

Testing Hearing

An Introduction

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Just before midnight on October 16, 2014, Times Square became a testing room, its scrolling digital billboards hijacked by Japanese sound artist Ryoji Ikeda's flickering barcodes, pixels, scan lines, and electronic snow. *test pattern [times square]* was billed as a “silent concert” in “one of the busiest and craziest areas in New York.”¹ Watching the twitching black-and-white screens, audience members wore wireless headphones and listened, individually, to a synchronized composition made up of the microsounds for which Ikeda is famous: chirping pulses, bursts of white noise, signal patter, circuit fry.² The multimedia installation opened with a single tone that swung dramatically upward in pitch until it exceeded the threshold of human hearing. This gesture referenced *Imaginary Landscape no. 1*, the pioneering electroacoustic work in which John Cage played a Victor tone record, generally used to calibrate instruments and room acoustics, at increasing speed to skew its frequency. Flipping Cage's conceit on its head, Ikeda took test sounds that had been turned into music (provocatively—this was Cage, after all) and turned them back into a test.

Ikeda's composition denaturalizes the homologous sounds of hearing tests and machine signaling, which have become increasingly familiar since the early twentieth century. *test pattern* calls the parameters of such tests into question: What sort of hearing function does a tone test? What is the boundary between “pure” tones and pulses of interference? In what ways do reference tones adjust and standardize listeners as well as calibrate equipment? Ikeda expands our understanding of when and where testing takes place, underscoring the ubiquity of the test as a modern form of knowledge-making. He reminds us that testing does not leave its subjects and objects of study unchanged—the plastic sleeve of the first *test pattern* album carried a warning sticker: “Caution! This CD contains specific waveform, impulse and burst data that perform a response test for loudspeakers and headphones. High volume listening of the last track may cause damage to equipment and

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eardrums.”³ Testing hearing can lead to injury, new medical diagnoses, and reconfigured social classifications.

test pattern invokes the entanglement of music, industrial sounds, and scientific disciplines that is central to *Testing Hearing: The Making of Modern Aurality*. The modern cultural practices of hearing and testing have emerged from a long interrelationship. Since the early nineteenth century, auditory test tools (whether organ pipes or electronic tone generators) and the results of hearing tests have fed back into instrument calibration, human training, architecture, and the creation of new musical sounds.⁴ Whether employed to detect impairment or skill, hearing tests proliferated alongside new sound-making and audiometric devices, as well as the professionalization of otology and deaf education in the nineteenth century. Hearing tests received a further boost around 1900 as a result of injury compensation laws and state and professional demands for aptitude testing in schools, conservatories, the military, and other fields. Applied on a large scale, tests of seemingly small measure—of auditory acuity, of hearing range—helped redefine the modern concept of hearing as such. During the twentieth and twenty-first centuries, the epistemic function of hearing expanded. Hearing took on the dual role of test object and test instrument; in the latter case, human hearing became a gauge by which to evaluate or regulate materials, nonhuman organisms, equipment, and technological systems. The present volume considers both the testing of hearing and testing *with* hearing to explore the co-creation of modern epistemic and auditory cultures—indeed, the creation of modern aurality.

On Tests and Testing

The dual character of testing hearing derives from two overlapping etymologies that have yielded slightly different meanings in the long history of “testing.”⁵ The first is *testifying*, that is, the witnessing of a particular event. In this context, the terms “test” and “experiment” have been used interchangeably since the early modern period to indicate the testing of philosophical propositions, beliefs, and opinions. In canonical accounts of the modern scientific method, hypotheses must also be tested, either through rhetorical persuasion or through observation, data collection, or experiment.⁶ Here, tests cannot be performed alone. They require the testimony of eyewitnesses or the “virtual witnesses” produced with the assistance of scientific writings and illustrations, and they often need to be repeated to establish validity.⁷ The second etymology of testing is linked to “teste” (Lat. *testum* = pot, vessel). In the fourteenth century, this word was used in alchemical experiments to mean

the cupel in which gold and silver were treated at high temperatures. Since the seventeenth century, “putting something to the test” has signified the examination of a wide range of substances, technologies, and emotional, physical, and mental states. This line of testing analyzes objects to identify elements, compares attributes to predefined benchmarks and norms, or delegates test subjects to stand in for a wider heterogeneous set. While these two etymologies are entangled, it is our contention that the latter has steadily expanded in significance in the modern era.

Over the last two centuries, applications of testing have circulated throughout the sciences and beyond. We find four significant shifts within the trajectory of testing as “teste.” First, tests are no longer simply applied to objects, but also produce knowledge about human and other animal subjects. Second, new forms of tests, combined with new statistical approaches and computational technologies, have facilitated an expansion of testing to broad cohorts and populations. Third, the ambit of testing has extended from the evaluation of physical properties to also include functional qualities of materials, living beings, technological systems, urban infrastructures, and outdoor spaces. In the extension of testing to functional qualities, it is evident that tests carry epistemological power. In modern electrical engineering, for instance, “black box” testing arose as a means to study the outputs of complex, massive, or unknown apparatuses based solely on inputs. The “black box” rapidly disseminated as a metaphor and tool for understanding such disparate phenomena as telephone lines, animal behavior, and human neurology.⁸ Here tests serve, fourth, as a means to examine areas of knowledge beyond human physical and perceptual reach.

These shifts redefine what qualifies as a test subject, as well as the potential contributions of these subjects (distinct from experimental ones) to the co-construction of knowledge. Everyone and everything can now be put to the test—whether by epistemological, industrial, artistic, or other cultural forces. This volume argues that testing as such became an enduring and wide-ranging social practice in the modern period. Individuals engage with tests from the moment they are born. Tests are built into daily lives with astonishing pervasiveness. Testing is a “cultural technique,” comparable to other key techniques such as writing, reading, painting, experimenting, seafaring, and filtering.⁹

Tests in the History of Science and Technology

Tests have until now mostly been regarded as the “boring” part of science—unchanging and without a history. Yet much as historians of science have shown for the ubiquitous “experiment,” the various forms of scientific testing

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also transformed or consolidated the definition of the object under investigation.¹⁰ And, while recent scholarship has shown experiments on music and sound to be flexible, with the same experiments being employed in more than one context (in the sciences, instrument making, musical performances),¹¹ tests have an even broader field of application. Accordingly, many modern tests are as significant for everyday life as they are for scientific and technological developments. (For more on the relation between tests and experiments, see the “Afterword” by Hans-Jörg Rheinberger.)

This volume shows that tests prompted the development of new scientific disciplines such as psychophysics, applied psychology, audiology, food science, and more. At the same time, new techniques of testing—for example, tests of threshold, just noticeable difference, range, and reaction time—arose across multiple disciplines, including but not limited to physiology, psychology, empirical aesthetics, and neuroscience. Some researchers accentuated minute individual differences and the inevitability of human limitations (“personal equations”), whereas others incorporated statistical data into broad categorizations of the normal and the pathological. Further, in their uneven efforts to quantify perception, both the practitioners and subjects of tests participated in the development of new standards of objectivity. As astronomers and other scientists pursued mechanical objectivity, for example, they sought to understand and minimize their own individual differences in observation; for the same reason, they also began to test the wide range of timing and precision in sensory responses.¹²

Indeed, as several chapters in *Testing Hearing: The Making of Modern Aurality* show, tests contributed to new forms of scientific objectivity altogether. The testing of human and nonhuman ears, in particular, prompted the invention of numerous means to standardize test procedures and render test subjects comparable. Testing became equally important for mass production and the administration of the social welfare state. Yet when applied in new contexts, by different people, and over longer time periods, tests undergo modification. Each of the historical cases discussed in this volume reveals how hearing tests proliferated and iterated in unanticipated ways, sometimes pushing against standardization or uncovering messy subjective experiences. Much in line with recent scholarship on scientific objectivity, we may say that objectivity has been a constant but moving target in the history of testing.¹³

Many tests applied in everyday life originated in the sciences, and they still bear the traces of experimental investigation. Some forms of test, however, entail observation, data collection, and inference from real-world events rather than modeling or experimentation. In these cases, the world is the testbed. As new building materials, technologies, and large technical systems emerged in

the modern period, testing codeveloped with these new fields of application. Testing started to play a major role during the planning phase of the applied sciences and the expansion of the modern state. Materials testing offices were founded, alongside national bureaus of standards, to facilitate building design, urban planning, technical engineering, and the food industry. Quality control testing emerged in the early twentieth century as a statistical method for setting minimum standards in mass manufacturing, with components and products sampled to monitor the production process. Testing now occurs at every stage of technical development, from design to manufacturing, marketing, maintenance, safety, and forensic analysis. In some cases, mathematical or physical models substitute for the direct testing of the thing under investigation. In engineering, testing often entails optimizing technology in comparison to a prototype or in conjunction with a human “user.” Test images, for example, enable the calibration of television and other electronic screens according to human visual function; test tones calibrate volume and pitch response for the audio signal.

Intelligence tests of humans and machines, genetic tests, clinical trials, newborn screens, test tubes, litmus tests, model organisms, and drug tests pervade the history and anthropology of science, though they have yet to receive comprehensive analysis. Everything has been rendered testable, such that tests are now central tools for planning and regulation across all possible fields. And whereas scientific experiments have largely been investigated in relation to inscription and visualization, the history of testing is decidedly multisensory.¹⁴ For instance, as engineers employ black box testing to grasp the workings of complex technological systems, psychologists apply aural and visual projective tests to similar ends with humans. Moreover, psychological tests are applied for widely disparate purposes, whether to diagnose disorders, demonstrate “occupational aptitude,” or evoke imaginative responses. This wide-ranging applicability is what allows tests to be taken from the industrial laboratory to the classroom, to the concert hall, to the radio broadcast, or from an aquarium to a nuclear submarine. As science has moved beyond the walls of the laboratory, so have tests. They are mobile, but they are not immutable. Tests are materialized networks: they are the manifestation of practices, ideas, values, and institutions.

Testing therefore serves as a political technology. The rise of the social sciences around the turn of the twentieth century relied heavily on the use of testing to establish both scientific and political credibility. It can be said that testing *was* experimentation for the social and human sciences. This suggests—once again—that the test holds substantial political weight. Tests produce numbers and other data, setting standards for scientific, industrial,

and educational policies. They are attempts to make the incomparable comparable. Testing calibrates, disciplines, and normalizes individuals, groups, populations, materials, and technologies. It is also a social practice that requires skilled testers and testees. From this perspective, the historical meaning of testing as witnessing gains new significance: testing enables individuals, groups, populations, materials, setups, and technologies to generate and practice a form of self-witnessing. Furthermore, the category of the “test subject” confers cohort status on a population with one or more testable features. As such, tests gave birth to the modern individual, who can also serve as a representative of the larger unit.

By declaring that the history of testing remains undertheorized, we certainly do not wish to imply that there has been no work on testing at all. We draw on several existing disciplinary clusters as a background for our project, perhaps most prominently the biopolitics of testing. In the wake of Foucault’s writings on biopolitics and governmentality, a number of studies have focused on the history of testing populations in medical, psychological, and educational institutions.¹⁵ Tests that compare individuals to statistical norms, these argue, define therapeutic resources and “create social categories (of ‘learning-disabled’ children, ‘high-risk’ employees) in order to preserve existing social arrangements.”¹⁶ In the medical sciences, where tests were originally diagnostic tools, they have over the last two centuries been used for both prognosis and prevention. New “screening” tests evaluate seemingly healthy subjects to estimate risk, detect presymptomatic disorders, or establish carrier status for genetic conditions. Governments screen their citizens for a wide variety of abilities and impairments. Cancer testing has differentiated into the stages of screening, diagnosis, carrier testing, and monitoring. Tests are also “gatekeepers, controlling access to employment, hospitals, and schools, and allowing organizations to shape their clients as a projection of their own economic and administrative needs.”¹⁷ Clinical trials in medicine, another site where testing and experimenting converge, entail rigorous protocols to weigh the efficacy and safety of substances in relation to living bodies; the accurate interpretation of such tests also requires the existence of a non-tested randomized control group. These trials are often performed on a global scale, where test subjects in postcolonial settings assume bodily risks as delegates for health care consumers elsewhere.¹⁸

Additionally, several publications in science and technology studies (STS) have addressed the testing of technology since the 1980s (for a review of the STS literature on testing, see Trevor Pinch in this volume). Rather than emphasizing the power of tests to identify, classify, confirm or falsify, and regulate, these studies have largely equated testing systems with experimental

systems. STS scholars have surveyed “testing traditions.”¹⁹ They have revealed entanglements between test and context, coined the term “projective testing” to describe comparison tests of new technologies being introduced to the market, and examined the historical formation of test juries and test settings.²⁰ In our view, this literature needs to be expanded through a more substantial and systematic engagement with the history of testing and its epistemic power. A closer look at the structures and agency of test systems, test sites, and transitions—from tests of objects to the testing of subjects and vice versa—provides new insight into large-scale technical control and prediction after industrialization. Reaching beyond the contrast between tests and experiments, we take tests to be not only disciplining, normalizing, or objectifying tools but also indices of complex epistemic dynamics and of disciplinary negotiations between the natural sciences, social sciences, humanities, arts, and industry.

Testing Hearing in and Beyond Audiometry

The testing of hearing proves to be one of the richest sites for historical inquiry into the epistemic power of tests. The education of speaking and hearing citizens, the development of telecommunications tools, and the optimization of public spaces and multimedia arts encouraged the proliferation of hearing tests as well as the invention of new procedures such as screening. The modern scientific and popular understanding of hearing—and the practice of hearing itself, reinforced through standardization and training—codeveloped with such testing. Hearing no longer exists without audiometry. Most obviously related to this volume’s theme is thus the historical arc of audiology, a topic on which otologists have produced a handful of internal studies.²¹ *Testing Hearing: The Making of Modern Aurality* builds on—and complicates—this literature. We extend the canonical narrative of the long history of audiometry into the twentieth and twenty-first centuries, querying rather than accepting as transparent and progressive the role of testing itself. (Most of the tests mentioned in this brief survey, and throughout the volume, can be accessed on the database “Sound & Science: Digital Histories,” <https://acoustics.mpiwg-berlin.mpg.de/sets/clusters/testing-hearing>.)

In Western medical history, diagnoses of hearing impairments go back at least to Hippocrates, although the earliest documented hearing tests only commence in the sixteenth century. Particularly prominent in the early period were tests of hearing through bone conduction, which made use of a rod held between the teeth and attached to a sound source.²² Through bone

conduction, it was possible to distinguish disorders of the eardrum from those of the nerves. Experiments on bone conduction hearing using tuning forks were later perfected and theorized by nineteenth-century physiologists, most notably Ernst Heinrich Weber in 1834 with his “Weber test” (using a fork placed on the forehead) and Heinrich Adolf Rinne in 1852 with the “Rinne test” (using a fork held beside the ear).²³ After 1864, testers used electric tuning forks that produced a pure tone series.²⁴

From the eighteenth century onward, hearing tests also addressed auditory acuity (the level of loudness of standard frequencies). This was initially done by placing ticking clocks at different distances from the listener; subsequent testers employed instruments including the “acoumeter” designed by Christian Heinrich Wolke, a language educator from northern Germany. Physicists and physiologists in this period also began to perform long series of experiments on the range of hearing (pitch levels) and the perception of minimal tone differences. These started with experiments using organ pipes and vibrating strings and were followed by experiments with loosely stretched strings; tuning forks, pipes, chirping crickets, and singing sparrows; sounding rods and the toothed wheel; a whistle adjusted by a micrometer screw; and, at the end of the nineteenth century, the first sets combining tuning forks, closed pipes, and Galton whistles to measure “continuous scales.”²⁵ Forming a feedback loop of sorts, acoustic properties—the power and frequency of individual tones, or loudness and pitch, measured and controlled using tuning forks, whistles, sirens, and sounding rods—dominated scientific understanding of the function of hearing in the late nineteenth century.

The same period also saw the development of instruments and methods to test more specific hearing abilities, such as the hearing of speech—that is, the perception of vowels and consonants. These included the Helmholtz tuning forks, von Kempelen speaking machines, and Appunn overtone apparatus.²⁶ Speech sounds also began to be analyzed for their suitability as testing tools. Drawing on the results, European physicians in the nineteenth century tried a number of schemes to measure hearing for speech: comparing the recognition of vowels and consonants; arranging phonemes by pitch, with fricatives in the highest range; and employing whispered speech to minimize the unique fundamental frequency of a speaker’s voice and thus pinpoint the “invariables” of each phoneme. By the late twentieth century, the extent of the challenge would become apparent to engineers developing machine listening systems and automatic speech recognition technology.²⁷

These tests of auditory acuity (loudness level), hearing range (pitch level), and speech perception grew out of an increasing interest among physiologists

and physicists in the capacities of human hearing, possible medical cures for disorders of the ear, and the development of measuring technologies and hearing aids. Over the course of the nineteenth century, studies of the perception of sound shifted from physiological and acoustic approaches to psychological frameworks—hearing tests reinforced existing epistemologies but also generated new ones. Pertinent topics of study included tests of “perfect pitch,” sensitivity to loudness or frequency, and the determination of cross-perceptual thresholds (e.g., the audiotactile interface). In turn, those tests relied on particular modes of defining and representing hearing ranges, from descriptive accounts to statistical graphics. If human hearing had long been conceptualized in terms of subjective *qualities* such as loudness or timbre, the establishment of psychophysics and related subfields in the nineteenth century spurred the *quantification* of this subjective experience, via the correlation of physical stimuli to sensation; moreover, hearing began to be approached as a continuum.²⁸

That shift marks the beginning of the period covered in *Testing Hearing: The Making of Modern Aurality*, one accompanied by the scientific and humanistic design of increasingly specific hearing tests for the arts, education and communication, colonial and military applications, or sociopolitical and industrial endeavors. Key among these contexts was music (see Alexander Rehding, Emily Dolan, Viktoria Tkaczyk, Sebastian Klotz, and Benjamin Steege in this volume). In the eighteenth and nineteenth centuries, audiology embodied the aesthetics of bourgeois Western musical culture.²⁹ For one thing, the principal tools for testing hearing perception came from music and musical instrument making: violin strings, tuning forks, metronomes, whistles, overtone apparatuses, and all sorts of musical devices.³⁰ New forms of cooperation between instrument builders and physiologists facilitated the design of increasingly specific testing tools. Here, the tools themselves were as much test objects as was the human ear. Most significantly, hearing tests required not only test subjects but also skilled testers whose competence in making and using particular musical instruments determined the validity of the test results.³¹ Structurally, testing procedures were thus initially derived from both musical instrument construction and physiological experimental practice: the capacity of the human ear was determined experimentally, after which laboratory experiments were reconstructed and applied to larger numbers of subjects in the form of medical tests outside the laboratory. Musical technologies informed the early parameters by which hearing was defined, the boundaries of the ear’s capacities, and the paradigm of “normal hearing.” Tests of hearing capacities also served as a basis of comparison in cross-cultural anthropological studies, most prominently in colonial expeditions.

In their pursuit of applications for hearing tests, investigators in the late nineteenth century recognized that their findings depended on the choice of test instruments, test subjects, testers, test procedures, and test locations. As a result, hearing tests were now considered valid only if applied to larger groups, in batteries of tests, and in different localities so as to objectively collect statistics and determine averages. In the same period, the rise of national and cross-cultural statistical surveys changed the stakes of these tests, which were conducted at larger scales to differentiate and reveal the distribution of human hearing capacities, sorting broad cohorts and populations as well as individuals.

To some extent, the history of hearing tests follows the seemingly ineluctable Foucauldian narrative of testing: testing establishes thresholds and statistical norms, which are incorporated into clinical or classroom tests and used to diagnose individuals. People found to be deviant from the norm are then treated or otherwise “disciplined.”³² Yet the ear has been more than merely the dependent variable in the history of hearing tests, the object being assessed. The ear and its technological delegates are also themselves test tools for the evaluation of objects, technologies, spaces, and large-scale systems. Building materials are evaluated based on models of human hearing; noise meters for managing public spaces incorporate standards based on loudness thresholds. Acoustic equipment is now constantly tested via calibration: in the laboratory, in the field, in the recording studio, and on the performance stage. The components of this equipment, if mass-produced, undergo quality testing at each stage of the manufacturing process (see Mara Mills and Roland Wittje in this volume). Such procedures are situated within the narrative of quality control more generally.

In the twentieth century, the field of acoustics underwent a paradigm shift, with electrical tools and metaphors supplanting musical ones.³³ Industrial research, largely conducted in telecommunications laboratories, reworked musical approaches with precision electronic instruments for pure-tone audiometry, substituted electrical metaphors for the anatomy and physiology of the ear, and asked new questions about hearing related to the ideals of transmission. The electroacoustic industry further gave rise to new tools and components such as the microphone, the vacuum tube amplifier, and the electrical filter, created and applied in an entangled context of science, music, and industry. At the same time, standards—measuring units, average thresholds, maximum allowable amplification—codified, embodied, or defined musical, scientific, and industrial values (see Jennifer Hsieh and Joeri Bruyninckx in this volume). Data from hearing tests are thus fed back not only to manage bodies but also to design objects, most obviously in the fields of music and

the electroacoustic industry, where hearing and listening preferences are used strategically in the creation of new buildings and environments, sounds and devices, and public policy. Hearing norms are built into all manner of audio apparatus, from telephones to stereo speakers (see Stefan Krebs and Jonathan Sterne in this volume).

Beyond audiometry, this anthology maps proliferating modes of testing across the twentieth century. As new testing procedures have appeared in the sciences and social sciences—the double-blind, the questionnaire, the software simulation, the market factors poll—they have quickly been deployed to test hearing. In some cases, hearing tests led the way in the development of these procedures. Classroom hearing tests, as an example, were among the first large-scale “screens” for medical impairments. Musical listening surveys and aptitude tests evaluated taste and learning as well as capacity; these tested music itself as well as the ears of workers, soldiers, marine biologists, and many other professionals (see Lino Camprubí and Alexandra Hui in this volume). New forms of tests, combined with new statistical approaches and large arrays of testing devices, facilitated an expansion of testing to particular musical skills, provoking aesthetic debates in academia and in musical praxis. In turn, human hearing capacities were tested via the arts, most especially experimental music, avant-garde art, sound film, and sound design.

A Guide to Testing Hearing: The Making of Modern Aurality

This volume amplifies the fundamental features, or problematics, of the double function of testing hearing—the human ear as periphery, measured by musical, industrial, or military modalities, and the ear as center, the human factor used in the testing of materials or the design of objects at times not even intended for humans. It argues that both hearing tests and testing with hearing had an enormous influence on the creation, maintenance, and destruction of auditory and broader epistemic cultures in the modern period.

Testing Hearing: The Making of Modern Aurality grew out of two conferences convened in 2015 and 2016 at the Max Planck Institute for the History of Science in Berlin. The essays are grouped thematically rather than chronologically to highlight submerged continuities and overt conflicts. Each chapter brings in a substantial case study (building on expertise in musicology, history of science, media studies, STS, and anthropology) to illuminate one of the four themes of the volume: “Testing the Culturally Molded Ear,” “Designing Instruments, Calibrating Machines,” “Managing Sound, Assessing Space,” and

“Testing Beyond Human Auditory Perception.” Together, the four sections respond to the reconfiguration of test subjects in the modern period and underscore the role of hearing in that process of reconfiguration. Understanding testing as a cultural technique allows us to trace negotiations between the sciences, music, and industry, all of which have undergone rapid but not necessarily linear change in the period covered by the authors, 1870 to the present. Arranging the contributions outside of time also foregrounds place, revealing relationships between local and transnational developments. Together, the contributions trace the contours of the political power of testing hearing, its invisible (but very audible) shaping and reshaping of the soundscape of modernity. The two codas offer a synthetic overview of the contributions as well as extended discussions on the volume’s contribution to historical epistemology (Rheinberger) and to the history of the testing sciences (Pinch). If readers intend to skip and skim, we encourage them to start with these concluding pieces.

Testing Hearing: The Making of Modern Aurality opens with human hearing as an object of testing. In the section “Sorting and Screening Human Hearers: Testing the Culturally Molded Ear,” contributors examine the ways in which hearing tests normalized, standardized, and obscured specific understandings of hearing and, by extension, reinforced the exclusion of specific communities. One such case is that of the resistance among some physicians and engineers to pure-tone audiometry as the principal measure of hearing function, examined by Mara Mills. In her study of researchers at American Telephone and Telegraph (AT&T) in the interwar period, Mills argues that their interest in establishing a measure for “useful” or “serviceable” hearing, which they identified with speech perception, was part of a broader quality control program for the expanding telephone system. The word and sentence lists they developed to test hearing not only became the standard for testing electroacoustic equipment but were also adopted by the medical field of speech audiometry. They were, however, *partial* with respect to hearing function, in both senses of the term: limited and biased. From a related perspective, Viktoria Tkaczyk’s examination of the new audiological testing procedures developed by the German tone psychologist and comparative musicologist Otto Abraham shows how musical aptitude tests originated in what was starting to be called the “nature versus nurture” debate among psychologists. Abraham’s tests marked a transition from testing hearing in the laboratory to statistical inquiries in everyday life, and from test design in the natural sciences to alternative testing practices in the emerging applied human sciences. Sebastian Klotz explores the history of cross-cultural hearing tests in the case of the Cambridge Anthropological Expedition to Torres Straits

(CAETS), a key endeavor in the formative years of British anthropology. The British experimenters' hearing acuity tests (presumed to measure intelligence) proved inconclusive, perhaps for the first time fully exposing the problematic relationship between biological difference and cultural relativism that permeated the discipline.

In "Designing Instruments, Calibrating Machines," the contributors emphasize device testing and design, analyzing the constraints placed on musical aesthetic systems by the inertia of tradition, the limitations of human perception, and the goals of industry and materials science. Emily Dolan examines public hearing tests to distinguish between old and new violins, revealing a positive feedback loop whereby new instruments are judged against old ones—which have, in turn, been updated to meet new standards of playing. She proposes that the violin can thus be regarded as a "mendacious technology": an instrument that lies about its own much-praised historicity. Similarly, the nineteenth-century sirens investigated by Alexander Rehding imitated the sirens of Greek mythology. The German tax collector and amateur astronomer Friedrich Wilhelm Opelt proposed an ambitious new music theory that unified major musical parameters—rhythm, pitch, and harmony—based on his redesign of Baron Charles Cagniard de la Tour's siren. In Opelt's hands, the sound-producing device became a test instrument that probed the limits of human hearing and is best described as "proto-digital." A contrasting case is the "analog modeling" software for musicians discussed by Jonathan Sterne. Many music technology companies have sought to reproduce the sonic signature of analog audio devices—amplifiers, compressors, signal processors, instruments—in the software domain. This is a classic case of remediation, where a new media form attempts to represent an older one, as well as of commodity fetishism. Sterne shows that analog modeling in the digital domain is one of the latest chapters in the long history of hearing tests, for it is at the moment of the listening test that engineers and users attempt to resolve competing epistemologies of sound.

The third theme addressed by the volume, "Managing Sound, Assessing Space," complements the previous sections on music and human hearing by turning to materials science, institutions, and standards. The three contributions make it clear that the tests performed in materials development, technological innovation, and the machinations of the state are all simultaneously tests of sensory perceptual systems. Indeed, they test—and renegotiate—the very boundaries of the hearing sense according to particular value systems. The chapters illustrate the tensions that arise as tools and standards for testing hearing disseminate across fields (music, science, industry) as well as national contexts. Exemplary in this respect is the application of Western

technologies of noise control in Taiwan from the 1960s to the present—the period of political transition from an authoritarian regime to a democratic state—as examined by Jennifer Hsieh. Beginning as a state promise to provide the public with a quieter, more civilized way of life, noise control soon became dominated by an inflexible technorational approach to noise that did not correspond well to human-perceived loudness. As residents call civic hotlines and interrogate the definition of noise, we see how individual perceptual judgments can, through noise abatement testing, be transferred to the state. Stefan Krebs compares three interdependent German research groups that began designing dummy heads for concert hall acoustics, research on sound localization, and binaural hearing aids in 1967. All three groups struggled to find reliable and reproducible methods for measuring the subjective experience of spatial hearing. The resulting dummy-head systems (artificial hearing testees) failed to represent an average human listener, yet facilitated the design of new spatial audio technology for displaced listening scenarios such as radio and the music recording industry. A closer look at by-products of testing procedures reveals that, not unlike experiments, tests may develop a life of their own and lead to unexpected scientific insights, technological invention, social dynamics, and aesthetic change. Roland Wittje's contribution examines the acoustic laboratory of Norges Tekniske Høgskole (NTH) in Trondheim, Norway, established in the late 1920s to test and certify construction materials. Such testing was mainly the domain of mechanical and civil engineering, but the acoustic testing of the materials was performed by physicists and electrical engineers, who built much of the measurement technology themselves to measure parameters of absorption, transmission, and reflection, and, ultimately if not entirely deliberately, produced new insights in oscillation research.

The final section of the volume examines the testing of nonhuman, or posthuman, hearing. In "World as Testbed: Testing Beyond Human Auditory Perception," the sounds are silent to human ears but exceedingly—existentially, even—meaningful. Joeri Bruyninckx asks how experimental psychologists in the 1930s and 1940s built on techniques for testing human hearing to determine the absolute upper frequencies of hearing for other mammal subjects. The ultrasonic domains of animal auditory perception (outside that of man) began to take on lives of their own. Propelled by various scientific, military, and commercial interests, fascination with the ultrasonic stirred imaginaries of sonic control. Lino Camprubí and Alexandra Hui's contribution examines another soundscape exclusive of human auditory perception, at least until the exigencies of nuclear war fueled the development of new listening practices. In the oceanic soundscape, marine life was defined relative to Soviet vessels

and was approached through an epistemology of error that would later, through negotiation with marine bioacousticians, become scientific knowledge. The development, standardization, and classification of both sounds and hearing practices under the water's surface thus provide a continuity between the secret search for errors and the open practice of marine biology. The case-study contributions to the volume conclude with the blast of nuclear weapons testing and a strange new sensory phenomenology. Benjamin Steege discusses anthropologist Günther Anders's response to the devastating human and environmental impact of U.S. nuclear testing in the mid-1950s. Where the fact of worldhood was being put to the test, Anders provocatively called for a "test" of the capacity for imagination through desperate acts of aesthetic listening and sober exercises in "techniques of feeling," an ethically naive and philosophically suggestive form of hearing as redemption.

Together, the contributions to *Testing Hearing: The Making of Modern Aurality* illustrate the variety of tests as well as the multiplicity of meanings that surround testing. Readers will recognize the consistently central role of science (from audiology to acoustics and sound engineering, architecture and urban planning, bioacoustics and marine biology, and anthropology and critical theory), music (from instrument making to the creation and provocation of new or old aesthetics, listening skills, and habits), and industry (from fledgling form to international conglomerates engaged in materials, technology, or music manufacture) in testing hearing during the modern period. As this volume demonstrates, a single test can have multiple uses and be reapplied again and again in different contexts. To test the senses is to traffic between the physical, the physiological, and the psychological; testing hearing thus attempts to make the untestable testable and the incommensurable commensurable.

A chronological reading of the stories told in this volume (as indicated in the previous section) would reveal that pivot points in the larger narrative of testing hearing occurred with the introduction of statistical thinking, recording technology, national standards, safety and quality regulations, and electrical control of sound. Some objects, anxieties, and, of course, sounds reappear across the contributions, often in unexpected places. Readers should keep their ears open for Dalton's whistle, Seashore's test of musical skill, the whine of the siren, the creatures of the sea. Concerns about the representation and communication of sound on paper or through other sounds also recur. The fidelity or authenticity of sound is, as always, a nagging problem for those creating sound objects and technologies. Also woven through all of the contributions is a thematic thread of the construction of norms. Forms of hearing were normalized and, at times, standardized. Tests too were

normalized and then applied to new and different epistemic problems, often with curious results. Hearing tests, we argue, have not only redefined modern hearing but have also altered the very meaning of “the test” and the academic fields from which they emerged.

Further materials related to this chapter can be found in the database “Sound & Science: Digital Histories”: <https://acoustics.mpiwg-berlin.mpg.de/sets/clusters/testing-hearing/introduction-hui-mills-tkaczyk>.

Notes

1. Lori Zimmer, “Experience Times Square.”
2. A video rendition of the *test pattern [times square]* can be found at Streaming Museum, <http://streamingmuseum.org/ryoji-ikeda-test-pattern-times-square/>. Between 2:23 and 2:25, two quick flashes of audience members wearing wireless headphones can be seen.
3. <https://www.discogs.com/Ryoji-Ikeda-Test-Pattern/release/1275360>.
4. Of the many works on aurality, Veit Erlmann’s *Reason and Resonance* and Ana María Ochoa Gautier’s *Aurality* cover a similar time span to our own.
5. Oxford English Dictionary, s.v. “test (n. 1),” accessed October 7, 2019, <https://www.oed.com/view/Entry/199677?result=1&rskey=7nKwTY&>.
6. See E. Bright Wilson, *Introduction to Scientific Research*.
7. Steven Shapin, “Pump and Circumstance,” 481.
8. W. Ross Ashby, *Introduction to Cybernetics*, ch. 6.
9. Bernhard Siegert, *Cultural Techniques*.
10. See Cyrus C. M. Mody and Michael Lynch, “Test Objects.”
11. Penelope Gouk, *Music, Science and Natural Magic*; Benjamin Wardhaugh, *Music, Experiment and Mathematics*; Alexander Rehding, *Hugo Riemann*; Myles W. Jackson, *Harmonious Triads*; Benjamin Steege, *Helmholtz*; James Q. Davis and Ellen Lockhart, *Sound Knowledge*.
12. Simon Schaffer, “Astronomers Mark Time.”
13. Lorraine Daston and Peter Galison, *Objectivity*; Flavia Padovani, Alan Richardson, and Jonathan Y. Tsou, *Objectivity in Science*.
14. Peter Galison, *Image and Logic*; Timothy Lenoir, *Inscribing Science*.
15. Stephen Jay Gould, *Mismeasure of Man*; Theodor Porter, *Trust in Numbers*; Rayna Rapp, *Testing Women*.
16. Dorothy Nelkin and Laurence R. Tancredi, *Dangerous Diagnostics*, 17.
17. Ibid.
18. See Adriana Petryna, *When Experiments Travel*.
19. Edward W. Constant, *Origins of the Turbojet Revolution*.
20. Donald McKenzie, “From Kwajalein to Armageddon?”; Trevor Pinch, ““Testing—One, Two, Three . . . Testing!””; Eefje Cleophas and Karin Bijsterveld, “Selling Sound.”
21. The earliest is a two-volume study by the Austrian otologist Adam Politzer, published in 1907–1913, followed by Karl Ludolf Schaefer’s 1914 article on investigating the acoustic

- functions of the ear and Harald Feldmann's 1959 history of audiology, translated in 1970. Politzer, *Geschichte der Ohrenheilkunde*; Schaefer, "Untersuchungsmethodik"; Feldmann, *History of Audiology*.
22. Girolamo Cardano, *De subtilitate*, Book 13, 387. The effect was visualized later in the frontispiece of John Bulwer's *Philocophus* of 1648, <https://doyle.com/sites/default/files/images/lots/511/1137511.jpg>.
 23. Ernst Heinrich Weber, *Annotationes*; Adolf Rinne, "Beiträge."
 24. August Lucae, "Untersuchungen."
 25. See, respectively, Joseph Sauveur, *Principes d'acoustique*; Ernst F. F. Chladni, *Die Akustik*; William Hyde Wollaston, "On Sounds Inaudible"; Félix Savart, "Über die Empfindlichkeit des Gehörorgans"; Francis Galton, *Inquiries*, 38–40, 375–78; Friedrich Bezold, "Demonstration der kontinuierlichen Tonreihe."
 26. All these are illustrated in Oskar Wolf, *Sprache und Ohr*.
 27. Richard Lyon, *Human and Machine Hearing*; Xiaochang Li, "Divination Engines."
 28. Myles W. Jackson, "From Scientific Instruments."
 29. Alexandra Hui, *Psychophysical Ear*.
 30. Laura Otis, *Networking*, 11.
 31. On the competence of testers, see MacKenzie, "From Kwajalein to Armageddon?," 413–14.
 32. Nelkin and Tancredi, *Dangerous Diagnostics*; Graeme Gooday and Karen Sayer, *Managing the Experience of Hearing Loss*; Jaipreet Virdi, *Hearing Happiness*; Jacques Vest, "Malingering Ear."
 33. Roland Wittje, *Age of Electroacoustics*.

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