Introduction

"Why don't biologists care as much about music as physicists do?" With this provocative question, an eminent physicist and historian of science set me on the quest that led to this book. I had just written *Music and the Making of Modern Science*, which argued that music has had a deep effect on the development of mathematics and physics, both ancient and modern. In my next book, *Polyphonic Minds: Music of the Hemispheres*, I turned to the history and significance of polyphony, the music of many voices, in particular its relation to the science of the mind and the human sciences in general. Finally addressing my friend's playful question, this book considers the relation between music and the development of the medical and life sciences. Though each of these books was intentionally written to stand on its own, not requiring that they be read in sequence, they are in fact siblings that together form a trilogy about the significance of music for the sciences.

Turning to my friend's question, it seems impossible to determine whether biologists and physicians care about music as much as (or in the same way that) physicists do. Many life scientists would dispute that they are less musical than physical scientists. For instance, the long tradition of musically gifted physicians could be set against the many physicists who were passionate about music.[1] Surely I cannot settle this intriguing question, which would require sociological study and probably has changed over time. Perhaps others might be able to address it fruitfully, but however many examples they could amass, in the end it is difficult to see how so many different individual cases could be weighed against each other.

Instead, I realized that my friend was playfully asking a deeper question: "Did music affect the development of biology and medicine in the same ways as it affected mathematics and physics?" In response, I will argue that the effects of music on the biomedical sciences are consequential and important but different in kind than for the physical sciences. The reasons for this go back to antiquity but reverberated for two millennia, continuing to the present day. Traditionally, medicine stood apart from the "quadrivium," the "four-fold way" of arithmetic, geometry, music, and astronomy, the "liberal arts" that began with the Pythagoreans. *Music and the Making of Modern Science* held that the physical and mathematical sciences were children of these ancient liberal arts, learning from music and her sisters how to connect number with physical reality.

This book argues that biology and medicine also came under the influence of Pythagorean mathematical and physical approaches. Indeed, from their earliest days, the Pythagoreans practiced a medicine that did not depend on divine influence, paralleling their application of number to the physical world. Thus, Western medicine was another "child" of the Pythagoreans, a child that gradually came to know its siblings, the physical and mathematical sciences. The earliest links developed between music, mathematics, and medicine as arithmetic was applied to the pulse and to the timing of "crises" in disease. Beginning about 1700, new ideas, tools, and techniques gradually transformed medicine and biology by seeking physical and mechanical explanations. Among these was an important "sonic turn" in these fields, by which I mean the use of sound to give new insights and interventions into living organisms. The ancient pursuit of Pythagorean ratios felt in the pulse ultimately led to new practices of listening to the body involving what I will call *sonic* and *rhythmic knowledge*

By comparison with the physical sciences, this sonic turn came later and had a different form and dynamic; it was not a single event but comprised successive waves. Sound offered a way to understand the hidden workings of living bodies that was not available even to the trained medical gaze or to observational biology based only on visible evidence. This sonic turn led to the development of such techniques as mediate auscultation and ultrasound, which became essential tools of the biomedical sciences. This turn toward sound also affected the superstructure of concepts these life sciences used to understand the bodies they were sounding. Most important, the ancient concept of living bodies as composed of humors gave way to a new concept in which those bodies were essentially formed by sensitive, resonant, and vibrating fibers, particularly understandable through their relation to sound. Also, in several instances, the structure of musical compositions (different between classical and Romantic works) provided different patterns for the structure of cure itself, patterns that fundamentally changed the nature of medical practice from outward observation to inward intervention by analogy with the ways music could affect and transform its listeners.

If music affected the physical sciences primarily through pitch or melody, it affected the biomedical sciences more through *rhythm*.[2] To be sure, the sonic turn involved all kinds of actual pitches and sounds, including a consequential move beyond human hearing to ultrasound. Yet even in ancient times, medicine had connected the musical ratios of rhythms to physiological phenomena, particularly heartbeats and the timing of crises in disease. The reconsideration of those rhythmic connections energized the sonic turn in the eighteenth century. Subsequently, the search to understand nerve signals extended to frequencies so low that they are perceived as rhythms rather than heard as pitches. Thus, the sonic turn led to a rhythmic turn as the analog perception of bodily sounds led to the discovery of binary, all-or-nothing neural rhythms.

The work presented here reflects a long development that involved the work of many before me. Daniel P. Walker, Penelope Gouk, Werner Friedrich Kümmel, and Jamie Kassler pioneered the study of music's relation to medicine, especially the use of music in healing.[3] Because they devoted so much attention to this topic, this book focuses on other aspects of the relation between music and sound and the biological sciences. Building on the work of these pioneers, James Kennaway, Ellen Lockhart, Mark Pottinger, Carmel Raz, Benjamin Steege, David Trippett, Axel Volmar, Janina Wellmann, and Rebecca Wolf settled in the new territory and noted new connections between music, medicine, and biology.[4] My work also builds on a growing wave of work by other historians of science and music such as Karin Bijsterveld, Robert Brain, Francesca Brittan, Stanley Finger, Heather Hadlock, Alexandra Hui, Myles Jackson, Julia Kursell, David Pantalony, Jacomien Prins, Tim Rice, Emily Thompson, and Viktoria Tkaczyk, who in different ways have illuminated interrelations of music, sound, mind, and body, particularly through the development of various technologies and devices.[5] The writings of Veit Erlmann and Jonathan Sterne helped me reflect on the connection of my work to sound studies, which concerns the neglected salience of sound for many sciences, technologies, and social institutions.[6] This book also contributes to disability studies by exploring the role of music and sound in the changing understanding of "melancholia," "mania," and "obsession" before they were viewed as medicalized disabilities or diseases.[7] I have also taken special care to draw attention to the contributions of women as well as to forgotten or little-known figures.

Because my topic required expertise not possible for any single person, I have relied on the specialized studies of many scholars: James Longrigg, Jacques Jouanna, and Vivian Nutton on ancient medicine, Nancy Siraisi on Renaissance medicine, Patrick Boner on Kepler, Tobias Cheung on fibers, Jacalyn Duffin on Laennec, Stanley Finger on the history of neuroscience, Axel Volmar on telephonic observation and sonification, Malcolm Nicolson and John Fleming on medical ultrasound, as well as many others.[8] I am glad to acknowledge my debt to them; I have tried to synthesize their contributions and add something further. The notes detail my sources so that readers may pursue these matters themselves.

In order to keep this book within manageable length, I have restricted its scope in various ways. Though I briefly consider various kinds of music therapy in historical perspective, my real concern is how music and sound have influenced the fundamental structure and practice of the biomedical sciences, a convenient modern term encompassing medicine and the various branches of biology. In order to focus attention on those fundamental aspects, I decided not to discuss most of the obviously sound-related aspects of animal behavior, such as hearing and otology or the songs of birds or whales, topics well discussed by others.[9] Likewise, I have not addressed the rhythms of chronobiology, which seem more dependent on light than sound, or rhythmic entrainment, or the rhythmic aspects of embryology extensively discussed by Janina Wellmann.[10] Nor have I discussed the biological theories of Jakob von Uexküll, who used music as a guiding metaphor to understand the *Umwelt*, the “surrounding world” experienced by animals.[11] Nevertheless, I have included bat echolocation as part of the sonic turn leading from animals to humans through ultrasound.

I have tried to keep in mind the adage that someone with a hammer sees nails everywhere.[12] Some of the most important chapters in the history of medicine and the life sciences (for instance, the development of the germ theory) do not involve sonic issues as far as I can tell. Though this book presents various—especially less familiar—cases of musical or sonic influence, I do not wish to make excessive claims about the ultimate place of music and sound in the biomedical sciences. I would like, though, to argue that sound and rhythm are significant threads in the intricate tapestry formed by the unfolding of these fields.

In that light, the term *music* will reach further than its ordinary connotations in common usage. For the ancient Greeks, *mousikē* included poetry and dance as well as what we consider “music” played by singers or instruments. Likewise, *rhythmos* began with the meters of music, poetry, and dance, then extended to the “rhythms” of sculpture and architecture, and eventually (as we shall see) to neural signals. Music along with arithmetic, geometry, and astronomy formed the quadrivium (as it later came to be called), meaning the “crossroads” or intersection of the four arts, which for the Pythagoreans and Plato constituted the central nexus of learning and the gateway to philosophy. As our story develops, “music” will also reach out to include all kinds of sounds, not just the restricted group of what once were considered “musical sounds,” as well as ultrasounds and infrasounds audible to other organisms (or the appropriate man-made instruments) and the use of such vibrations in probing and even altering bodies.

The book is organized into four large parts. Part I considers the connections joining music, biology, and medicine as they developed from ancient Greece to the seventeenth century. Part II presents the sonic turn emerging from the growing understanding of the body in terms of fibers that were not only static structural elements but also enabled dynamic motion and even vibration. Growing since Greek and Roman medicine, these fiber theories led to a revival of musical approaches to cardiology during the eighteenth century that then grew into the new forms of sonic physical diagnosis, percussion and mediate auscultation. Part III turns to the influence of music and sound on reconsidering the typology of mental illness and on new therapies such as mesmerism. Part IV considers the varied array of contemporary biomedical sciences that rely on sonic information, including echolocation, ultrasound, sonic methods in neurophysiology, and other emerging approaches. In them, the sonic turn led to a rhythmic turn, in which the universal language of the nerves turned out to be a binary, all-or-nothing code whose changing rhythms—and frequencies—encode all bodily motions, sensations, and mental states.

Part I begins with the interrelations of music, medicine, and biology as they emerged somewhat less directly than those between music and the physical sciences, which reflected the intimate connections between music, arithmetic, geometry, and astronomy within the quadrivium. Chapter 1 outlines the relation between Greek medicine and natural philosophy, especially the role played by Pythagorean thought. Alongside their mathematical and musical studies, the Pythagoreans also emphasized medical practice. Though the healing arts initially stood apart from the quadrivium, Pythagorean thought influenced the rational medicine of the Greeks as carried forward by Alcmaeon, Philolaus, and the Hippocratics. Some of them described the body in terms of four liquid humors, a concept that only became central in late antiquity. For the Hippocratics, number regulated the timing of the crises of illnesses, the crucial moments in which the patient would either turn the corner toward renewed health or worsen. Important categories of disease were governed by fixed patterns of crisis, knowledge of which was crucial for physicians, whose understanding of those patterns they transmitted to the patients and their families, even if their scope of therapeutic action was limited. In light of its special quest for knowledge and healing, Plato held up medicine as an exemplar for the practice of philosophy, considered as the healing of souls from ignorance and delusion.

The controversies surrounding the Pythagorean program are the subject of chapter 2. Aristotle argued that *physis*, the realm of growth and change that included what we now call biology and physics, is not governed by numbers; instead, he advocated empirical but qualitative investigations. His arguments against the possibility of applying mathematics to physics tended to separate biology from music, as well as from the other mathematical sciences. Still, when Greek medicine moved to Alexandria, it both continued Aristotle's empirical work and also drew on Pythagorean ideas. In particular, Herophilus connected musical ratios with the functioning (or diseases) of the pulse, on the analogy with the various musical intervals those ratios represented when applied to vibrating strings, glasses, or pipes.

As chapter 3 relates, these connections between ratios and pulse patterns grew in importance during and after Roman times because Galen paid them considerable attention in his vast and influential compilations of medical knowledge. Then too, writers on music such as Aristides Quintilianus discussed Herophilus's ideas and described the fundamental processes by which music therapy operated. Authors as diverse as Martianus Capella and Augustine paid attention to the music of the pulse. As Rome was overtaken by invaders, Boethius described *musica humana* as the correlate in the human body of the cosmic harmonies. By taking up this influential concept as well as Herophilus's ideas, Muslim translators and commentators such as al-Kindī, Hunayn, al-Rāzī, and Ibn Sīnā played a crucial role in keeping these ideas alive and transmitting them to the West.

Chapter 4 presents the continued reverberation of Herophilus's teachings throughout the Middle Ages and Renaissance. Even before Galen's texts were generally available, many writers (such as Hildegard von Bingen) discussed the use of music to treat melancholia, a particularly important example of *musica humana* applied to medical practice.

Harking back to the ancient connection between astronomy and music, Robert Grosseteste and many others connected these interventions with the influence of the planets; astrology was a common tool of medieval medicine. After the writings of Galen and Hippocrates returned to circulation, the medical school of Salerno took up the intriguing ideas of pulse music, as did later physicians such as Pietro d'Abano, who connected them with contemporary music and rhythmical theory. In turn, they influenced other medical writers in the fourteenth and fifteenth centuries. Among musical writers, Bartolomé Ramos de Pareia and Franchinus Gaffurius made connections between music, medicine, and astronomy. Above all, Marsilio Ficino drew together these musical, astrological, and medical strands as he presented the first translations of many Platonic and neo-Platonic works, along with commentaries that greatly influenced his contemporaries. Ficino's influence reached across Europe, becoming common currency also in literary works ranging from Shakespeare's plays to Robert Burton's encyclopedic treatment of melancholia, which often referred to the relation between music and medicine.

Johannes Kepler took Platonic ideas about music to new heights throughout his extraordinary body of work. Though best known for his crucial innovations in astronomy, Kepler also reflected on medicine and biology as they related to music and astrology. As innovative as he was, Kepler drew on a Platonic and Aristotelian framework in which physics and biology (as we now call them) together formed what he called "physiology," in which musical harmony was the essence of what he called "soul," animating not only humans and animals but the Earth and the whole cosmos. Chapter 5 treats the ramifications of his harmonic physiology, ranging from his reflections on the symmetries of beehives, pomegranate seeds, and snowflakes to the "spontaneous generation" he envisaged for comets and new stars. Though Kepler dismissed many elements of vulgar astrology as groundless, his fundamental geometrical and musical archetypes mandated what he thought were well-grounded connections unifying physiology throughout the heavens and the Earth. These connections formed the basis of his purified astrology. In his *Harmony of the World* (1619), he used these connections as he tried to persuade James I of England to heal the "cross-shaped wounds" that afflicted Protestants throughout Europe (including Kepler himself) by taking up arms in their defense, thereby engaging the various "hard" and "soft" (major and minor) harmonies of the heavens. In contrast, his astrological work for Albrecht von Wallenstein called that preeminent generalissimo to heed the harmonies indicating that he should turn toward peaceful means.

Tarantism presents a striking, perhaps even unique, example of music as curative agent. Chapter 6 considers how those bitten by spiders would respond to certain kinds of music that excited them to frenzied dancing. This music seemingly exacerbated their distress yet was capable of relieving them if they could dance long enough. In that case, their eventual collapse and subsequent recovery seemed to show that the music had paradoxically purged their malady by making it worse. Tarantism also raised questions about the nature and timing of its crises, which seemed to reoccur on anniversaries of the original bite as well as on the Feast of St. Paul, the patron saint venerated by those afflicted by venomous bites.

As medicine sought to go beyond the visible manifestations of illness, sound offered ways to access the hidden interiority of body and mind, the sonic turn introduced in part II. Chapter 7 considers how the body went from being considered primarily an assemblage of humors to an ensemble of sensitive constituents, fibers, and organs capable of responding sympathetically to sonic vibrations. Sound thus called for and offered a new way of thinking about the body that would explain the responsivity of living organisms without recourse to vital forces that defied rationality and mechanics. Poised between the visible and the invisible, sound offered a new way to mediate between matter and vital activity.

This sonic turn came in several distinct (and somewhat disconnected) waves. In the mid-eighteenth century François-Nicolas Marquet proposed a musical notation of normal pulse that connected its felt pulsation with heard music (a minuet), though without attempting to hear (rather than feel) those rhythms, as described in chapter 8. His minuet reflected contemporary musical styles, as did his notations for various kinds of abnormal pulse, though without relating those rhythms to heart function or disease. Given Marquet's relative obscurity, his ideas received a surprising amount of attention in articles by Joseph-Jacques Ménuret de Chambaud in the famous *Encyclopédie*. Though vitalists such as Ménuret and Théophile de Bordeu rejected Marquet's work, mechanists such as Albrecht von Haller included it in the larger discourse about the physiological manifestations of bodily fluids and fibers.

The decisive phase in the sonic turn included the diagnostic techniques of percussion and mediate auscultation advocated by Leopold von Auenbrugger and René T. H. Laennec. Chapter 9 explores their musical backgrounds in relation to their work. Both were deeply involved with music, Auenbrugger (and his daughter Marianne) with Joseph Haydn and Antonio Salieri, Laennec with Breton folk music. Though neither discussed Marquet's work, they had been trained in the mechanistic physiology of Haller, which was notably open to musical and sonic approaches. Auenbrugger used musical vocabulary to present his work on thoracic percussion; Laennec's musical experience shaped his exploration of the new timbres he discovered using his stethoscope in the emerging practice of mediate auscultation.

Part III turns from physical diagnosis to the search for a new typology of mental illness and the emerging sonic interventions that addressed them. Chapter 10 explores the changing meanings of "mania" and the emergence of what now are called obsessional-compulsive disorders. Yet decades before clinical descriptions of "monomania" and idée fixe, a symphony by Gaetano Brunetti gave a detailed dramatization of a musical obsession he called *manía*. In his Symphony "Il Maniático" (1781), Brunetti's solo cello is fixated on an oscillating semitone. The orchestra around him tries to shake him from his obsession by cheering him up, but the "maniac" cello persists, though to some degree reshaping his fixed notes to accord with the surrounding harmonic context. In the end, the cello seems to give up its obsession by inducing the orchestra to perform equally obsessive figurations of its own, as if all together recognized the obsessional qualities of the classical style itself. Written for the crown prince who later reigned as Carlos IV, the symphony can be read as a message of sympathy regarding the prince's struggles with his obsessional father, then reigning as Carlos III, not to speak of the half century of Spanish royal insanity that had gone before. Then too, the symphony seems to poke fun at the rather obsessional style of Luigi Boccherini, a rival composer at the court.

Where Brunetti offered a new kind of musical insight into psychic maladies, Franz Mesmer used music as a crucial means to induce radical changes in mental and physical states. He was steeped in music, a noted performer on the recently invented glass harmonica, and was involved with the Mozarts and other musicians. Chapter 11 shows how Mesmer's "animal magnetism" relied on music as a powerful modality of treatment as well as providing a basis for his theoretical foundations and self-understanding. Drawing on the procedures by which the classical style manipulated musico-dramatic crises, Mesmer was able to alter the timing and rhythm of therapeutic crises, long considered to be inalterable characteristics of each disease.

Music continued to be an important factor in hypnotic therapy even after Mesmer's successors turned away from his reliance on crises, beginning with his disciple Amand-Marie-Jacques de Castenet, marquis de Puységur, who preferred a deep somnambulistic state to Mesmer's convulsive crises with their violent disorder and possible menace. Chapter 12 relates the ways Jean-Martin Charcot used a tam-tam (a large gong) to induce profound states of hypnotic sleep verging on catalepsy in which patients would be intensely suggestible. Charcot's work came after the tam-tam had become familiar in orchestral practice, beginning with funeral marches during the Revolution in which the tam-tam played an overwhelming role, thereafter becoming a staple of operatic dramaturgy. Though Charcot's work was shadowed by the deliberate imposture practiced by some of his associates and patients, even if it is taken to be suggestion or deception, it operated through musical models of dramatic disruption. The tam-tam's complex mixture of overtones seemed to overwhelm consciousness, overriding normal mental responses, compared to the sequence of conscious (but intensely felt) states Mesmer induced through the harmonica's unfamiliar sounds.

Finally, part IV addresses new frontiers of sound beyond those audible to unassisted human hearing, beginning with the investigation of how bats fly in the dark, pioneered by Lazzaro Spallanzani at the end of the eighteenth century. The bats' "sixth sense" was identified as hearing only in the twentieth century, after their mysterious methods of navigation had been imitated by early developments in sonar and radar. Only after World War II was the electronic technology available to detect the bats' sounds as ultrasonic. That technology ultimately rested on the hetrodyne principle, developed from the musical phenomenon of "Tartini tones." Chapter 13 details the interweaving strains of biological investigations and military technology that grew from the bats' navigation and eventually illuminated these animals' uncanny skills.

Ultrasound went on to have enormous importance for many kinds of clinical diagnosis, as outlined in chapter 14. After two world wars, the development of sonar led to many attempts to ultrasound the human body. These all faced unfamiliar problems of understanding acoustic echoes in the body's complex, reflective internal environment, so different from locating submarines or ships. For a surprisingly long time, experimentation relied on makeshift bricolage of war-surplus electronics and audio equipment. Industrial ultrasonic flaw detectors were repurposed by applying their probes to the human body, but interpreting the resultant images posed many difficulties. Prior practices based on looking at X-rays were misleading when applied to ultrasonic echoes, which required newer modes of visualization than those adapted even from radar and sonar. Building on the work of others and using these new modes, Ian Donald and his collaborators brought ultrasound to wide acceptance for the first time. In so doing, they had to attend to the body acoustically, not just visually, by addressing the new acoustic "slices" of the body that led to tomography and thereby to the three- and four-dimensional imaging that became universal medical practice in both ultrasonic and computerized tomography (CT) scans.

The final four chapters concern the use of sonic techniques to explore the functioning of the nerves. Chapter 15 begins by connecting vibrating nerve fibers to more general concepts of "nervousness" that gained traction in the eighteenth century. Above all, Luigi Galvani's discovery of the connection between electricity and muscular action called physiology to investigate their interrelation, especially the role of the nerves. Much depended on the details of the instruments deployed to observe that electrical activity, particularly the galvanometer. Using it, Emil du Bois-Reymond demonstrated that muscular contraction led to electrical activity. Hermann von Helmholtz measured the speed of those nerve currents and used tuning forks to regulate electrical stimulation of the nerves as well as to time their response. He also listened to the sounds made by muscles as they contract, investigations Julius Bernstein carried further as he developed a chemical theory by which membranes mediate nerve action.

The new technology of the telephone proved very useful in pursuing these ever more detailed studies of the precise details of how nerves and muscles work, as chapter 16 recounts. Du Bois-Reymond was able to make a frog's leg twitch or lie still, seemingly by commanding it through a telephone attached to the nerve. Other researchers were able to use electromagnetic tuning forks to stimulate a nerve whose response they heard through a telephone receiver. Bernstein and others conducted ever more elaborate experiments that converted the rattling sounds they heard in the telephone into moving light beams that could make permanent traces along photographic plates. In 1900, Nicolas Wedensky considered the telephone "virtually irreplaceable" in tracing any arbitrary point in a nerve without disturbing its connection to the muscle, able to hear the action of poison as it acted on the nerve. Likewise, Rudolf Höber used the telephone with new "valve amplifiers" to catalogue a whole range of sounds he evoked from muscles stimulated at various frequencies. He and Ferdinand Scheminzky began using loudspeakers to make the sounds of nerves and muscles audible through an entire room.

The scene then shifts in chapter 17 from Europe to Britain and the United States. The quest to measure the firing of a single neuron taxed the different limitations of the available instruments. Using great ingenuity and skill, Keith Lucas proposed and argued for the all-or-nothing action of muscle fibers by gradually paring them apart and noting the quantized "steps" in their contraction. To establish the truth of this principle in general, he realized, would require measuring the electrical activity of a single nerve cell. After his untimely death, his student Edgar Adrian fulfilled this quest by finding the output of a single nerve through listening to its amplified signal, at first through a telephone and later through a loudspeaker. His student Bryan Matthews turned the loudspeaker into an even better recording device than contemporary galvanometers or oscilloscopes, the "Matthews oscillograph" in use until after World War II. These sonic devices did not merely render the nerve action audible; they were important in separating a single neuron from others and locating its signal. So significant was this technique that Adrian played gramophone records of his nerve experiments during his Nobel lecture in 1932.

Chapter 18 reflects on the epistemic significance of hearing versus seeing or analyzing purely numerical data. Episodes from the later work of Adrian exemplify *rhythmic knowledge*, in which the "analog" perception of bodily sounds led to hearing "binary" neural rhythms that characterized critical changes in living processes. Registering such rhythmic knowledge can bypass the complex dialectic of objectivity versus subjectivity as it has been theorized by historians of science for the visual analysis of scientific phenomena. Rhythmic knowldge gives direct access to living processes in real time, through the vivid aural experience of their changing rhythms. Thus, the thrill of hearing the "machine gun" firing of a cat's visual neuron helped David Hubel and Torsten Wiesel in their landmark studies of vision in the late 1950s. Indeed, audio monitoring is still used in neurophysiology labs around the world, such as Leslie M. Kay's group studying the olfactory bulb at the University of Chicago. There and in many other labs and classrooms students are initiated into the special kind of hearing needed to find a single neuron. In the process, they learn to hear how different parts of the brain *sound* different.

Many of the other sonic techniques discussed here have entered into new phases, as chapter 19 relates. Diagnostic ultrasound now can be run through a smartphone, allowing practitioners far from medical centers to use this powerful tool inexpensively. Even though the venerable practice of mediate auscultation has fallen into neglect as a core skill of physicians, computer-assisted auscultation (CAA) allows greatly enhanced stethoscopes that facilitate powerful analysis of the sonic signal past the limitations of human ears, easily transmitted for remote consultation. Handheld ultrasound devices allow a similar ease and portability of this crucial diagnostic tool. Likewise, handheld "brain stethoscopes" enable quick and ready diagnosis of silent seizures through sonifying the electroencephalogram. Moreover, sonifications of genomic data open the possibility of understanding the genomes of human and coronavirus in new ways through hearing their detailed structure.

Though these developments echo and update earlier discoveries, the biomedical sciences continue to rely on sonic and rhythmic knowledge. If the evidence of the past is any guide, these modes of knowledge will continue to be a valuable resource to overcome the limitations of the human gaze by finding ways to hear critical changes in the deluge of numerical data. We are only at the beginning of sounding bodies.

Throughout the book, when I refer to various "♪ sound examples," see http://mitpress.mit.edu/sounding-bodies. That link will give further information on purchasing enhanced digital editions that will be available in a variety of formats, in which the text and examples are easily and seamlessly available; in them, you need merely touch an example to hear and see it. Readers with special needs will also find instructions for accessing the audio and visual examples in alternate forms.

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Sounding Bodies

Music and the Making of Biomedical Science

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