Abstract We tend to associate the sciences with seeing—but scientists, engineers, and physicians also use their ears as a means for acquiring knowledge. This chapter introduces this essay’s key questions about the role of sound and practices of listening in the sciences, and explicates their relevance for understanding the dynamics of science more generally. It defines the notion of sonic skills, situating it in the wider literature on the auditory dimensions of making knowledge. It presents the case studies on which the essay draws, explaining their geographical, temporal, and methodological scope and the researchers behind them.

Keywords Listening for knowledge · Sonic skills · Science · Medicine · Engineering

Acoustic Signatures
On the afternoon of July 11, 2014, Dutch Public Radio 1 broadcast an interview with science journalist Diederik Jekel. He had breaking news: American geologists had discovered a “super ocean” some 300 miles below the earth’s surface. The journalist immediately added a qualification. What the Americans had actually found were some stone minerals, originating from the earth’s deep layers, that included water molecules. This prompted the talk show host to ask how certain scientists could be of the super ocean’s existence. The journalist explained that the
American geologists knew they had *in fact* found water when they sent sound waves deep into the earth. The stones had melted in the earth’s heat, and just as a knock on a table sounds different from a knock on a glass of water under the same conditions, the melted material sounded different from the non-melted. The talk show host was quick to conclude: “We know it,” she said, “but we have not seen it; it has not been [proven] experimentally.”¹

Apparently, she had trouble believing the geologists’ ears. Their findings had not yet been *proven*, because the phenomenon had not been *seen*. By suggesting that hearing something is not sufficient to prove its existence, whereas seeing it would actually establish the fact, the interviewer posited a direct link between seeing and true science or ultimate knowledge. She may have learned to do so from scientists themselves, who tend to work in offices packed with printouts and scans around computer screens, producing publications rich in diagrams, graphs, and other images. Indeed, the American geologists in search of water had used seismic data gathered during earthquakes, often referring to infrasound waves: sound waves below the human audible range. At times, these infrasound waves are translated into frequencies that humans can hear, but more often they are made *visible*, in graphs. In the medical world, ultrasound waves—sounds above the human audible range—are used to create images of the body’s interior, such as images of the unborn. Even scientists interested in frequencies that are directly audible to them, like most of the sounds of birds or language, usually turn their sound recordings into images before they start analyzing the objects of their interest. Some such images, including spectrograms and sonograms, also make their way into the scientists’ publications and presentations, often accompanied by other forms of visual data representation.²

Nevertheless, scientists do listen for knowledge. In early 2015, an international group of geophysicists published an article claiming that particular patterns in the sounds of glaciers might reveal where and how those glaciers were calving. They had made sound recordings with hydrophones—underwater microphones—and taken photos at the same time. This enabled them to link various glacier sounds to distinct forms of ablation through “acoustic signatures” that indicated, for example, whether the ice was disappearing below or above the water surface (Glowacki et al. 2015). Other physicists monitor the condition of dikes by recording the structures’ inner sounds with microphones, while biologists listen to the sounds of whales, insects, and birds.³ In military
contexts, too, scientists of various backgrounds have left their mark on listening technologies. During World War I, detecting and locating hostile submarines, artillery, tunnel-building, zeppelins, and bomber aircraft involved not only listening in on the enemy’s wireless communication, but also developing hydrophones, geophones, sound-ranging equipment, and sound locators, as well as training personnel for such mediated listening—listening, that is, enhanced by acoustic and electroacoustic means. In the interwar years, huge acoustic mirrors were built to detect aircraft, while sonar (in full, Sound Navigation and Ranging) was designed to locate enemy vessels in both world wars and beyond. Most of these technologies were “passive,” in the sense that they merely captured the sounds produced by the objects of their interest. But sonar can also be “active,” generating sound to detect objects through echolocation. In both cases, listening was a key dimension of the military use of these technologies.

Listening for knowledge is also embedded in more everyday practices. Since the early nineteenth century, doctors have used stethoscopes to listen to their patients’ hearts and lungs as a way of investigating their health. Engineers in the automotive industry and mechanics in garages use automotive stethoscopes to listen to the functioning of car engines or the car’s other moving parts. Another well-known tool is the Geiger counter, a device that transforms data about radiation not only into numbers but also into clicking sounds, informing and warning us of what we cannot see or sense in other ways. This capacity makes the Geiger counter, or more correctly the Geiger-Müller counter (Volmar 2015), a device for “sonification”: “the use of nonspeech audio to convey information” (Kramer 1999). And yet when today’s general practitioners or hospital specialists listen to our body and hear something seriously wrong, they will probably suggest checking our blood with the help of chemical analysis or “looking inside” with help of X-ray technology, magnetic resonance imaging (MRI), or other devices resulting in images. Even the glacier researchers emphasized that their tests would have to be repeated before anything “definitive” could be said. Capturing sound is one thing; interpreting and assessing the results is quite another, and is highly dependent on the contexts in which listening takes place.

This book-length essay aims to understand the ambiguous and at times contested position of listening for knowledge in the sciences. It does so by tracking the shifting status of sonic skills in science, medicine,
and engineering across the long twentieth century, the theme of a project at Maastricht University that I will describe in more detail below. The project was primarily interested in sound and listening as a way of acquiring knowledge about human bodies, animals, machines, or other research objects, and thus in sound and listening as a means rather than an object of research. For our project’s selection of case studies, this meant leaving out fields that prioritize the understanding of sound, hearing and listening per se, such as acoustics, psychoacoustics, otology, and audiology. Of course, theories and techniques from these fields have affected listening for knowledge in other areas (Kursell 2008; Hui 2013; Hui et al. 2013; Erlmann 2010). But the project’s main focus is not research about sound, hearing and listening. Instead, practices of listening in the sciences take center stage—specifically, listening practices applicable to sounds in the frequency ranges audible to humans. And rather than dealing with the forms of listening that people engage in when interacting in conversations, this study is about listening, within the sciences, to the sounds of phenomena that do not talk back. The special relevance of listening’s fluctuating standing in the sciences, this essay claims, is that it offers new insights into the significance of timing, trust, and accountability in knowledge making.

**Sonic Skills**

This essay, then, aims to study listening for knowledge in the sciences by focusing on the use of “sonic skills.” Sonic skills, as I use the term here, include not only listening skills, but also the techniques that doctors, engineers, and scientists need for what they consider an effective use of their listening and recording equipment. Examples of such skills would be the proper positioning of a stethoscope on a patient’s body, the handling of magnetic tape recorders in bird sound recording, or simply archiving sound samples for easy retrieval. To understand listening for knowledge, therefore, we need to study not only the skills related to listening proper, but also those that ensure sounds can be amplified, captured, reproduced, edited, compiled, accessed, and analyzed.

These skills can be examined as embodied and encultured techniques, just as Jonathan Sterne did in *The Audible Past* (2003), where he introduced the notion of the “audile technique” to articulate his interest in the context-specific bodily postures and usages of mediating instruments that are intended to isolate, intensify, and direct acts of listening. I apply
a similar analysis to the sonic skills of making, recording, storing, and retrieving sound in addition to listening to sound. This implies that listening cannot be studied in isolation from the other senses. Its historically embedded relations with other sensory modalities, especially tactile and visual modalities, are crucial (see also Krebs 2015; Supper 2016).

Three clusters of issues are of particular interest here. First, for what purposes have scientists, engineers, and physicians lent their ears to the objects of their interest? Did that listening elicit new types of questions, and if so, of what kind? Second, how exactly have these experts employed their ears to make sense of what they studied? In what ways, and with the help of what tools, did they listen to what they examined? And how did—and do—they master such sonic skills? Third, under what conditions have sonic skills, alongside visual ones, been accepted as “objective” paths of inquiry in science, engineering, and medicine? And under what conditions did visual skills partially displace sonic skills again? Why, for instance, did the use of sound spectrograms become widespread in ornithologists’ research practices after the 1950s, whereas just a few decades earlier, in the late 1920s, bird researchers had welcomed film sound recorders and electrified gramophones with great enthusiasm? And why, at least at first glance, has the auditory presentation of scientific data still not become very popular, apart from warning devices such as the Geiger counter?

Although I will address these questions in relation to the long twentieth century—that is, including the late nineteenth century and early twenty-first century—I concentrate on the period beginning in the late 1920s. This was when the use of sound recording technologies such as the electric phonograph and gramophone took off in many areas of research, including ethnology, ethnomusicology, and ornithology, affecting both the listening practices and scholarly debates in these fields (Stangl 2000; Sterne 2003; Mahrenholz 2008; Mundy 2009, 2010). In the early days of ornithology, for instance, making field recordings of birds still required a seven-ton truck carrying a disc-cutter, microphones, cables, and an electric oven for softening wax. As a result, only the most urbanized parts of the wild could be studied—which of course affected the content of the recordings. The rise of the magnetic tape recorder in the early 1950s reshaped listening practices in ornithology once again, enabling collaboration with amateurs, storage of recordings in large sound archives, and the comparison of recordings originating from a wide variety of places. And from the late 1950s, ornithologists could
turn to the sound spectrograph, a device that transformed audio recordings into sound spectrograms, triggering new standards for valid scientific proof (Bruyninckx 2013).

In this book, I will often refer to “the sciences” as a shorthand for science, medicine, and engineering. This does not imply, however, that the dynamics of auditory epistemology in the science-based professions, such as medicine and engineering, has been the same as in the natural sciences themselves. Despite fears that medical auscultation might be “a dying art” (a discourse recently analyzed by anthropologist Tom Rice 2013: 164), learning to listen with the stethoscope is still a standard component of medical curriculums worldwide. Similarly, those working in car repair shops and the automotive industry consider the mechanic’s stethoscope an essential tool, the use of which is an acknowledged learning-by-doing aspect of practical training (Krebs 2012). In contrast, as far as I am aware there are no courses in listening, or acknowledgement of the need for listening skills, in the science programs at universities. This distinction is just one obvious difference between the natural science professions—fields with legally assigned jurisdiction concerning particular forms of expertise (Abbott 1988)—and the sciences themselves.

As I hinted above, this essay is the outcome of work by a group of researchers at Maastricht University who for several years participated in the Sonic Skills project. They include historian of science Joeri Bruyninckx, medical anthropologist Anna Harris, historian of technology Stefan Krebs, sociologist Alexandra Supper, and musicologist Melissa Van Drie. In 2008–2009, I outlined the project’s questions, key concepts, case studies, methods, and theoretical approaches in a grant proposal for which I was awarded a VICI grant by the Netherlands Organization for Scientific Research (NWO) in 2010. Joeri Bruyninckx and Alexandra Supper were both PhD students at the start of the project, and also contributed as postdocs in later phases; the others were involved as postdoctoral researchers. I coordinated the project from its inception until its completion in mid-2015.

This essay aims to synthesize the insights from the project’s case studies. It draws on the two Ph.D. dissertations and the journal articles, book chapters, and outreach activities that resulted from the project, as well as the rapidly expanding body of literature on the epistemology of sound and listening written by colleagues elsewhere. In essence, my way of referring to the literature produced within the Sonic Skills project does not differ from my use of secondary literature produced outside of the project. But the Sonic Skills publications have defined the scope of my
arguments, which are grounded in a systematic comparison of the project cases. Moreover, my role as principal investigator has given me privileged access to many of the interviews, observations, and historical sources behind the publications, leading to a deeper understanding of the project outputs than is possible for external publications. Occasionally, I will refer to these original sources and data with quotations that are more extensive than the ones to be found in the project publications.

To develop my argument here, I also rely on an article about listening modes in the sciences that I co-authored with Alexandra Supper and was published in *Interdisciplinary Science Reviews* in 2015. The key sections of that article constitute the heart of Chapter 3, now complemented by a discussion of the incidence of particular modes and some additional examples of listening. I am grateful to Alexandra for allowing me to reuse this article. I owe a great deal to the other Sonic Skills researchers as well. We devoted several meetings to the issue of listening modes by exchanging examples and refining the initial definitions while making use of the significant adjustments to these notions in Supper’s dissertation. I also benefited tremendously from the Sonic Skills expert meeting mentioned in the acknowledgments.

By comparing the cases and claims from the earlier publications, I intend to answer our project’s overarching questions about the use and epistemology of sonic skills in the sciences. Ideally, however, this essay will also lead readers to, or back to, the rich original work that underlies it—work that offers much more than the insights brought together here. Below, I will refer to the “we” of the project participants several times, for instance in Chapter 3. But let me first explain our historiographical and theoretical points of departure, and how these are rooted in previous scholarship on science, medicine, and engineering.

**Sensory Practices in the Sciences**

It is hard to find a scholar today who is willing to defend the claim that the dominance of visual forms of representation and proof in the sciences is best explained by the essential qualities of seeing, hearing, or other forms of sensory perception. Or, to be more precise, it is hard to find such a person in the academic fields that most strongly inform this essay: history of science, technology, and medicine; the interdisciplinary field of science and technology studies; history and anthropology of the senses; and constructivist strands within sound studies.
In cultural studies, art theory, and acoustic ecology, the situation is different. In those areas, there are indeed authors who argue that seeing creates the kind of distance from objects that scientists are after, whereas hearing enables a more intimate relation with the world. It was the pioneer of soundscape research, composer and acoustic ecologist Raymond Murray Schafer, who—inspired by Marshall McLuhan’s work—distinguished between an “inward” drawing ear and an “outward” looking eye (Schafer 1967: 2; 1994/1977). Because of this orientation, he treated hearing as the better sense, and so did many of his followers. In this type of storyline, dubbed “the audiovisual litany” by Jonathan Sterne, seeing creates distance, calls upon the intellect, and focuses on the superficial, whereas hearing surrounds us with sounds, is inclined to the affective, and penetrates deep into the heart of the matter (Sterne 2003: 16). More recent varieties of this way of thinking are less schematic, but still underline the apparent natural affinity of the auditory with associative thinking and unfixed positions (Labelle 2011: xviii–xix), or present the auditory as troubling “the visually inspired epistemologies that we take for granted: the clear distinction between subject and object, inside and the outside, self and the world” (Bull 2006: 112). Immersion in sound, declares the “new orthodoxy” in sound art as critically discussed by music scholar Will Schrimshaw (2015: 155), is an experience that precludes reason.

In the fields with which our project is affiliated, however, most scholars seek contextual explanations for the significance of visual strategies in academic knowledge making. In the history of science, for instance, three interacting shifts have been held responsible for the dominance of visualization. In the seventeenth century, natural philosophy’s focus on hermeneutic readings of the world and natural history’s interest in classification gradually gave way to a new culture of science in which experiment and observation became important requirements for legitimate knowledge (Pickstone 2000, 2007). Who witnessed what, and where, made all the difference to an experiment’s scholarly validity. Early reports of experiments in the meeting rooms of academic societies, published as letters, recounted which learned men had actually attended and added detailed images of the events in order to enable “virtual witnessing” (Shapin and Schaffer 1985: 60). This focus on eye-witnessing did not mean the reports neglected the sounds of the experiments (Schwartz 2011: 93–95). But over time, scientists would increasingly describe their work in visual terms.
Historians of science regard two other developments as relevant for understanding this development. The first is the rise of print in the fifteenth century and the growing availability of books thereafter. The enhanced circulation of printed materials enabled texts, calculations, and illustrations to be systematically compared, triggering critical reflection and expanding the academic community. As time went by, the easy exchange of printed reports also naturalized a new notion of “witnessing,” one that involved reading proceedings as opposed to attending the experiments proper (Johns 1998). The second relevant change is the emergence of “mechanical objectivity” as an epistemic ideal in eighteenth and nineteenth century science. This dismissed the human body’s status as a trustworthy witness of natural phenomena, favoring instead their automatic registration by machines. Mechanical objectivity, Lorraine Daston and Peter Galison (1992, 2007) have shown, experienced its heyday in the 1920s, after which “trained judgment” by expert scientists gradually acquired validity—at least as a supplement to mechanical objectivity. Still, for a long time, doing science was largely about reading the instruments that registered natural phenomena for the scientists—a visual activity indeed. Furthermore, many of these instruments translated what they registered into graphs, and thus visual representations.

By the time these studies in the history of science appeared, science and technology studies (STS) had entered the stage, the product of a genuine interest in the everyday practices of science. Until the 1980s, the study of science had striven to demarcate rational science from irrational beliefs by formulating universal criteria for scientific knowledge. Scholars in STS moved away from over-idealized conceptions of science and turned their attention to “science-in-action,” a term coined by Bruno Latour. Latour and his colleagues aimed to trace how science was done in practice, in the laboratory and beyond. One of their questions was how scientists managed to turn local findings into global truths. Latour’s own answer contributed importantly to understanding the role of visualization in scientific representation. He showed that inscriptions, such as tables and diagrams, can effectively circulate locally acquired data across geographically disparate networks of knowledge because they are both immutable and mobile. And he pointed out that such inscriptions can be easily cascaded and superimposed on paper—an example being numeric data printed on maps (Latour 1986, 1987).

It is not that the interpretation of these visual resources was, or is, always immediately self-evident to the community of scientists involved.
After any presentation at any science conference, many questions will focus on the proper reading of the graphs. Similarly, the introduction of visualization techniques such as photography, X-ray, probe microscopy, or planet observation by panoramic cameras has never come with instant transparency or an obvious way to decode the resulting images. On the contrary, each new visualization strategy gives rise to fierce debate as to what exactly the images represent. Novel images have to be made commensurable with existing representation techniques in order to become legible (Pasveer 1989, 2006; Te Hentenepe 2007; Mody 2014), and that entails new skills: formerly unknown features of a phenomenon only “pop out” through digital image processing, for example, because “a skilled vision is crafted into the image from the outset” (Vertesi 2014: 25).

Research into visualization techniques has thus significantly refined our understanding of how knowledge and visual displays interact. Michael Lynch (1990), for instance, explained that interaction by describing how diagrams and images in the life sciences act as an “externalized retina” that structures the production of scientific facts through the schematic redefinition, mathematical order, and solidification of the objects under study. If Lynch focused on the conventions of “consensual ‘seeing’ and ‘knowing’” in the sciences (p. 155), Eugene Ferguson studied nonverbal “visual thinking” in design at the individual level (Ferguson 1992). Such visual literacy did not remain limited to scientists, but gradually spread among the general population through the consumption of visual toys and other forms of educational entertainment (Stafford 1994; Tufte 1997).

STS scholars’ work on the laboratory practices of scientists unveiled much more than the visual aspects of knowledge making, however. As historian of science Lissa Roberts (1995) suggested, it was only in their published writings that eighteenth-century chemists sidelined touch, hearing, smell, and taste. While carrying out their experimental work, they still enlisted their senses to interpret what had happened, carefully attuning their bodies to their instruments. Harry Collins’s field studies of the lab work of present-day physicists showed how the “tacit knowledge” that scientists develop about their experimental set-ups often makes it impossible for others to fully replicate their experiments. The result is an infinite “experimenters’ regress” (Collins 1985). Collins drew his notion of tacit knowledge from the work of Michael Polanyi (1983/1966), and initially defined it as “an embodied kind of know-how irreducible to symbolic terms” (Collins cited in Mody 2005: 176; Collins 2001).
It is wise to note at this point that not all science draws on embodied knowledge. Think of the cognitive focus in contemporary mathematics—even if much mathematics-in-action does involve enacting arguments through jottings, annotations, and erasures on blackboards and scrap paper (Barany and MacKenzie 2014). But despite exceptions such as most of mathematics, the discussion of embodied and tacit knowledge has been an important source of inspiration to STS scholars researching the role of the senses other than seeing in science, medicine, and engineering. Natasha Myers (2008), for instance, has remarked on the significance of *gestural* knowledge in the crystallography of proteins. Crystallographers use graphical software to model their proteins in three dimensions, but the most experienced among them check the draft models by imagining the protein dimensions and characteristics in terms of their own corporeal experience of building earlier protein models. They also use their bodies as resources for communicating a “feel” for molecular structures to novices.  

Similarly intriguing is Sophia Roosth’s (2009) account of “sonocytology” in nanotechnology research, whereby cell wall vibrations are recorded with scanning probe microscopes and amplified to volumes audible to humans. In the first years of the twenty-first century, she explains, the US scientist Jim Gimzewski introduced sonocytology as a noninvasive technique for studying cellular interiors, contrasting with invasive forms of research such as chemical analysis. He initially studied yeast cells, but later began to listen diagnostically to the “difference between healthy and cancerous cells” (p. 341). Gimzewski interpreted the sounds as referring to particular forms of cellular motion and metabolism. The epistemological effect of studying cells in terms of sound, Roosth argues, was to conceive of cells “in time and in context,” or, more specifically, in terms of interior time and—with an ear for the transmission of sound—acoustic micro-milieus (p. 338). And when Gimzewski claimed to hear his yeast cells “screaming,” he also anthropomorphized them (p. 339).

This work is of fairly recent date, but the theme of listening in science, engineering, and medicine entered the STS research agenda much earlier, often linked to an interest in tacit knowledge. Sociologist of science Jens Lachmund (1994), for example, studied the rise of the stethoscope and auditory knowledge in nineteenth-century medicine by examining the work of the Parisian physician René Laennec and his Viennese colleague Joseph Skoda. Laennec not only invented the stethoscope
in 1816, but also created the very first codification of lung sounds—a codification that was intended to help physicians relate the body’s murmurs to its medical condition. In an attempt to explain the nature of these sounds to uninitiated physicians, Laennec compared them with the sounds of animals, musical instruments, and urban life, and occasionally used musical notation. In his view, however, such codifications could never be sufficient to learn auscultation: hospital training was indispensable for acquiring the right skills (Lachmund 1994, 1999).

Jacalyn Duffin (1998) finds that attention to Laennec’s musical skills is crucial to understanding his successful use and teaching of the stethoscope. However, those skills were not enough to disseminate Laennec’s lung sound codification beyond the Paris hospitals. The hospital and research practices of Skoda’s Vienna, for instance, were rather different from those in Paris, with limited access to patients but more extensive connections with laboratory research. These divergences gave rise to different types of lung sound codification. Whereas Laennec had worked inductively and assumed a one-to-one relationship between sounds and pathologies, Skoda reasoned more deductively, developing an auditory form of differential diagnosis that started by excluding potential causes with the help of acoustic knowledge of the body and its inner resonances (Lachmund 1994, 1999). Although I will return to Lachmund’s research in the next chapter, it is worth discussing in some detail here, for it neatly articulates the way that the rise of a new instrument afforded new listening practices and forms of auditory knowledge, but did not simply determine the character of those practices and knowledge. In different settings, the same instrument may lead to diverging epistemologies.

The stethoscope happens to be one of those auditory instruments that turned up in various contexts, and not only medical ones. As early as the 1920s, technical literature on car manufacturing told of engineers listening to car engines in order to detect problems in the machines. To track the car’s lowest frequencies, for instance, they used a metal rod that transmitted the engine’s vibrations to the engineer’s teeth (Snook 1925). Over time, car manufacturing and repair businesses also started to work with automotive stethoscopes, with the deliberate intention of transferring the prestige of the stethoscope, the “hallmark of a doctor” (Rice 2013: 74), to the profession of the mechanic (Krebs and Van Drie 2014). But it was more than just an icon of expertise: car mechanics listened to engines to detect the causes of flaws in the first place (Borg 2007).
Listening to machines was not limited to the automotive industry. Gerard Alberts, a historian of information technology, has explained how 1950s operators of digital computers at the Philips Physics Laboratory in the Netherlands missed the “trustworthy” rattling sounds of electromechanical calculators and decided to make the computers’ calculation processes audible through speakers. Adding loudspeakers to the computers created an “auditory monitor,” restoring a sensory relation with the equipment and making it possible to listen to computers in order to debug them (Alberts 2000, 2003: 17, 23). Listening has also been mentioned in the wake of scholarly interest in “situated actions” in engineering and repair (Suchman 1987). For technicians servicing photocopiers, Julian Orr has shown, “the succession of noises narrates to the experienced ear the progress of the operation” (Orr 1996: 98; Pacey 1999). This is why the technicians Orr studied hated noisy customer sites: the noise hampered their auditory focus on the machines. For similar reasons, factory workers long resisted the use of ear plugs, which deprived them of auditory cues about how well the machines on the shop floor were working (Bijsterveld 2008, 2012).

Patterns of sound are no less relevant at the laboratory bench. Investigating materials science, Cyrus Mody has discussed how the sounds of the valves, pumps, and outputs of laboratory instruments give the staff information on the experiments’ quality and content: “Learning these sounds and the experimental rhythm they indicate is part of learning the proper use of the instrument,” including “tacit knowledge of the sounds made when tools are not operating smoothly” (Mody 2005: 186). Some laboratory employees say that data expressing periodicity are much better processed with the ears than with the eyes. Intriguingly, they also find that the aesthetics of sound enhances “embodied interaction with the instrument” (p. 188).

The growing interest of STS scholars in the everyday practices of science, medicine, and engineering has thus both articulated the relevance of the nonvisual senses for knowledge making and explained why that relevance does not become immediately apparent when reading scientists’ work or attending their presentations—many listening activities take place behind the scenes of science, but are no less important for that science. In the history and anthropology of the senses, there has been a similar acknowledgment of the multimodality of sensory orientation. For many years, historians and anthropologists seemed almost obsessed with characterizing particular periods or even entire cultures in terms of
a predominating sense. Cultural historian Peter Bailey, for instance, distin-
guished between the modern West, which he believed to have had a
visual focus ever since the advent of print, and “pre-modern societies,”
which had been “predomi-nantly phono-cen-tric, privileging sound
over the other senses in a world of mostly oral-aural communi-cat-on”
(Bailey 1996: 55). Anthropologists, in contrast, claimed that sight had
held the highest position in Western cultural representations of the
senses since antiquity (Classen 1997), or discussed present-day cultures
with alternative sensory orientations, such as the Kaluli people in the
tropical forests in Papua New Guinea and their auditory epistemology—
or “acoustemology” (Feld 2003; Feld and Brenneis 2004).

Today, however, it seems that more and more scholars are adopt-
ing Jonathan Sterne’s critique of the assumption that the history of
the senses should be “a zero-sum game, where the dominance of one
sense by necessity leads to the decline of another” (2003: 16). Some of
these scholars have pointed out the significance of sound for Westerners’
everyday spatial and symbolic orientation in the nineteenth or twen-
tieth century (Corbin 1999; Bull and Back 2003); others argue that a
“perceptual equilibrium” has been present since at least the later medie-
val period (Woolf 2004). Anthropologist Tim Ingold has taken this one
step further: instead of studying cultures as mere filters of sensory expe-
rience, we should examine how people are informed by their senses, and
by all their senses together, as they are moving through particular worlds
or cultures—worlds that themselves have particular materialities. This
renders the idea that seeing is a static and distancing experience uncon-
vincing: it unjustly conflates seeing with visualization. We constantly
move our head or focus in and out when looking at something; only our
drawings and pictures solidify a particular perspective. Moreover, study-
ing one sensory modality, such as hearing, makes no sense if we fail to
acknowledge its interconnections with other sensory modalities (Ingold
2000, 2011a, b).

These remarks bring me full circle, back to the predominance of
anti-essentialist approaches with which I started this section. Those
assumptions were the starting point of the Sonic Skills project as well. We
insisted on a practice-oriented approach that keeps an eye and an ear
open for the role of tacit knowledge in the sciences and for scientists’
use of their senses as they move around in different settings. Although
several useful studies on listening in the sciences have been published,
they leave many questions open. What about the commonalities between
various strategies of listening, for instance? The role of music? The differences between professional contexts and the academic sciences? I will return to these systematic issues below. But let me first discuss our project’s selection of the case studies.

**CASES OF SOUND AND LISTENING**

To attain a better understanding of the role of the senses in knowledge dynamics, we considered it important to select a variety of sites where scientists, engineers, and physicians perform their work. Among other parameters, those sites vary in terms of public accessibility—the literature suggests a difference between the public presentation of science and what happens behind the scenes. This inspired us to choose both settings where experts are among colleagues (such as factories, laboratories, and the field), and more open environments, such as hospitals, where lay people are present, or conference halls and other venues at which scientists present their results to the wider world. This enabled us to include contexts of both professional expertise (hospital, factory) and scientific expertise (field, lab, conference). The multisite approach also allowed us to cover different phases in research and design, ranging from tinkering with technology on shop floors to trial-and-error in laboratories, from recording natural phenomena to displaying scientific data through sonification.

Our preference for particular cases within each of these sites resulted from several other considerations. One was the idea of encompassing a wide array of sonic tools: technologies that have allowed scientists, engineers, and physicians to focus on, amplify, record, or transform sound, such as listening rods in engineering, stethoscopes in medicine, tape recorders in field research, or software in sonification. Another was the wish to understand how novices acquire sonic skills, most notably in hospital settings. With Brian Kane (2015: 8), we believe that in the process of cultivating such skills, “much of the cognitive effort involved in the initial training is offloaded onto the body.” Observing the training of sonic skills before they are naturalized opens them up for analysis. This objective is akin to Thomas Porcello’s work on how studio engineers learn to understand sound (Porcello 2004) and to the work by Tom Rice and John Coltart on how medical students come to handle the stethoscope (Rice and Coltart 2006; Rice 2013). Whereas Rice and Coltart focused on the use of the stethoscope in cardiology for diagnosing heart diseases, we addressed respiratory medicine and lung diseases.
It was these considerations that largely defined our geographic scope, as we followed the clusters of scientists, engineers, and physicians chosen across Western Europe, the United States, and Australia. Our attention to local specificities responded to Michele Hilmes’s 2005 comments on early sound studies work, in which she warned against creating “a seemingly transhistorical, transcultural essentialism that is actually predicated closely on an American model” (Hilmes 2005: 258).

Based on these various concerns, we decided to focus on the listening practices of the following groups. Stefan Krebs studied engineers and mechanics in the automotive industry of Germany and France (1920s–present) and in a paper factory in the United Kingdom (1970s–present). Joeri Bruyninckx investigated ornithologists in field settings in the United States, the United Kingdom, and Germany (1920s–present), and present-day scientists in material physics and molecular biology in laboratories in the Netherlands and the United States. Melissa Van Drie asked how physicians listened, and taught medical students to listen, to their patients’ lungs in France, the United Kingdom, and the United States (1950–2010), while Anna Harris did the same for contemporary doctors and students in the Netherlands (Maastricht University Skills Lab) and Australia (Royal Melbourne Hospital Medical School). Alexandra Supper examined the listening practices of sonification experts in Western Europe and the United States who were participating in the International Community for Auditory Display (ICAD), established in 1992. Finally, I researched cross-case issues such as listening modes, the verbal expression of sound, and notation, extending the range of examples while gathering historical information on shifts in sonic skills.

For nearly all cases, we combined traditional historical methods with ethnographic observation, interviewing, and reenactment. The historical methods included archival work, oral history interviewing, and analyzing published historical sources such as scientific and trade journals, textbooks, instruction manuals, and the published memoirs of ornithologists and recordists. Our ethnographic approaches included observing scientists, engineers, mechanics, medical staff, students and sonification experts in labs, on shop floors, in hospitals, and in presentation and performance venues; studying their logbooks, making recordings, taking pictures, and carrying out in-depth, semi-structured, and qualitative interviews with them.

We also investigated how past scientists created sound recordings or employed sonic research tools by reenacting their use of historical
instruments ourselves or attending such reenactments. Work done by
our colleagues Peter Heering and Aleks Kolkowski was a source of inspi-
ration. Peter Heering is a former member of the “Oldenburg School”
in the history of science, which analyzed historical experimental prac-
tices by replicating scientific experiments from the past, greatly impro-
ing historians’ understanding of the affordances of particular tools and
why they were worthwhile for scientists and wider audiences at the time
(Heering 2008). Aleks Kolkowski is a researcher, artist, and violinist with
extensive experience in reconstructing past practices of sound record-
ing, using period technologies such as the mechanical phonograph, the
electrical phonograph, and 78 rpm gramophones. He allowed Joeri
Bruyninckx and other team members to witness him working with the
tools of early ornithological recordists. In addition, Bruyninckx experi-
enced the skills involved in using lab instruments by observing lab scien-
tists and technicians working with those instruments. Stefan Krebs visited
an old paper factory in the UK to listen to its machines together with
the operators. Melissa Van Drie worked with the audio cassettes that
had once instructed stethoscope-related skills to medical students, while
Anna Harris co-listened to body and hospital sounds along with doctors,
nurses, and students, at times employing the sounds she recorded on the
wards as an elicitation technique in her interviews (Harris 2015). And
Alexandra Supper learned to make sonifications in order to gain firsthand
experience of the interrelated skills this process required. In all these sit-
suations, we were able to reinvoke some elements of the tacit knowledge
associated with the activities, and to acquire better understanding of the
distinctions applied by the people we studied.

An example of such deeper insights in the notions used in the com-
unities examined is that one of our team members, Alexandra Supper,
learned to distinguish between several sonification techniques. One is
“audification,” or “scaling existing vibratory signals into human hear-
ing range” (Harris 2012: note 3), as when seismographic vibrations
are transformed into audible signals in order to understand and predict
the dynamics of earthquakes (Dombois 2001). Another is parameter
mapping, whereby sound parameters such as pitch, duration, loud-
ness, and timbre are controlled by the characteristics of the underlying
data. Proponents of sonification claim that the auditory display of data
is especially useful for an exploratory analysis of large, multivariate data-
sets, where certain patterns, such as variations on a time or spatial series,
may be easier to detect by ear than by eye (Baier et al. 2007; Dayé and
Despite such claims, sonification is still highly contested in the sciences, and is often treated as a form of music or sound art rather than as science proper. Indeed, techniques of sonification have also been employed by composers, occasionally in collaboration with scientists. In this sense, sonification is something of a “breaching experiment” (Garfinkel 1967), challenging taken-for-granted conventions in the sciences.

**Sensory Selectivity**

This essay’s ultimate aim is to present insights into the issue of sensory selectivity—the high value attached to specific sensory modalities or their combinations—in the production and validation of scientific and professional knowledge. Rather than proclaiming a victory of the visual in science, pleading for the emancipation of hearing at the expense of seeing, or defending a perceptual equilibrium, I will investigate when, how, and under what conditions the ear has contributed to knowledge dynamics, whether in tandem with or as an alternative to the eye. To this end, I combine a synchronic analysis of listening modes and sonic skills with a diachronic analysis of how listening practices in the sciences have developed over time. The conceptualization of listening modes and sonic skills will help to refine my historical analysis and to systematize my comparison of cases, culminating in a theory that explains the shifting relevance and legitimacy of listening practices in science, technology, and medicine.

I devote an entire chapter to the notion and relevance of modes of listening, but would already like to mention here that our project distinguished between three purposes of listening—monitory, diagnostic, and exploratory listening—and three ways of listening: analytic, synthetic, and interactive. This novel classification of listening modes in science, engineering, and medicine has been derived both from primary sources and from the still scattered secondary literature on listening in the sciences and other domains, such as radio (Douglas 1999). Some of the modes of listening, as well as the ability to switch between different modes, are enabled by particular tools and by the sonic skills that scientists, physicians, and engineers have developed to handle them. I have already defined sonic skills as the skills required for making, recording, storing, retrieving, and listening to sound. They include the skills used by scientists for representing and sharing sound, such as the skills of recording sound with help of musical notation—as early ornithologists did.
These concepts of listening modes and sonic skills helped us to systematize our comparative analysis, informing a theory of sonic skills that identifies the conditions under which particular listening modes and sonic skills, as ensembles of listening for knowledge, have been accepted or rejected as a legitimate entrance to knowledge in the sciences. Our theory gives special prominence to three conditions. The first is the timing of interventions in science, technology and medicine, and how this has been afforded by tools such as stethoscopes, recording devices, and software programs. How did these relations between science and technology (in the form of tools) affect the status of listening in science, engineering, and medicine? Did the tools enable easy switching between modes of listening, afford a quick response to urgent issues, or alter the options for comparing data? The second condition is trust and the historically generated distinctions between the sciences and the professions. Work by Andrew Abbott (1988) on how professions claim and are endowed with irreducible, exclusive expertise and Richard Sennett’s study (2008) on the significance of craft in professional work inspired us to ask why listening remained more significant in medicine and engineering than in some other contexts. In addition, Pierre Bourdieu’s (1984) eye for the role of bodily discipline in acquiring a professional habitus, and the linkages between habitus and wider social practices, has helped us to understand the use of the stethoscope in both the world of doctors and the world of the engineers who tried to copy doctors. The third condition is the growing need for public accountability of science, and thus a shift in the relations between science and society. What does this imply for the position of music in the sciences, for instance? How did the putative links between sonic skills and musical abilities—such as the ability to notice and record differences in pitch, rhythm, or timbre—affect the acceptability of listening practices in science, technology, and medicine? Alexandra Hui has shown how in mid-nineteenth-century German and Austrian psychophysical research on the sensation of sound, musical skills were regarded as scientific skills. Yet by the end of that century, “the value of musical skill had become contested” among the researchers involved (Hui 2013: 145). Did this devaluation of musical skills in knowledge making continue in the twentieth and twenty-first century? If so, what should we make of scientists’ eagerness to reach out to wider audiences by bringing sound and music into the equation?

The answer to this last question may clarify why the science journalist cited at the outset of this chapter chose to refer to the sounds of
the super ocean deep in the earth, even though the scientists who actually published on the topic had been watching graphs of vibrations. Exploring such issues will help me to build a theory that distinguishes not only between synchronic listening modes and sonic skills, but also between diachronically changing relationships of science and technology, science and professions, and science and society—one that explains the shifting legitimacy of listening for knowledge and the changing ensembles of sonic skills in the sciences. All this will be brought together in the final chapter. First, though, in Chapter 2, I analyze how scientists, physicians, and engineers employed, talked about, and transcribed sound—issues that also allow me to introduce most of our case studies in more detail. Chapter 3 proceeds with a discussion of listening modes in the sciences. The argument then moves from a synchronic to a more diachronic perspective, as Chapter 4 analyzes the shifting conditions that explain why listening for knowledge has so often been contested, and Chapter 5 asks why listening nevertheless kept returning in the sciences.

Notes

1. Radio1, VARA, *De Nieuws BV*, July 11, 2014, available at http://www.denieuwsbv.nl/Singleview.12722.0.html?tx_ttnews%5Btt_news%5D=121545&cHash=9450eb67a786024bc91133b11557b309 (last accessed February 12, 2015). The group of scientists was led by geologist Steven Jacobsen from Northwestern University, Evanston, Illinois. The mineral rock was ringwoodite, and the water had been located at a depth between 410 and 660 km below the earth’s surface (see also Coghlan 2014; Schmandt et al. 2014).

2. Spectrograms, or sound spectrograms, are three-dimensional graphs representing sound across time. Time is displayed horizontally (on the x-axis), the spectrum of frequencies is presented vertically (on the y-axis), and the sound’s intensity is expressed as shades of gray. Frequency and intensity refer to the acoustic properties of sound, whereas pitch and loudness refer to the perception of these properties by humans. In the early years of the sound spectrograph, the terms *spectrogram* and *sonogram* were almost interchangeable. At times, sonogram was used for specific spectrograms, such as speech sonograms or bird sonograms. Today, the term sonogram is most commonly used for medical ultrasound images.

3. For the use of acoustic technologies in the monitoring of dikes, see http://www.dijkmonitoring.nl/index.php/dijkmonitoring-keuzetool/
4. Geophones were employed to listen to the sounds of underground activities. These instruments resembled stethoscopes, but had microphone membranes to record the sounds and cable connections to transmit them (Encke 2006: 120). On other military listening devices created in World War I, see Rawlinson (1923: 112 and 103–120), Hoffmann (1994: 268), Volmar (2012, 2014), and Bruton and Gooday (2016a). Elizabeth Bruton and Graeme Gooday (2016b) specifically discuss listening to submarines. For listening during land-based combat, see Lethen (2000) and Schirrmacher (2016); in tunnels and trenches, see Encke (2006); and for air defense, see Judkins (2016). On acoustic mirrors for air defense in the interwar years, see Scarth (1999), Van der Voort and Aarts (2009) and, again, Judkins (2016). On the history of active sonar, see Hackmann (1984).

5. The relevance of these questions has also been mentioned in the Oxford Handbook of Sound Studies, edited by Trevor Pinch and Karin Bijsterveld (2012: 11–12).

6. See, for instance, https://www.youtube.com/watch?v=9JDhEwMS_U5 (last accessed March 16, 2015).

7. See the Sonic Skills Project Website, http://fasos-research.nl/sonic-skills/, and the virtual version of the Sonic Skills Exhibition, at http://exhibition.sonicskills.org/ (both last accessed March 30, 2017).

8. Bijsterveld, Karin (2009). Sonic Skills: Sound and Listening in the Development of Science, Technology and Medicine (1920 to now). Grant Proposal, Netherlands Organisation for Scientific Research. Short version available at http://www.nwo.nl/en/research-and-results/research-projects/95/2300157595.html (last accessed March 16, 2015).

9. For anthropologist Stephen A. Tyler, in contrast, the defining moment for the “hegemony of the visual as a means of knowing/thinking” in the West is not the rise of print, but the rise of literacy (Tyler 1984: 23). Writing itself is a kinetic action, but one that ultimately reduces speech to a thing seen, “freezing thought in visible form” (Tyler 1984: 33). That is why, in Tyler’s argument, the diffusion of literacy has pushed aside the use of verbal metaphor for thinking and knowing (“I say to myself” for “I think”) in favor of visual metaphor (“I see” for “I understand”).

10. For other work on how gestures contribute to the articulation of images, see Katja Mayer (2011) on node-edge sociograms and Morana Alac (2014) on functional Magnetic Resonance Imaging (fMRI).
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