) that enabled them to control multiple "channels" of sound at once, thus making it possible to foreground the location and movement of sounds as compositional parameters.[11] As the French-born, U.S.-based composer Edgard Varèse would say about *Poème électronique* (1958), an eight-minute electroacoustic composition projected over hundreds of loudspeakers inside the Philips Pavilion at the 1958 World's Fair in Brussels, "The music was distributed by 425 loudspeakers. . . . The loudspeakers were mounted in groups and in what is called 'sound routes' to achieve various effects such as that of the music running around the pavilion, as well as coming from different directions, reverberations, etc. For the first time I heard my music literally projected into space" (Varèse [1959] 1998, 170).

What Varèse called "spatial music" had antecedents not only in earlier musical traditions, however, but equally in the scientific practices of earlier eras. Varèse himself was inspired by the writings of Hermann von Helmholtz, which led him to experiment with sirens to create "parabolic and hyperbolic trajectories of sound" in works like *Amériques* (1918–1921; revised 1927) and *Ionisation* (1929–1931), giving form to what he called "my conception of music as moving in space" (Varèse [1959] 1998, 170). The very *idea* of multichannel music, however, was also arguably prefigured in scientific spectacles of previous centuries. In the *Invisible Girl*, a popular spectacle that was widely exhibited in the United States and Western Europe in the early nineteenth century, sound was simultaneously transmitted from a single source to four trumpets, which served as proto-loudspeakers (see figure 1.2). A visitor posed a question to an unseen girl by speaking into the bell of any one of the four trumpets. Her answer was

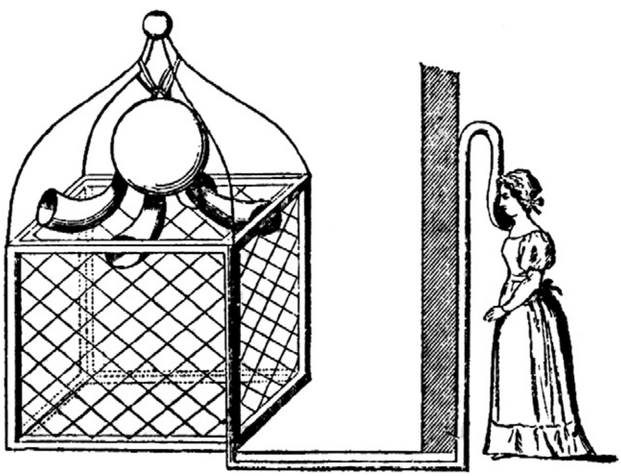

Figure 1.2
Illustration of the *Invisible Girl* from Rodolphe Radau's *Wonders of Acoustics* (Radau 1870, 62).

returned from all four of them at once, projected in what might be thought of as an early form of quadraphonic (four-channel) sound.

One advertisement for the *Invisible Girl* promised that "the voice of a living female . . . will answer questions put by any person present, Or maintain a *Conversation*, either in *Whisper*, or in a more *Audible Tone*; the Lady will also, if requested, entertain the company with specimens of vocal music, producing a most peculiar Effect" (cited in Connor 2000, 352; emphasis in original). Undoubtedly this peculiar effect resulted from the transformation of the sound of the singing voice as it was transmitted through the exhibit's apparatus. It would have equally resulted, however, from the uncanniness of hearing the same voice emanating from several points at once, an acoustic effect that would have rarely, if ever, been experienced so distinctly and reproduced so consistently.

The trumpets in the *Invisible Girl* acted both as reflectors or "projectors" of sound, and equally as receivers or "collectors" of sound. As such they would have recalled the many varieties of speaking trumpets and hearing trumpets that circulated in Western Europe by the early nineteenth century. The speaking trumpet had roots in ancient cultures but it was revived and popularized in the 1670s by the English diplomat and inventor Samuel Morland, who designed several varieties of what he called the *Tuba Stentoro-Phonica* in 1670, and who subsequently published a detailed pamphlet on it (Morland 1672). A fashion for the speaking trumpet soon "spread throughout Europe, not only in the scientific world, but also in aristocratic and musical circles" (Barbieri 2004, 205).

In listening to the voice as it was projected via the speaking trumpet, Morland wondered how it was that voices could permeate the air while flying about "like Atoms" in it, only to be conveyed with "stupendious agility" to the soul (Morland 1672, 7).[12] He concluded only that the more one asked such questions the less one could be assured of the answers. Sound, and more specifically sound when considered in relation to its spatial effects—its effects in the material and spiritual world—lay outside the bounds of physics and philosophy. Morland thus abandoned the idea of developing a new philosophy of sound, but only after he conducted numerous tests with the speaking trumpet in which he tried to determine how sound was "multiplied" or amplified when it was projected through it, a process he illustrated in *Iconismus II* (see figure 1.3). In this figure, a voice produces "rays" of sound, depicted as straight lines inside the trumpet, and a multitude of sound waves that Morland described as "percussions of air." These percussions ripple forward from the speaker's mouth, and outward from the trumpet's bell, spreading in concentric waves ("spherical Undulations") until they meet some point of opposition, at which point they are reflected—"reundulated, multiplied, and reverberated" (11)—throughout the vicinity. Sound is everywhere at once and perpetually in motion. A voice has become air, or, more precisely, a movement of the air.[13]

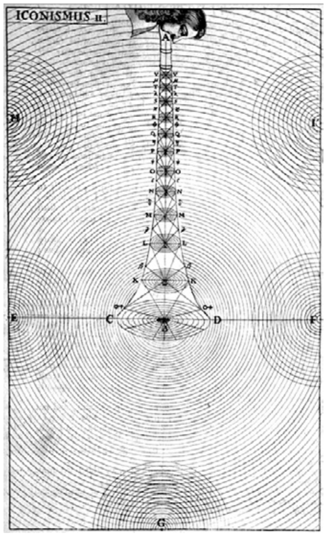

Figure 1.3
Iconismus II by Samuel Morland, depicting the physics of the speaking trumpet (Morland 1672, 8).

In seeking to perfect the design of the speaking trumpet Morland commissioned a variety of instruments in glass, brass, and copper. His trumpets ranged in size from 2.8 feet to an astonishing twenty-one feet in length, with bells measuring between eleven inches and two feet in diameter. On quiet and windy days, they could transmit speech clearly at a distance of nearly three miles over water. In 1671 Morland's associate Francis Digby wrote a letter to the British Secretary of State praising Morland's invention. In a passage from this letter that predicts the ear trumpet, a device that would come into fashion only in the mid-eighteenth century, Digby distinguished the use of the instrument when it was turned "trumpet-wise" from when it was turned "ear-wise." He remarked that "by laying one of these Instruments to the Ear, the Words are heard more distinctly" (Morland 1672, 4). Thus, from its inception, the speaking trumpet had two inclinations. Used as an instrument of speech, it functioned as a megaphone—a device for amplifying the voice and projecting it to distant places. Used as an instrument of hearing, it functioned as a receiver of sounds, one that focused distant sounds, seemingly bringing them closer to the listener's ear (see figure 1.4). In this latter inclination it was understood as a "reverse megaphone" (Chladni [1809] 2015, 153) and also as a "microphone," which was originally conceived as an aural analogue to the microscope—a device for magnifying quiet or inaudible sounds (Marsh 1684, 482).[14]

The growing popularity of auditory technologies like the ear trumpet, an early hearing aid that required the listener to turn *toward* the source of sound, gave strength to the idea that

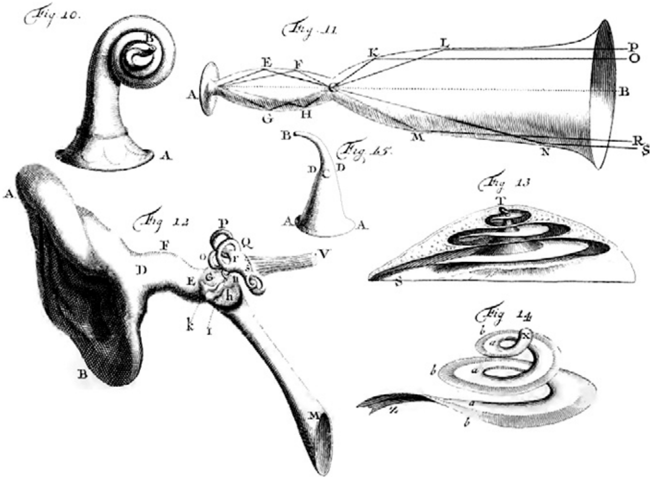

Figure 1.4
Varieties of eighteenth-century speaking trumpets and ear trumpets from Pieter van Musschenbroek's *Elementa* ([1734] 1739, facing p. 728).

not only the spatial properties of sound, but also the spatial aspects of hearing warranted further scientific attention. In early modern Europe, audition was studied almost exclusively as a monaural (one-eared) phenomenon. From the writings of Eustachius (1563) and Hieronymus Fabricius ab Aquapendente (1600) to treatises by John Elliot ([1780] 2013), Antonio Scarpa (1789), John Cunningham Saunders (1806), and Samuel Thomas von Soemmerring (1806), it was the physiology of the *single* ear that was under scrutiny in Western anatomy and medicine. Influential texts made scant, if any, reference to the action of hearing with both ears, what is now called "binaural audition," and what is widely understood as a fundamental aspect of "spatial hearing" (Blauert 1983): sensing the location, distance, and direction of sounds. Anatomical illustrations of the hearing apparatus from the early modern period almost invariably depicted a single ear, and depicted it as an isolated object, divorced from the cranium and floating in negative space. The ear, once excised, was further divided into constituent parts that played distinct roles in the physiology of hearing. An instrument thus isolated and fragmented, the ear-in-action was not easily linked back to the head from which it had been both literally and conceptually separated. To go from "the ear" to "the ears" in physiology required an even greater leap. In *Philosophical Observations on the Senses of Vision and Hearing* (1780), for example, the English physician and natural philosopher John Elliot briefly mentions the idea of hearing with both ears, but asserts that "though we have two ears, yet we hear singly" (Elliot [1780] 2013, 38). Thus, even as Elliot alluded to the idea of binaural audition, he dismissed its potential effects.

The physiological mechanisms of binaural audition would remain only superficially examined over the next fifty years, traceable to a handful of scientific papers (see Brech 2015, 17–33). Of particular interest among these are the 1796 experiments of the Italian physicist Giovanni Battista Venturi in which a blindfolded listener attempted to determine the direction of the sound of a flute being played around forty to fifty meters away. Venturi's experiments were conducted under different conditions of hearing: when one ear was stopped, when both ears were open, and while the listener remained stationary or else turned in place. Such experiments effectively laid the groundwork for theories of binaural audition to emerge. However, Venturi's work was "largely ignored and quickly forgotten" (Théberge, Devine, and Everrett 2015, 15), and the concept of binaural audition remained mostly elusive until the 1850s. In 1832, for example, the English surgeon David Tod spoke to the difficulty of accounting for two-eared hearing. "Nothing is more common than to say that we hear with our Ears, but it is far from being an easy matter to explain," he wrote (Tod 1832, 36). "We hear from above, below, before, behind, from the right and from the left, and from all points. How do we become acquainted with the direction from whence sounds reach us? This is a question which every one who has investigated the economy of the Ear has been unable to answer, even plausibly; for all that has hitherto been said on the subject is equally unscientific and uninteresting" (36).

1.5 *Stereophonica*

Stereophonica picks up at the point that binaural audition enters the scientific lexicon and spatial hearing becomes a sustained object of scientific inquiry. Chapter 2 explores spatial hearing in the nineteenth century in connection to binaural and stereo technologies of this period. It tracks the rise of the binaural listener, an auditor who listened through a binaural apparatus and observed sound in three dimensions. The binaural listener was a *descendent* of the binocular viewer that, as Jonathan Crary (1990) has argued, emerged around the same time in connection to three-dimensional viewing apparatuses like the stereoscope. I show how a science of binaural audition emerged in connection to an existing science of binocular vision, and how theories of auditory space perception were developed in connection to existing theories of visual space perception. This chapter also examines the binaural listener in connection to technologically mediated sonic cultures of the nineteenth century, in particular through a discussion of the théâtrophone, a broadcasting system that transmitted live opera, music, and theater to mass audiences in stereo.

The binaural listener, born of and disciplined through nineteenth-century medicine and science, would soon become mobilized and militarized through warfare. Chapter 3 examines the development of technologies for sound location during the First World War: technologies that enabled military auditors to track the position of the enemy by listening to its movements. I explore how the listening act was reconfigured through the military science of sound location, and how this science shaped wider definitions of sound, in particular by making concrete the idea of sound as observable energy—as something to be *sensed* versus merely *heard*.

The science of sound location would have far-reaching repercussions. In particular it would resonate in postwar industrial research on sound recording and reproduction. Chapter 4 traces this historical connection through the work of scientists at Bell Telephone Laboratories (BTL), some of whom were directly involved in sound location research for the U.S. military during the First World War, and who subsequently designed some of the first systems for stereo and multichannel sound recording, transmission, and reproduction. BTL publicized its innovations in stereophony through a series of public demonstrations that were experienced, in one case, by over half a million people. I revisit BTL's demonstrations between 1933 and 1940, examining the confluence of scientific, aesthetic, and musical concerns that shaped these modernist versions of nineteenth-century spectacular science.

Part of my project in *Stereophonica* is to turn attention to the work of scientists and engineers who contributed in distinct ways to changing ideas of acoustic spatiality but whose work remains under-recognized or even unknown. Chapter 5 is conceived in this vein. It revisits the work of Harold Burris-Meyer, a drama instructor and sound technician at the Stevens Institute of Technology, New Jersey, whose work on sound was distinctly influential in a number of contexts in the 1930s and 1940s but is only now beginning to gain wider scholarly attention (Volcler 2017). I show how the idea of an "optimized acoustical environment" shaped Burris-Meyer's work in a number of contexts: multichannel sound design for the theater; "scientifically planned" music for the Muzak Corporation, where he served as vice president in the late 1930s; and applied psychoacoustics (psychological acoustics) for warfare during the Second World War. At the core of all these projects was a desire to create acoustic spaces that were optimally designed to produce specific emotional and physiological responses in listeners, whether theater audiences, industrial workers, or enemy combatants.

Chapter 6 returns to the realm of music and sound art, exploring the development of multichannel electroacoustic music in the 1950s and sound installation art in the 1960s and after. It considers how various musical and sonic practices of this period reflected, resisted, and produced particular conceptions of space—whether Cartesian and Euclidean conceptions of absolute mathematical and geometrical space, or extended concepts of social and political space. By turning attention to contemporary artists including Heidi Fast and Rebecca Belmore, whose sound works intervene in social and political spaces, this chapter makes a case for considering how "spatial music" and sound art can constitute a poetics, as well as a politics, of space.

Chapter 7 explores the visual representation of sonic environments or "soundscapes" through an examination of noise maps and sound maps, notations for soundscape that emerged in the twentieth century, and that have had enduring applications in noise legislation and acoustic ecology (the ecology of sonic environments). This chapter focuses on the noise mapping of cities, sonic environments that have particularly come into view through mapping. It examines the roots of noise mapping in such phenomena as early graphic notations for noise; decibel tables and charts; pictorial and iconographic noise maps; and "isobel maps" and sound maps by the Canadian composer R. Murray Schafer and the World Soundscape Project. By connecting specific visualizations of noise to specific forms of anti-noise legislation, this chapter suggests that conceptualizations of sonic environments are not limited to the world of ideas or aesthetics, but can have profound effects on environments and societies, at times to deleterious effect.

Chapter 8 stays in the realm of the acoustic city. It investigates recent approaches to sonic urbanism: ways of encountering and understanding the city in relation to sound. Taking Beirut as a case study, I examine the work of sound artists and urban designers whose sonic practices reveal aspects of the city that are either occluded from view or difficult to apprehend given the complex entanglements of local and transnational forces that shape cities today. I take interest in Beirut both as a city of the Global South, the fastest growing sphere of urbanization today, and as a city of perpetual upheaval and "mutation" (Atallah 2017). I consider urban sonic practices in Beirut not only for their conceptual innovations, but also in a forensic capacity: as *evidence* of what has happened, and is happening, in the city.

Stereophonica thus grapples with an array of historical phenomena connected to sound and hearing as they are understood in relation to space. It charts what may seem like an improbable path from studies of auditory space perception in the nineteenth century to the work of contemporary artists who reveal and reorient urban spaces through sound. This path moves outward, from the intimate and interior spaces of the human body to the enormous complexes of modern cities. Rather than trace a linear trajectory through any one historical route, however, I revisit a series of historical episodes in which the understanding of sound and space were distinctly transformed: the birth of a science of spatial hearing; the rise of acoustic defense; the invention of stereo sound recording and reproduction systems; the development of spatial music and sound installation art; the advent of noise mapping and sound mapping; and emergent modes of sonic urbanism. Each of these phenomena represents a distinct shift in how sound is created, experienced, or understood in relation to space. Further, each sheds light upon evolving acoustic and auditory cultures, ways of listening, and changing ontologies of sound and space. By focusing on such transformative episodes, whether they last several years or several decades, my aim is to set into dialogue various realms of thought and practice that bear upon contemporary ideas of acoustic and auditory spatiality, but that are normally kept distinct within such disciplines as philosophy, physics, music, and urban studies.

It is for a similar reason that this study takes a wide historical lens. Each chapter could theoretically form the basis of a much longer discussion or even an entire book. The chapter on stereo sound reproduction at Bell Telephone Laboratories in the 1930s, for example, could be expanded to include Alan Blumlein's parallel, and better known, work on stereo reproduction in England. It could likewise be extended to the present day, taking into consideration more recent manifestations of spatial audio like Ambisonics and virtual reality (VR) audio. My aim, however, is not to chart a comprehensive history of any single scientific, technological, philosophical, or cultural phenomenon connected to evolving ideas of sound and space. I have chosen not to write, for example, a comprehensive history of spatial audio or a history of multichannel music. Rather, my aim is to cut *into* and *across* normally distinct histories, in order to show how various conceptions of acoustic and auditory spatiality have evolved over time and in connection to one another. Whereas a history of multichannel music would be underpinned by a predominating set of concerns that emerged from musical cultures and communities, I am interested in ideas that emerged between the worlds of music, engineering, warfare, theater, industry, and urban design. I avoid retracing already familiar paths, by omitting certain topics that could fit within the scope of this study but that have already received considerable attention elsewhere, such as the development of architectural acoustics; or else by drawing attention to under-recognized historical figures or practices.[15] I therefore devote considerable attention to experimental projects, whether in science, music, art, or their interstitial spaces—including experiments that failed, were limited in their scope, had troubling ethical implications, or simply did not "succeed" in entering mainstream discourses and canons, but that are nevertheless important because of their conceptual, technical, and aesthetic innovations. It is within these experimental practices, those that test the boundaries of a field, that I find particular interest, especially with respect to ideas that defied conventional thinking and, in some cases, put wider social or cultural conventions under pressure.

While the book's title evokes the concept of stereo audio, and while several chapters are in fact devoted to a discussion of stereo in the sense of two-channel or multichannel sound, I propose the term *stereophonica* as a much broader category of phenomena that extends far beyond stereo sound to embrace sound in all of its spatial manifestations. The concept of *stereophonica* includes spatial music, sound installations, urban soundscapes, sound maps, and much more. It suggests that a vast range of acoustic phenomena can be understood as spatial—and even that most, if not all, acoustic phenomena can be designated *stereophonica*: phenomena that are spatially constituted and manifested. While music traditionally has been represented and analyzed as a temporal phenomenon, which is to say in relation to its unfolding in time, positioning music as *stereophonica* reinforces the idea that a spatial analysis of music is needed, and that such an analysis can only enrich our understanding of music's effects. It also understands *all* music as essentially spatial, with "space" understood in physical as well as social and political terms. The broad scope of *stereophonica* as a category likewise invites us to reposition all aural cultures as spatial phenomena. In a sense, the concept of *stereophonica* aims to recover the dimension of space in the analysis of all acoustic, auditory, musical, and sonic cultures.

Finally, in contrast to discourses that understand "space" as a void to be filled with sounds, my discussion shows that acoustic and auditory spaces have never been empty or neutral, but instead have always been replete with social, cultural, and political meanings. The case studies are chosen to reflect a particular progression both within and across them: how spatial conceptions of sound and hearing were hypothesized, tested, applied, codified, problematized, and politicized. *Stereophonica* reveals how different concepts of acoustic and auditory space were invented and embraced by scientific and artistic communities, and how the spaces of sound and hearing themselves were increasingly measured and rationalized, surveilled and scanned, militarized and weaponized, mapped and planned, controlled and commercialized—in short, modernized. In the next chapter, I trace these modernizing impulses through the figure of the listener, a figure that, over the course of the nineteenth century, was increasingly understood in connection to three-dimensional space, and was thus made ever more real, more dimensional, more "solid"—what the ancient Greeks called στερεός, or *stereós*.