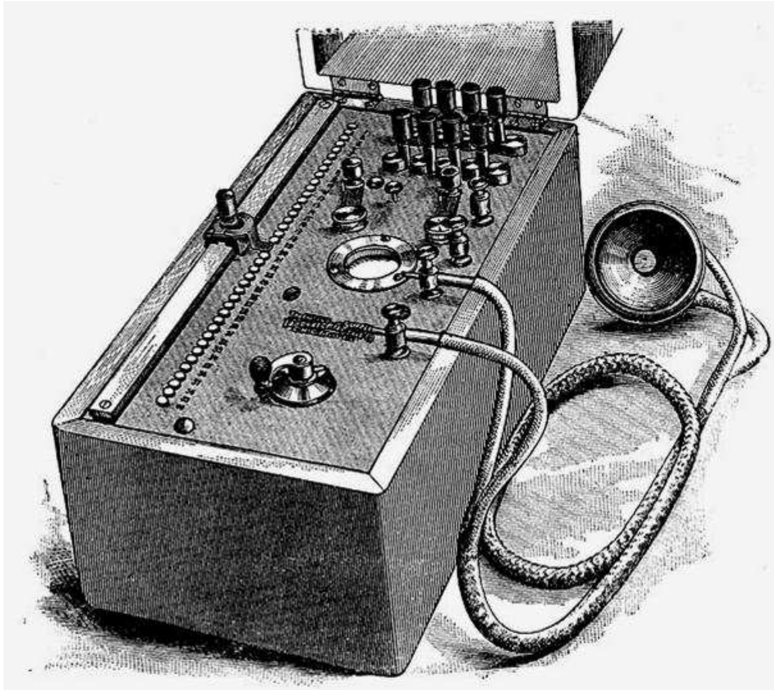

C.E. Seashore. Electric audiometer.
From C.E. Seashore, “New
Psychological Apparatus II:
An Audiometer.”

Deafening: Noise and the Engineering of Communication in the Telephone System

MARA MILLS

> *Scientific men . . . have elaborated theories of optics—and look at the result? Wonderful mechanical adaptations of optical principles, before undreamt of, and which, otherwise, would never have been discovered. Might not an analogous result attend the philosophical investigation of the faculty of speech; and acoustic and articulative principles be developed, which would lead to mechanical inventions no less wonderful and useful than those in optics? A subject so little explored, and so open to operations, is, at least, full of* promise *to science.*
>
> —Alexander Melville Bell, *Principles of Speech and Dictionary of Sounds* (1863)[1]

Francis Galton carried in his pocket a brass whistle, a tenth of an inch around. By means of a small screw, its frequency could be varied from 6,000 to 84,000 vibrations per second. The whistle was designed to test the upper boundary of hearing. Galton followed upon the work of William Hyde Wollaston, the physician who had reported a startling "species of *partial* deafness" in 1820: otherwise "perfect" ears were in fact "insensible" to high-frequency sounds, such as the cries of bats and the chirps of crickets.[2] Galton devoted many entertaining hours to hearing assessment:

> It is only too amusing an experiment to test a party of persons of various ages, including some rather elderly and self-satisfied personages. They are indignant at being thought deficient in the power of hearing, yet the experiment quickly shows that they are absolutely deaf to shrill notes which the younger persons hear acutely. . . . Every one has his limit.[3]

Galton recommended his whistle for any well-equipped anthropometric laboratory, though he regretted its lack of a gauge for loudness.[4] He warned that room echoes and extraneous noises would have to be controlled for accurate tests—

they, too, seemed to impair hearing.[5]

Alfred Mayer, at the Stevens Institute in New Jersey, wrote in 1876 "on the obliteration of the sensation of one sound by the simultaneous action on the ear of another more intense and lower sound." Listening to an American clock with four ticks per second and a Dresden watch with five shorter and higher-pitched ticks per second, he discovered that the tick was "stamped out of the watch" when the timepieces aligned. "It is difficult not to believe that some accident has suddenly interfered with the action of the watch instead of merely with our own sensations."[6] Mayer went on to pit one musical instrument against another, and to play musical tones in the presence of "noises"—fire bells, the "clatter of horses." These experiments confirmed the phenomenon that would come to be known as *masking*, whereby one sound (or, eventually, signal) interferes with the reception of another, causing what seems to be a temporary "impairment" of the ear.

"Why do we measure mankind?" Galton asked an American audience in 1890. His own reasons were numerous: to "rank" people and races against one another; to identify the normal and the exceptional for given traits; to track changes in one's own development; and to identify individuals by their unique characteristics. Statistical studies of human hearing had to wait until the turn of the century, however, when such procedures gained a new rationale: the industrialization of communication. In the 1920s, American Telephone and Telegraph (AT&T) and the New York League for the Hard of Hearing gathered the first mass data on auditory thresholds. The two organizations collaborated to build the first commercial electronic audiometer, which they then used for tens of thousands of hearing tests.

Why measure mankind? The telecommunications empire—the largest company in the world for much of the twentieth century—was concerned with efficiency and cost. In the hopes of connecting its system to the average ear, and in turn exploiting that ear's limitations to establish the requisites for "intelligible" transmission across imperfect lines (and later still, to transmit compressed speech), AT&T launched a comprehensive study of speech and hearing in 1913. Harvey Fletcher, who eventually directed these investigations, remarked that the company's physiological turn was motivated by prior successes with the electrical and mechanical aspects of communication engineering:

> It was apparent that great advantages would come from similarly analyzing speech and hearing, for if we could accurately describe every part of the system from the voice through the telephone instruments to and including the ear, we could engineer the parts at our disposal with greater intelligence.[7]

The medium of the telephone was not only designed to "extend" speech across space, it would ideally reduce speech by eliminating its imperceptible or inessential components.

The League for the Hard of Hearing hoped to establish new categories of hearing impairment in pursuit of rehabilitation and, eventually, meticulous school tracking.[8] "Scientific writers insist upon continuing the slovenly practise of lumping all together as 'deaf,'" wrote a team of League social workers in 1926.

> Can any expression, so carelessly flung about as this, make claim to be considered scientific? There is another side to this question of accurate nomenclature, the human side. It is pretty well understood that an incorrect epithet hurts. It hurts the deaf man to be called "deaf and dumb." The word "deaf" stings the *deafened* like a whip lash.[9]

A League bulletin from the previous year categorized the person born deaf as a member of a separate culture: "He, who has never known hearing, . . . has no consciousness of loss. Does he like to be confused with a group which has to be helped—retrained—educated? *He does not!*"[10]

In order to distinguish themselves from the deaf population, League members insisted upon their own impairment and medico-technical needs. Petitioning for hearing loss to be recognized as a military disability in 1918, Annetta Peck, Estelle Samuelson, and Ann Lehman coined the term *deafened* to indicate "all persons who are not congenitally deaf." The concept could refer to "gradual diminution or total loss of the sense of hearing."[11] "Hardness of hearing" had been used as a euphemism for both deafness and "semideafness" since the sixteenth century.[12] The New York League wanted a new nomenclature that distinguished between those who *acquired* hearing loss through infection or injury and those with "deaf" identity—which, according to their terms, meant people born deaf and raised in institutions, whether manual *or* oral.[13]

League members reported that the word *deafening* produced results:

> Proof of its suitability quickly came, for, strong in the psychological attitude which it induced, we sought and obtained from the Surgeon-General's offices the classification of the deafened as cripples—that is, as handicapped persons. This was a revolution, for from that day forth we have held our place in social work as physically handicapped, not physically defective.[14]

The distinction between *defect* and *handicap* expanded the realm of deafness from the innate and essential to the environmental and partial (though nonetheless physical). If *defect* signaled "the absence of something essential," *handicap* signified an impediment, a disability in a given situation, a disadvantage that might be normalized. However, as deafened activists won medical and technical resources—and as they began to apply these to children—they inevitably encroached upon those deaf identities from which they had hoped to distinguish themselves. Moreover, because the League and AT&T worked at cross-purposes, their collaboration had the unintended consequence of narrowing cultural standards for "good" communication.

As one result of their relationship with the League, telephone engineers adopted the concept of "deafening," abstracting it from physiological injury to include temporary "hearing impairments" caused at any point along a telephone circuit: room, transmitter, line, repeater. Their audiometric surveys generated a curve for the threshold of hearing; that is, the "normal" minimum intensities required for hearing each of the perceptible frequencies. For people with hearing loss, this curve was "raised." It turned out to be similarly raised when "background noise" on either end of the line masked the telephone signal. Within the telephone system, the audiometer began to serve as a literal means for measuring the debilitating effects of room and street noise—as well as "line noise" from electrical sources—on reception. As Norman French and John Steinberg of AT&T explained in 1948, "Unwanted sounds in the ear have a masking effect on speech. . . . They may arise from electrical disturbances originating within or without the communication system or from ambient noise."[15]

This history is one of the routes by which "noise" came to signify an "unwanted disturbance" in electronics even beyond the realm of sound or the field of electroacoustics. By the middle of the twentieth century, as engineers realized that noise could be controlled but never fully eliminated from a communication channel, Norbert Wiener would use the audiogram as a generalized model for the rate of information transmission. Beyond measuring physical impairment to the ear, the audiogram came to indicate the capacities of a media system. Similarly, Claude Shannon's formula for "channel capacity"—the component of information theory that predicts the maximum amount of information a given noisy channel can transmit—reproduced the formula used within the telephone system for the measurement of speech articulation via audiometry.

Within the field of sound studies, historians have offered a number of explanations for the rise in complaints about "noise" in Europe and the United States across the late nineteenth and early twentieth centuries: the increasing density of urban populations; the cacophony of new machines; the introduction of audiometric surveys; the evidence from epidemiology regarding noise-related hearing loss; the presence in the workplace of communication technologies that required keen listening; and, in the twentieth century, the paradigm of industrial efficiency.[16] Yet, as Karin Bijsterveld has argued, what counted as "noise" in most modern complaints was *subjective*—noise was defined not as loudness or irregularity but as a threat to the dominant social order:

> Noise as "unwanted sound," whether regular or unpatterned, has often been associated with a disruption of a particular social order, terrifying at times, whereas rhythmic and/or loud, positively evaluated sounds have been associated with strength, power, significance, masculinity, progress, prosperity, and last but not least, control.[17]

Bijsterveld, following Robert Beyer, mentions that this concept of noise as "unwanted" sound—specifically masking desired communication—entered the scientific lexicon via telephone engineering.[18]

Previously, acousticians had classified noise as irregular or nonperiodic sound. In the early twentieth century, some sources of noise continued to be defined according to their frequency characteristics rather than their desirability. For instance, atmospheric noise and thermal noise from electronic components were characterized by random electrical fluctuations.[19] These electrical "perturbations" in the atmosphere and in vacuum tubes became known as "noise" because they first manifested as static and other such sounds on radio and telephone receivers.[20] This is another route by which noise entered electronics at large. Thermal noise, for instance, eventually accounted for "snow" on television screens. Increasingly, telephone engineers studied the arbitrary thermal noise inside their channels rather than the noise in rooms and outdoor telephone spaces. However, they continued to understand this noise within the telephone system as "unwanted"—intrinsic to the medium but extraneous to the signal.[21] From the audiogram to information theory, noise determined the capacity of a system and the susceptibility of its receiver to information loss, or deafening.

Jacques Attali has further questioned the "subjective" elements that accompanied noise on its journey from acoustics to electronics:

> A noise is a resonance that interferes with the audition of a message in the process of emission. . . . Noise, then, does not exist in itself, but only in relation to the system within which it is inscribed: emitter, transmitter, receiver. Information theory uses the concept of noise (or rather, metonymy) in a more general way: noise is the term for a signal that interferes with the reception of a message by a receiver, even if the interfering signal itself has a meaning for that receiver.[22]

The telephone system translated human speech into controlled, directed signals. The definition of noise as a quantifiable perturbation added a degree of objectivity to this "subjective" phenomenon. Assumptions about good and bad communication were thus "naturalized" (a strange word to use in this context) as they were built into machine networks.

Telecommunications companies made pragmatic decisions about the quality and "naturalness" of their speech reproductions. Within the telephone system, the ideal sounds were intentional, individual, and uninterrupted.[23] Speech furthermore became a commodity, and as such some of its seemingly unremarkable properties were disproportionately scrutinized: speed, intelligibility, redundancy. Fletcher, in explaining the necessity for "physical measurements of audition" to the telephone company in 1923, argued that loudness was the salient aspect of speech in any noisy medium: "In the telephone business, the commodity being delivered to the customers is reproduced speech. One of the most important qualities of this speech is its loudness."[24]

Finally, the foundational association of noise and "deafening" caused transmission interferences to be inflected with pathology. Deafening spread from an individual impairment to a predicament for an entire communication system. This is not to say that communication engineering proceeded from the assumption of universal human debility. Numerous media theorists have conjectured about "technology's prosthetic function" and inferred that a generic "disability" is somehow fundamental to the modern condition. For instance, Geoffrey Winthrop-Young and Michael Wutz, in introducing Friedrich Kittler's *Gramophone, Film, Typewriter* to an English-language audience, state that modern media technologies "substitute for physiological impairments and extend the sensory apparatus."[25] Although the telephone system frequently resourced deafness and hardness of hearing, it was not developed as a compensation for deficiencies; telephones were clearly designed to connect to the average ear, the limitations of which were a boon to *efficiency*. Hearing loss became a communicable disease in the early twentieth century, but for those who experienced it as a temporary malady it was always caused by defects lodged elsewhere: in the environment, in imperfect communications equipment, or in other people. And despite the League's efforts to do away with the language of "defect," Fletcher used precisely this term to commend audiometry and articulation testing: methods valuable "not only in determining defects in transmission, but defects in the production and reception of speech as well."[26]

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Otology emerged as a medical specialty in the nineteenth century. William Wilde (Oscar's father) was one of the first practitioners as well as one of the first to collect statistics on hearing.[27] Wilde's 1853 textbook included a chart that arranged the impairments of 200 patients with reference to their anatomical appearance, pain, and "hearing distance."[28] Wilde counted "hearing distance" as the greatest number of inches from the ear at which a patient could detect the ticks of his watch. Many of his contemporaries would have begun using tuning forks, the sets newly standardized, to assess "partial hearing" for particular frequencies.[29]

Even forks did not emit pure tones, however. Thus, in the late 1870s, many scientists began experimenting with the diagnostic capabilities of the telephone, its affordances for the manipulation of electrical currents and their conversion into sounds. In 1878, within two years of the telephone's production, Arthur Hartmann converted the receiver into an "acoumeter," or early audiometer. He added a tuning fork to the telephone circuit, hoping its vibrations would yield a proportional frequency response in the electric current. He also attempted to regulate loudness; however, the sound from the tuning fork continually decreased in intensity.[30]

David Edward Hughes, the one-time music teacher who became a prominent inventor in the field of telegraphy, built a similar device in 1879.[31] Hughes offered a prototype to Benjamin Ward Richardson, who gave it the name "audiometer."[32] Assembled from a telephone, a battery, and a movable induction coil, it produced 200 different grades of intensity for a given frequency. Richardson tested the hearing of fifty individuals and was astonished at the "suddenness with which sound is lost" at the threshold of audibility in each case.[33] He recommended the audiometer for several purposes: diagnosis, the hiring of telegraphers and railway employees, and the evaluation of suspicious hearing remedies.

Alexander Graham Bell, too, repurposed his telephone into an audiometer. By varying the distance between telephone coils, he was able to adjust the intensity of the current and hence the loudness of sound from the receiver. In 1885, he used this device to test the hearing of 700 schoolchildren in Washington, DC, concluding that a full 10 percent had hearing loss.[34] Telephone receivers still did not emit pure tones; nor did they provide a precise measure of intensity. Most otologists remained suspicious of electrical audiometry.[35]

Psychologist Edward Wheeler Scripture, who trained in Leipzig under Wilhelm Wundt and then furnished the Yale laboratory for "the new psychology" in the 1890s, was less interested in "rough tests for deafness" than in precise measurements of the "just noticeable difference" (JND) between tones.[36] In 1892, a member of his lab tested ten schoolchildren of each age from six to nineteen in order to determine their sensitivity to changes in musical pitch. How discriminating was human hearing?[37] How many distinct tones could be detected by the average ear? These studies of least perceptible differences also suggested that some elements of physical sound were redundant or irrelevant.

Jonathan Crary has linked this variety of sensory research, which originated in nineteenth-century German psychophysics, to the twentieth-century "engineering of vision."

> Once the empirical truth of vision was determined to lie in the body, it was then that the senses and vision in particular were able to be annexed and controlled by external techniques of manipulation and stimulation. This was the epochal achievement of the science of psychophysics in the mid-nineteenth century—above all the work of scientist-philosopher Gustav Fechner—which rendered sensation measurable and embedded human perception in the domain of the quantifiable and the abstract. Vision thus became compatible with so many other processes of modernization. It was a critical historical threshold in the second half of the nineteenth century when any significant qualitative difference between a *biosphere* and a *mechanosphere* began to evaporate.[38]

By quantifying the sense of vision, entrenching it in a manipulable body, and connecting or simulating it with machines, "the so-called age of mechanical reproduction" set the preconditions for "the dematerialized digital imagery of the present."[39] Yet Crary's focus on visual recordings—the dominant bent among media historians—offers little insight into the electrical technologies that intermediated mechanical and digital reproduction. To the contrary, the engineering of *communication*—telegraph, telephone, radio—merged the quantification of perception with techniques for electrical transmission and coding. To be sure, communication engineering was the paradigm by which all media would eventually become digital and interactive.

Scripture's pupil, Carl Seashore, developed the first commercially successful electric audiometer in the United States in 1899. He added a galvanometer to the previous circuit of telephone receiver, battery, and induction coil. Seashore's audiometer made only a "clicking" sound, although it offered a precise visual measure of forty gradations of intensity.[40] The standards for diagnosis were still uncertain. Seashore estimated that the "average threshold for normal ears lies near the middle of the scale."[41] Nevertheless, that same year nearly 7,000 Chicago schoolchildren had their hearing tested with the Seashore audiometer.[42] Directed by D.P. MacMillan from the "child study department" of the city public schools, this survey was part of a project to assess the "physical basis of dullness," with hearing loss seemingly correlated to school impediments and social deviance.[43]

With the turn of the twentieth century, "hardness of hearing" became an identity category in the United States, broadly inclusive of people with hearing *loss* (as opposed to people born deaf).[44] In 1909, the New York League for the Hard of Hearing was founded as an offshoot of the Nitchie School of Lip-Reading, Annetta W. Peck serving as the first president.[45] By 1913, League members recruited otologist Harold Hays to their membership after reading an article he had published in *The Volta Review*, a journal founded by Bell and dedicated to oralist technology.[46] In 1915, several lip-reading teachers who visited the New York League were asked to form groups in their own cities. By the following year Chicago, Boston, San Francisco, Los Angeles, and Newark each had their branch of the League.[47] In 1917 League volunteers began making presentations on hearing loss prevention and quackery at the annual meetings of the American Medical Association. Members undertook a number of projects during this time, some of which would now be classified as medicalizing, others as building disability culture: they arranged lip-reading competitions, organized dance classes and afternoon teas, assisted members with employment, offered an on-site "handwork shop," and wired theaters for the new electric hearing aids.

Steven Epstein has claimed that AIDS activism was "the first social movement in the United States to accomplish the large-scale conversion of disease 'victims' into activist-experts."[48] The "deafened" movement is a clear precursor. The League for the Hard of Hearing, which quickly went national in the United States, pushed for ties with the American Medical Association and with AT&T. These "lay experts" established scientific facts as well as medical treatments.

By 1919, the New York League had launched the American Society for the Hard of Hearing. Peck convinced her personal physician, Dr. Wendell Phillips, to take on the national presidency.[49] The following year, members began to focus their efforts on the prevention and treatment of childhood hearing loss. They formed partnerships with the New York Board of Education and the state Department of Health, at first simply distributing literature about hearing to public schools. The *New York Times* interviewed Peck about the rapid expansion of this advocacy group. She replied:

> We are constantly looking out for opportunities to serve other organizations and the general public. We have helped scientists in their search for infor-

Edmund Prince Fowler with first vacuum tube audiometer, 1922. Photograph courtesy AT&T Archives and History Center.

> mation to use in developing hearing devices; we have worked toward the prevention of deafness, so that the city Departments of Education and Health have been awakened to the urgency of the need, and are willing to co-operate with us.[50]

Around that time, Phillips met Dr. Edmund Prince Fowler at the Manhattan Eye, Ear, and Throat Hospital. Fowler had been an army colonel and had returned from the war with an interest in rehabilitation and hearing measurement. Phillips introduced him to the New York League and encouraged him to develop an audiometer for group screening.[51] Fowler's neighbor, Alexander Nicholson, happened to be employed by Western Electric, the manufacturing branch of AT&T. Together, Fowler and Nicholson decided to record test sentences on a phonograph disc, using a Rochelle salt crystal transmitter to convert the sound waves to electrical form and send them through sets of headphones.[52]

Nicholson brought the prototype to Fletcher at AT&T. Fletcher was interested in research related to hearing loss, partly because his father was deaf.[53] Moreover, AT&T was increasingly committed to audiometry in the interest of the telephone system itself, as recalled in a 1935 report to the U.S. Federal Communications Commission:

> The intensity of a speaker's voice and its component frequencies must be known as well as the sensitivity of the listener's ear at different intensities and frequencies before it is possible to design to their best advantage a telephone system consisting of instruments, lines and other associated equipment with functional properties dependent on frequency and intensity. . . . Considering the hearing part of the program, it was at once appreciated that the methods used by doctors for measuring hearing such as tuning forks, watch tick, acoumeter, and the like, were not suited to the study.[54]

As early as 1910, engineers at Bell Laboratories had begun to investigate the condition of the reproduced speech within the telephone system. Irving Crandall, who directed these studies prior to Fletcher, was particularly interested in measuring "articulation"—the "literal reproduction" of speech sounds—as opposed to intelligibility (the reproduction of "meaningful" sounds, which were comparatively easy to identify on a noisy channel) or naturalness (the reproduction of the "artistic" or "human" qualities of speech).[55] Initially, measurements were made of the percent of nonsense sounds correctly transmitted along a given line. However, it soon became clear that the listener's hearing needed to be taken into consideration and the reproduced speech assessed even more precisely via the

intensities of its component frequencies.

Fletcher suggested rebuilding Fowler's audiometer with vacuum tubes to allow volume control and an electric wave filter to transmit tones with measurable frequencies. He recommended the continued use of headphones, made from telephone receivers, to control the audiometer's sounds as much as to block outside noises: "When high frequencies are produced in an ordinary room, standing waves occur, due to the reflection from the walls. . . . This source of error is avoided when the sound is delivered directly to the ear by a telephone receiver."[56]

Robert Wegel of Western Electric took over the collaboration with Fowler, and by 1922 they announced the 1-A, the first commercial electronic audiometer.[57] When Wegel and Fowler presented their audiometer to the American Otological Society, they also introduced new ways to conduct, and organize the data from, mass hearing tests. First, they exhibited "area of sensation" graphs for the zone of hearing that fell between minimum audibility and the threshold of feeling.[58] To obtain a tentative minimum curve, Wegel and Fletcher had tested the ears of seventy-two people who were "not obviously 'hard of hearing'" and who might represent the "average telephone user."[59] For the upper curve, they tested the ears of forty-eight people for the intensity at which sounds produced a tickling or painful sensation.[60] Within this zone, measurements from any individual could be plotted and related to statistical norms. Fowler and Wegel named the "curve plotted so as to show the variation of minimum audible sensitivity with frequency" an *audiogram*.[61]

Hearing loss curves. From Harvey Fletcher, *Speech and Hearing in Communication.*

With widespread audiometric testing, AT&T hoped to enroll the average ear into its system for the "scientific management" of communication (an example of what John Durham Peters calls "media as applied physiology").[62] Wegel stated,

> It has become important in the design and development of telephone apparatus and circuits to know quantitatively the various functional characteristics of the ear since the ear is an important dynamical unit in the long series of vibration transmitting apparatus constituting a telephone system. A complete analysis of this problem involves not only the properties of the physical circuit, but also the characteristics of the ear and voice and of the air passages between the mouth and transmitter and between the ear and receiver.[63]

This type of engineering is a species of biopower, a term Michel Foucault defined as "the set of mechanisms through which the basic biological features of the human species became the object of a political strategy, of a general strategy of power."[64] However, "applied physiology" in this case is neither an "anatomo-politics" for disciplining the individual body nor a "biopolitics" meant to regulate and transform populations. Although the screening and public hygiene efforts of the New York League were certainly biopolitical, a third type of biopower is indicated within the field of telephone engineering, an *ergonomopolitics of objects*. And whereas the ergonomic optimization of human beings—as in the transformation of workers' bodies under Taylorism—is accounted for by Foucault's anatomo-politics, an "ergonomopolitics of objects" describes the molding and regulation of technology according to human norms.[65]

As a clinician, Fowler preferred a chart that lent itself to diagnosis and treatment. In contrast to "areas of sensation," he proposed that the audiogram measure "percent loss of hearing" from a "reference zero" of minimum audibility.[66] He suggested that the "normal" threshold of hearing—which could only be determined by more extensive surveys—be defined as zero "sensation units" (SU).[67] A given individual's hearing would be plotted on this new audiogram chart as SUs "less sensitive than normal." At "high C," for example, the average individual could sense 270 distinct steps of volume (smaller changes in volume would be undetectable).[68]

The SU descended from the "transmission unit" (TU), which was a measurement of the loss of sound power over telephone lines. The TU expressed a ratio of any two quantities related to the magnitude of an audio signal (e.g., amplitude or current). When applied to a listener's perception of sound pressure level at either end of a telephone line, Ralph Hartley of AT&T explained, "the difference in loudness of two sounds may be measured by the number of intermediate steps

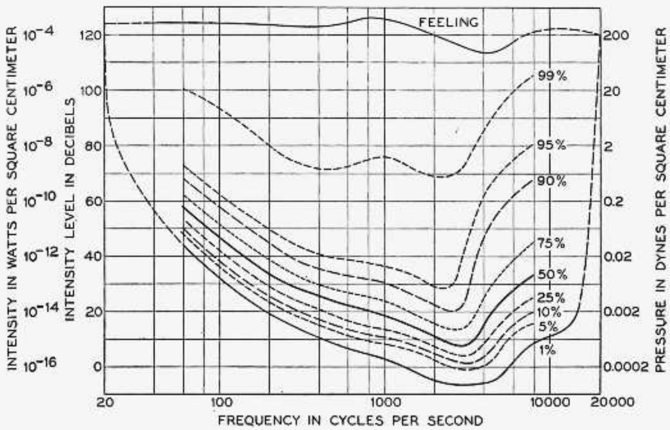


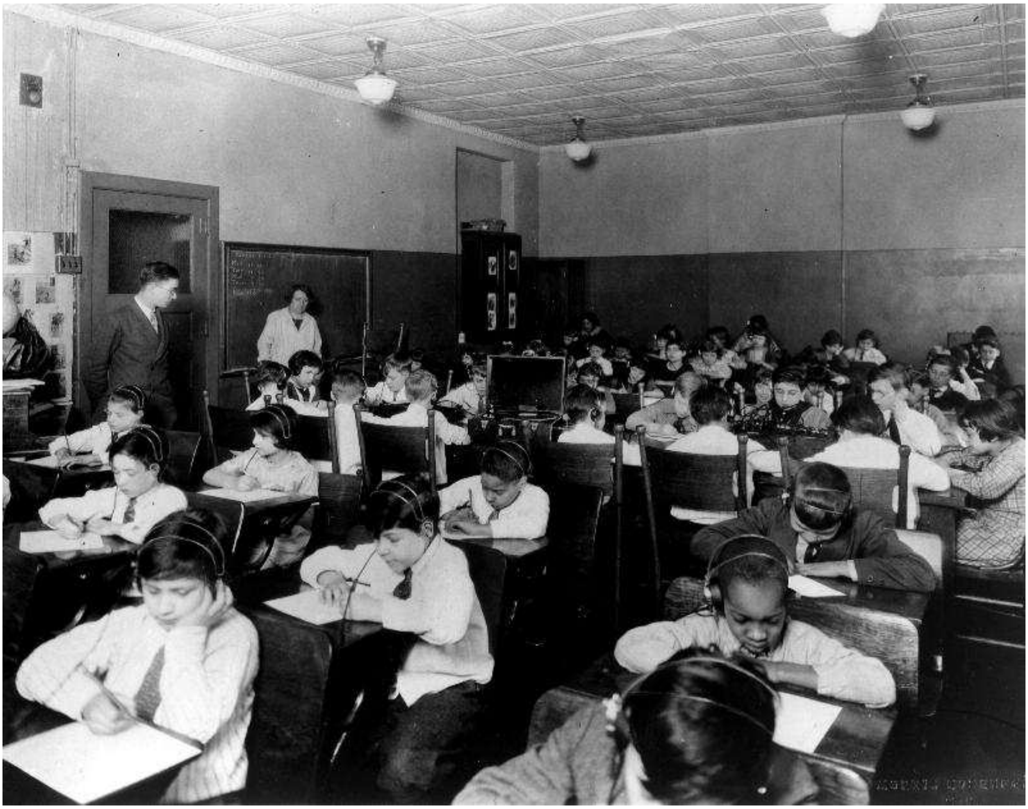
Fig. 96.—Auditory Areas When Hearing is Impaired. The curves are indicated by the percent of a typical American group who can hear sounds below the given level.

that can be distinguished in passing from one loudness to the other."[69] In 1928, Hartley proposed replacing the "transmission unit" with the *decibel*, which was also an approximation of the "just noticeable difference" in changes of sound intensity.[70] Although the decibel would eventually be applied to magnitude ratios in electronics and optics, within acoustics the reference level of 0 dB was defined as the average human threshold for a tone of 1,000 hertz.[71] Alongside this work in psychoacoustics, Hartley developed one of the earliest general theories of communication. As Jont Allen has argued, Hartley offered "the first formulation of channel capacity" in another 1928 article, "Transmission of Information." The formula was based on "count[ing] the number of intensity levels" that could be distinguished by the receiver in a given system—a "concept related to counting JNDs."[72]

After AT&T introduced the 1-A audiometer, the educational committee of the American Federation of Organizations for the Hard of Hearing "appealed to the company to devise a means of group testing."[73] By 1924 Fowler and Wegel came out with the 2-A, an inexpensive portable model. The following year they released a "phono-audiometer," which consisted of a modified phonograph set connected to forty to eighty telephone receivers. Large groups, such as classes of children, could be tested in one "sweep" with this device, a scenario that appealed to both AT&T and the American Federation.[74]

In 1925, Phillips became the first otologist to be elected president of the American Medical Association. He aggressively promoted annual school examinations among other public health measures. That year, representatives of Bell Laboratories and the New York League tested more than 4,000 students in New York City schools. Fletcher plotted distribution curves for each classroom tested, but he found the norm remarkably difficult to pin down: "The results are so inconsistent that it is impossible to differentiate between the normal and hard of hearing pupil."[75]

In 1926, the American Federation formed a Committee on the Survey of Hard of Hearing Children, Fletcher serving as chairman. Participation from groups in twenty-three cities resulted in a quarter million hearing tests, using both the new audiometers and the older methods.[76] Fletcher concluded that 8–12 percent of all students had "defective hearing"—a potential epidemic, as he warned the readers of the *Journal of the American Medical Association*.[77] The New York League framed these surveys in economic terms—it was a "waste" for teachers to repeat themselves for hard of hearing students and a waste for those students



to repeat grades.[78]

After three more years of surveys in 107 cities, however, screening tests were still not standardized: noisy classrooms and broken equipment distorted test results; whose ears should be factored into the minimum audibility curve was unclear. Under the direction of W.C. Beasley, the U.S. Public Health Service conducted a separate nationwide survey in 1936. In twelve cities, 9,000 adults of all ages were tested with the 2-A audiometer and the assistance of Bell Telephone Laboratories.[79] Of this group, 4,662 were selected who reported neither hearing problems nor exposure to environmental noise. After clinical examination and statistical calculation, only 1,242 were determined to have "normal" hearing. The average minimum audibility for this small group became the new recommended reference zero, formally adopted by the American Standards Association in 1951.[80]

Hoping for a still more comprehensive survey, AT&T installed hearing test exhibits at the 1939 New York and San Francisco World's Fairs and tested 750,000 pairs of ears.[81] Curiously, the World's Fair normal curve proved to be ten decibels lower than that of the National Health Survey. In the 1950s, British studies indicated that the U.S. Public Health Service standard was as much as fifteen decibels too high—presumably because it included data from adults of all ages.[82] By the 1970s, William Noble would argue that because all of these surveys discounted hard of hearing and/or older subjects, their "reference zeros" typified "not the norm of hearing but an extreme aspect of that norm." And, he reminds, "One might still *report* normality of hearing because, of course, normality of hearing can mean anything from good hearing to adequacy of hearing for one's general life purposes."[83]

The New York League clearly encroached upon the hearing world in the early decades of the twentieth century, helping to medicalize age-related hearing loss.

Harvey Fletcher of AT&T, testing hearing at a New York public school. Photograph courtesy AT&T Archives and History Center.

Their efforts, moreover, resulted in the singling-out of individuals with previously undetected hearing impairments. "Many mistakes and accidents in transportation and industry which were formerly credited to dullness or slow thinking, are now known to have been due to impaired hearing," cautioned an advertisement for one audiometer. "Similarly in educational institutions, an examination of so-called 'dull students' frequently reveals defective hearing as the cause of slow progress."[84]

Yet the League also encroached upon the Deaf world, and the expansion of the category of "hearing loss" ultimately worked against the hard of hearing activists' initial goal of a clear demarcation between deafness and deafening. Over the long term, audiometry exacerbated the tensions between "deafened" and signing Deaf cultures.[85] For one thing, childhood screenings identified as "hard of hearing" individuals who might otherwise be considered deaf and educated in sign language. With the advent of portable electric hearing aids in the same period, a growing number of those children were "mainstreamed."

In those same years, audiometry facilitated the transfer of "noise" from audition to information, ear to receiver, acoustic wave to electronic signal. In 1924, researchers at AT&T began to apply the 1-A audiometer to measure "the efficiency of hearing" on telephone lines.[86] Rogers Galt explained that a "noise audiogram" could be used to quantify the masking effects of unwanted sounds:

> Among the characteristics of a noise, one of the most significant is its deafening effect upon the human ear. This property is the basis of the engineering definition of a noise as an extraneous sound which interferes with the reception of other sounds. In common experience, the hearing of speech or of music is continually subjected to interference by such noises as the din of street traffic or the shuffling of feet and banging of chairs in a room.[87]

By 1926, as Emily Thompson has detailed, a "noise audiometer" also began to be deployed by noise abaters and the New York Department of Public Health to determine the rates of temporary deafening in various parts of the city.[88]

Fletcher announced a paradigm shift regarding the definition of noise in *Speech and Hearing*, his 1929 survey of electroacoustics. Physicists such as Hermann von Helmholtz had defined noises to be sounds that were neither speech nor music and that had unpredictably complex frequencies.[89] Fletcher reframed noise within the context of intention and control. For him the term signified any "extraneous sounds which serve only to interfere with the proper reception . . . the sound may be periodic or non-periodic." These sounds included background speech in a room where a telephone was in use ("room noise") and stray currents

Hearing Tests at the 1939 World's Fair. Photograph courtesy AT&T Archives and History Center.

in telephone lines. The interaction between power lines ("line noise"), for instance, "sound[ed] like a hum having a definite pitch and for that reason it might be classified as a musical tone. However, due to the interference which it causes to the proper recognition of the transmitted speech sounds, it is classed as noise."[90]

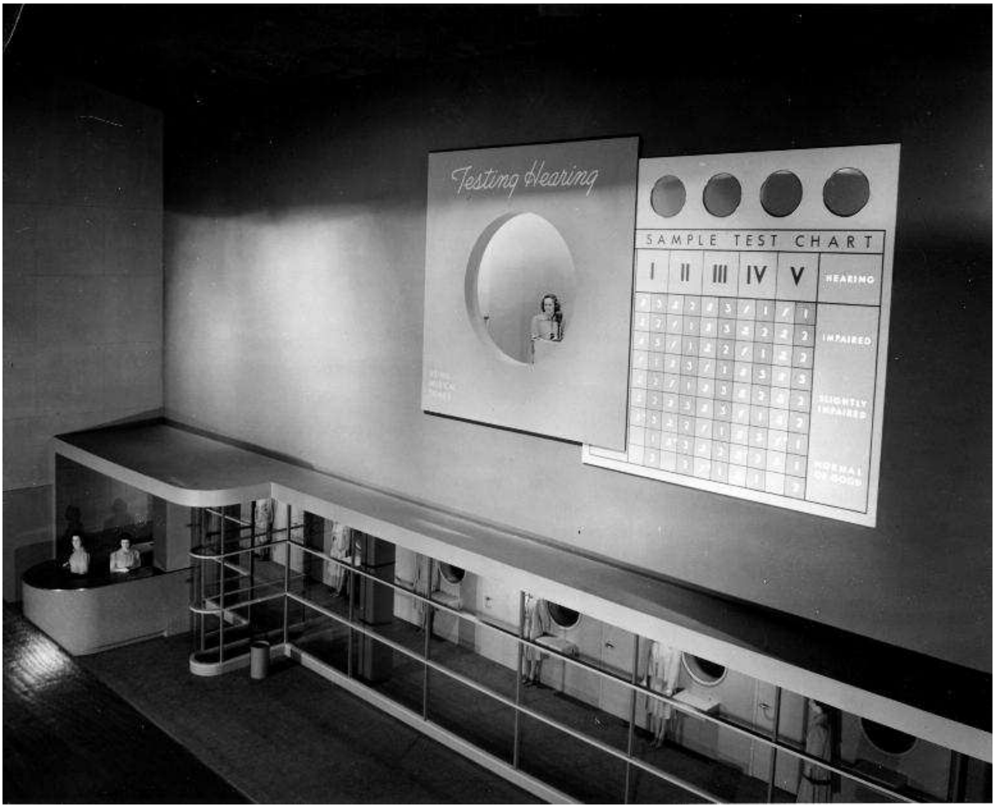
Fletcher had begun a term as President of the American Association for the Hard of Hearing in 1928. Taking a cue from his colleagues at the New York League, he also defined noise as "the deafening effect":

> A convenient way to describe the effects of noise on the ability to hear is to say that the person immersed in such a noise has a temporary hearing loss. As long as the noise is present, this hearing loss is as real as though the person were permanently deafened. If a high pitched noise is present, so far as any interpretation is concerned, it has the same effect as nerve deafness. If a low pitched sound, low in intensity, is present, it will produce only a depression in the audiogram. However, as it increases in intensity, it will not only cause a lowering in the pitch range near the pitch of the tone, but throughout the whole range, so that neither high nor low tones can be heard. By properly choosing the quality and intensity of the noise, an ear that is normal can be made to give an audiogram corresponding to any type of deafness.[91]

Because the audiogram focused only on function, and because hearing was already being measured *through* the telephone apparatus, any part of this communication system (line, ear, speaker, room) could be varied to the same effect. More than being "unwanted," within the context of telephone engineering even relatively benign sounds—such as "shuffling feet"—had become pathological to communication. Thus every volume of *Transmission Systems for Communications*, published by Bell Labs in several editions between the 1950s and the 1980s, included a section on "impairments," a term that originally referred to the effects of noise on an intended signal, and eventually included those of echo, crosstalk, and distortion.

|||||

Audiometry was applied to the measurement of "articulation" as well as to the perception of tones and noise. In contrast to the earliest studies of articulation, which assessed the recognition of nonsense sounds over phone lines, engineers began to divide speech into twenty or so frequency bands. The "sensation level"



of each band—its level of intensity above the threshold of hearing—was measured, and any masking effects were then subtracted. That masking resulted not only from extraneous "noise" but from processes internal to speech itself—the "components of preceding speech sounds within the band" as well as "speech components in adjacent bands"—soon became clear.[92] These insights would eventually provide the basis for "lossy" digital coding in which this "noise" that had finally penetrated the heart of speech and music was determined to be perceptually "irrelevant" and thus eliminated in the interest of compression.[93]

By 1947, an Articulation Index had been devised to measure the audible proportion of a speech signal—in short, by adding the sensation levels, minus masking, of each frequency band. Jont Allen has recently demonstrated, mathematically, that this index "is a Shannon channel capacity." In other words, Shannon's "maximum amount of information that may be transmitted on a [noisy] channel without error" is equivalent to this earlier measure of the amount of telephone speech perceived by a given listener.[94] In practical terms, regarding the capacity of the telephone system, Fletcher eventually determined that "substantially complete fidelity for the transmission of speech is obtained by a system having a frequency range from 100 to 7000 cycles per second and a volume range of 40 decibels."[95] (Allen also notes that Fletcher was one of Shannon's managers at Bell Labs in the 1940s.)

By the time that Norbert Wiener published *Cybernetics* in 1948, engineers could extrapolate noise and deafening to communication systems as diverse as television and radar. According to Wiener, the masking or interruption of any electronic signal maintained "a close relation to the audiograms used to measure the amount of hearing and loss of hearing in a given individual."[96] The rate of information transmission available in a channel, he argued, depended on the width

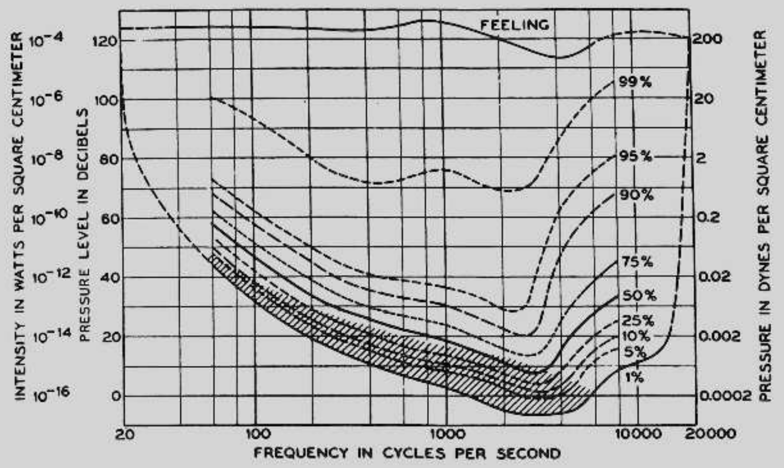


Fig. 97.—Auditory Areas with Average Room Noise Present.

of the channel and on its signal-to-noise ratio. "The intensity of the internal noise of the receiving system" could be represented along the lines of "the threshold of audible intensity" in the "area of sensation chart" designed by Wegel and Fowler. Similarly, the "upper boundary" of hearing, or threshold of pain, could be correlated to "the intensity of the greatest message the system is suited to handle." Just as Wegel and Fowler described the area between the two as "a measure of the capacity of the normal ear to sense sound," Wiener concluded that this area "is taken as a measure of the rate of transmission of information."[97]

Lev Manovich explains that the "incorporation of the concept of noise is what distinguishes modern information theory." To a limited extent, communication engineers began to deploy noise for useful purposes—for instance to mask secret communications during wartime. Yet, Manovich argues,

> Noise, always present in a communication system, whether natural or man-made, is the limit to perfect communication and, consequently, the limit to faultless human information processing. Noise is the source of error. And error is the worst enemy of the human-machine system in post-industrial cybernetic society.[98]

The redefinition of noise as "interference," its expansion to all categories of signal, and the comparison of its effects to hearing loss rendered deafening as endemic to industrial modernity. As communication between people—and between people and machines—has become increasingly technified, the purview of temporary deafening and the value of instantaneous, uninterrupted, and controlled communication have simultaneously increased. Likewise, despite the commonness of the diagnosis, physiological hearing impairment continues to be described as extraordinary, undesirable, and unacceptable.

Area of sensation chart as applied to the "deafening" effect of room noise. From Harvey Fletcher, *Speech and Hearing in Communication*.

Notes

1. Alexander Melville Bell, *Principles of Speech and Dictionary of Sounds, Including Directions and Exercises for the Cure of Stammering and Correction of All Faults of Articulation* (Washington, DC: Volta Bureau, 1916), 41. Reprint of an undocumented 1863 edition. Emphasis in original.

2. William Hyde Wollaston, "On Sounds Inaudible by Certain Ears," *Edinburgh Philosophical Journal* 5 (July 1820): 161. Allard Dembe has found mention of noise- and age-related hearing loss in European literature dating to the early modern period. Only in the nineteenth century, however, were the effects of noise quantified and placed into statistical perspective. One result was the insight that the perception of higher tones declined with age. Allard Dembe, "Noise-Induced Hearing Loss," in *Occupation and Disease: How Social Factors Affect the Conception of Work-Related Disorders* (New Haven: Yale University Press, 1996), 160–228.

3. Francis Galton, *Inquiries into Human Faculty and Its Development* (London: J.M. Dentf, 1907), 26–27.

4. Francis Galton, *Outfit for an Anthropometric Laboratory* (London: Privately printed, 1883), http://www.galton.org/essays/1880-1889/galton-1883-lab-outfit.pdf.

5. Francis Galton, *A Descriptive List of Anthropometric Apparatus, Consisting of Instruments for Measuring and Testing the Chief Physical Characteristics of the Human Body* (Cambridge, UK: The Cambridge Scientific Instrument Company, 1887).

6. Alfred Mayer, "Researches in Acoustics," *Philosophical Magazine* (1876): 500. In the sentence "It is difficult . . . ," Mayer is quoting Alexander J. Ellis, who performed a similar experiment.

7. Fletcher, *Speech and Hearing* (New York: D. Van Nostrand, 1929), v.

8. In the language of disability studies today, *impairment* continues to refer to a physical "limitation" or a "medically classified condition," whereas *disability* refers to "those social barriers which are constructed 'on top of' impairment." However, the ratio of the physical to the social within each category is a subject of debate. Colin Barnes, Geof Mercer, and Tom Shakespeare, *Exploring Disability: A Sociological Introduction* (Cambridge, UK: Polity Press, 1999), 2.

9. Annetta W. Peck, Estelle E. Samuelson, and Ann Lehman, *Ears and the Man: Studies in Social Work for the Deafened* (Philadelphia: F.A. Davis Company, 1926), 172. In part, the League's fixation on nomenclature must also have been a reaction to the growing stigmatization of deafness and sign language. Oralism spread along with evolutionary theories that portrayed sign language as primitive. In 1880 the international Milan Congress—made up of businessmen and oral educators—voted that the oral method was preferable to sign, especially for workplace efficiency. By 1901, many American states began legally to enforce this type of education.

10. "Why We Distinguish between Deafened and Deaf," *The Bulletin of the New York League for the Hard of Hearing* 3 (December 1925): 1. League authors were more critical of sign language users than of oral deaf people; one author described sign as a "strange language" that "made the deaf appear separated from the rest of the human family." "Why We Ban Manual Language," *The Bulletin of the New York League for the Hard of Hearing* 3 (January 1926): 1. These *Bulletins* are available at the New York office of the Center for Hearing and Communication (formerly the LHH).

11. Peck, Samuelson, and Lehman, *Ears and the Man*, 9.

12. In the nineteenth and early twentieth centuries, a bewildering number of classification

schemes were used within the educational, medical, and social work communities. For an example of one system, see Samuel Sexton, "On the Classification of Deaf Pupils with a View to Improve the Facilities for their Education," *American Annals of the Deaf* 32 (1887): 148–156.

13. Today most "oral" deaf people are mainstreamed, and Deaf identity is associated with sign language use.

14. "Why We Say 'Deafened,'" *The Bulletin of the New York League for the Hard of Hearing* 3, no. 7 (1925): 3.

15. N.R. French and J.C. Steinberg, "Factors Governing the Intelligibility of Speech Sounds," *Journal of the Acoustic Society of America* 19, no. 1 (1947): 91.

16. R. Murray Schafer, *The Soundscape: Our Sonic Environment and the Tuning of the World* (Rochester, VT: Destiny Books, 1994); Karin Bijsterveld, *Mechanical Sound: Technology, Culture, and Public Problems of Noise in the Twentieth Century* (Cambridge: MIT Press, 2008); Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900–1933* (Cambridge: MIT Press, 2002); and Dembe, *Occupation and Disease*.

17. Bijsterveld, 37.

18. By the mid-twentieth century, telephone engineers distinguished between noise and "distortion," the latter referring to an undesired change in the signal itself. More recently, random "noise" has been distinguished from "interference."

19. For another reflection on Gaussian noise as a subset of the more inclusive term *noise* in electroacoustics engineering, see Schafer, 182.

20. Mischa Schwartz, "Improving the Noise Performance of Communication Systems: 1920s to Early 1930s" (paper presented at the Smithsonian National Postal Museum, Washington, DC, 17 October 2007), www.postalmuseum.si.edu/symposiums/schwartzm-paper.pdf.

21. Through the end of the twentieth century, noise was depicted as "unwanted signals that are always present in a transmission system." John R. Pierce and A. Michael Noll, *Signals: The Science of Telecommunications* (New York: Scientific American Library, 1990), 52. Less frequently, noise was put to strategic use, a topic discussed in the conclusion of this article.

22. Jacques Attali, *Noise: The Political Economy of Music*, trans. Brian Massumi (Minneapolis: University of Minnesota Press, 2006), 26–27.

23. For a brief discussion of the ways telephone speech took priority over other workplace sounds and affected the definition of "noise," see Bijsterveld, 68.

24. Harvey Fletcher, "Physical Measurements of Audition and Their Bearing on the Theory of Audition," *Bell System Technical Journal* (October 1923): 153.

25. Geoffrey Winthrop-Young and Michael Wutz, "Friedrich Kittler and German Media Discourse Analysis," in Friedrich Kittler, *Gramophone, Film, Typewriter* (Stanford: Stanford University Press, 1999), xxxiv.

26. H. Fletcher and J.C. Steinberg, "Articulation Testing Methods," *Journal of the Acoustic Society of America* 1 (1930): 1.

27. For a more detailed account of the early history of audiology and hearing charts, see Harald Feldmann, "A History of Audiology: A Comprehensive Report and Bibliography from the Earliest Beginnings to the Present," *Translations of the Beltone Institute for Hearing Research* 22 (January

1970): 1–111.

28. William Robert Wilde, *Practical Observations on Aural Surgery and the Nature and Treatment of Diseases of the Ear* (Philadelphia: Blanchard and Lea, 1853).

29. For more on this topic, see Myles Jackson, *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century German*y (Cambridge: MIT Press, 2006).

30. Arthur Hartmann, "Eine neue Methode der Hörprüfung mit Hülfe electrischer Ströme," *Arch. f. Physiol*. [Archiv für Physiologie] (1878), 155, quoted in C.C. Bunch, "Historical: The Development of the Audiometer," in *Clinical Audiometry* (St. Louis: The C.V. Mosby Company, 1948), 159. Hartmann supervised the Nose and Ear Clinic at Rudolf Virchow Hospital in Berlin. He also helped open German oral schools for "partially and totally hard of hearing children." The author of texts on lip-reading, he was one of the first otologists to dedicate an entire book to the topic of deafness (*Deaf Mutism*). D.R.P., "Obituary: Arthur Hartmann (of Berlin), 1849–1931," *The Journal of Laryngology and Otology* 47 (March 1932): 227.

31. G. Burniston Brown, "David Edward Hughes, F.R.S., 1831–1900," *Notes and Records of the Royal Society of London* 34, no. 2 (1980): 227–239.

32. Benjamin Ward Richardson, "Some Researches with Professor Hughes' New Instrument for the Measurement of Hearing; the Audiometer," *Proceedings of the Royal Society of London* 29 (1879): 65–70.

33. Richardson, 67.

34. "The April Meeting of the National Academy of Sciences," *Science* 5, no. 117 (1885): 354. Glasgow otologist Thomas Barr's 1886 series of watch-tick tests, comparing the hearing of 100 boilermakers with mail carriers and ironworkers, is often named the first epidemiological study of hearing. As early as 1830, others had begun to investigate occupational hearing loss. Dembe, *Occupation and Disease*, 163.

35. This was due in no small part to the expense and complex maintenance of the audiometers available at the time. Dembe, *Occupation and Disease*, 181.

36. E.W. Scripture, "E.W. Scripture," in *A History of Psychology in Autobiography Volume III*, ed. Carl Murchison (New York: Russell and Russell, 1936), 231–261. Scripture's books were among the first American publications in experimental psychology. See especially E.W. Scripture, *The New Psychology* (New York: Charles Scribner's Sons, 1898); and E.W. Scripture, "Psychological Notes," *The American Journal of Psychology* 4, no. 4 (1892): 581.

37. J.A. Gilbert, "Experiments on the Musical Sensitiveness of School Children," *Studies from the Yale Psychological Laboratory* 1 (1892–1893): 80–87.

38. Jonathan Crary, "Unbinding Vision," *October* 68 (Spring 1994): 22.

39. Jonathan Crary, *Techniques of the Observer* (Cambridge: MIT Press, 1992), 2. Crary is primarily interested in the emergence of "subjective vision," whereby it was recognized that the body was capable of producing its own optical illusions, severed from any external referent. In telephone engineering, the human body was investigated as one component in a communication chain. Sound waves and other worldly phenomena continued to be important topics of research.

40. He recommended adding a tuning fork to the circuit to produce tones, and by 1919 he had produced a pitch-range audiometer.

41. C.E. Seashore, "New Psychological Apparatus II: An Audiometer," *Studies in Psychology from the University of Iowa* 2 (1899): 162.

42. Tests were performed at the schools with the least city noise. D.P. MacMillan, "Some Results of Hearing Tests of Chicago School Children," in *Journal of Proceedings and Addresses of the Fortieth Annual Meeting of the National Educational Association* (Chicago: University of Chicago Press, 1901), 880.

43. MacMillan, 884. From 1899 to 1913, several other districts conducted screenings in the hopes of catching undetected hearing loss that might otherwise be responsible for school and social troubles. See Etta V. Leighton, "The Hard-of-Hearing Child in the Public School," *The Volta Review* 14 (February 1913): 672–680.

44. Today, "hardness of hearing" generally means "partial hearing loss," with "late-deafening" referring to "post-lingual" deafness. (And in this usage, "post-lingual" means "after the development of speech," *not* "after language acquisition.")

45. "The March of Time," *The Bulletin of the New York League for the Hard of Hearing* 18 (June 1940): 1, 7; and "Here We Go Again—Into 1955," *The Bulletin of the New York League for the Hard of Hearing* 32 (June 1955): 1, 6.

46. Annetta Peck, "Organizations for the Hard-of-Hearing: Their History, Purpose and Promotion," *The Volta Review* 25, no. 9 (1923): 392.

47. Peck, 393.

48. "The AIDS movement stands alone, even as it begins to serve as a model for others." Steven Epstein, *Impure Science: AIDS Activism and the Politics of Knowledge* (Berkeley and Los Angeles: University of California Press, 1996), 8.

49. Although he was initially apprehensive about his possible out-of-pocket expenses, ultimately "his entry into The New York League for the Hard of Hearing in 1914 added authority and power to its work." "Dr. Phillips as a Social Worker," *The Bulletin of the New York League for the Hard of Hearing* 12 (December 1934): 1–2.

50. "For the Hard of Hearing," *New York Times*, 13 November 1921, X9.

51. Rose Ann Palmer, "The New York League for the Hard of Hearing in the Context of the Progressive (1900–1918) and the Neo-Progressive (1960–1975) Eras" (PhD diss., New York University, 1997), 138.

52. Neil Weir, *Otolaryngology: An Illustrated History* (London: Butterworths, 1990), 224.

53. Jont Allen, "Harvey Fletcher's Role in the Creation of Communication Acoustics," *Journal of the Acoustic Society of America* 99 (April 1996): 1825.

54. AT&T to Federal Communications Commission, "Audiometers: History of Development," 1 August 1935, in Western Electric File, Kenneth W. Berger Hearing Aid Archive, Kent State University.

55. I.B. Crandall, "The Composition of Speech," *Physical Review* 10 (1917): 74–76.

56. Harvey Fletcher, "Audiometric Measurements and their Uses," *The Volta Review* 26 (January 1924): 10.

57. Several researchers built electronic audiometers in Berlin in 1919, but for various reasons these did not become widely available. Dembe, *Occupation and Disease*, 181.

58. Edmund Prince Fowler and R.L. Wegel, "Presentation of a New Instrument for Determining

the Amount and Character of Auditory Sensation," *Transactions of the American Otological Society* 16 (1922): 119; and Edmund Prince Fowler and R.L. Wegel, "Audiometric Methods and their Applications," *Transactions of the 28th Annual Meeting of the American Laryngological, Rhinological and Otological Society* 28 (1922): 98–131.

59. Fowler and Wegel, "Audiometric Methods," 103.

60. Harvey Fletcher and R.L. Wegel, "The Frequency Sensitivity of Normal Ears," *Proceedings of the National Academy of Sciences* 8 (January 1922): 4–7.

61. Fowler and Wegel, "Audiometric Methods," 99.

62. John Durham Peters, "Helmholtz, Edison, and Sound History," in *Memory Bytes*: *History, Technology, and Digital Culture*, ed. Lauren Rabinovitz and Abraham Geil (Durham, NC: Duke University Press, 2004), 177–198.

63. R.L. Wegel, "The Physical Characteristics of Audition and Dynamical Analysis of the External Ear," *Bell System Technical Journal* 1 (November 1922): 56. He also noted how "much has been learned about the normal ear by the investigation of the characteristics of abnormal ears."

64. Michel Foucault, *Security, Territory, Population: Lectures at the Collège de France, 1977–1978*, trans. Graham Burchell (New York: Palgrave Macmillan, 2009), 1.

65. Similarly psychotechnics—the precursor field to ergonomics—distinguished between the "psychotechnics of subjects" and the "psychotechnics of objects." Taking up this term, Kittler describes cinema and other media as psychotechnologies. See, for instance, Friedrich Kittler, *Literature, Media, Information Systems: Essays*, trans. John Johnston (New York: Routledge, 1997), 99.

66. Fowler and Wegel distinguished between their statistical norm and the myriad audiograms that represented the hearing of "normal" individuals.

67. On the sensation unit, see Edmund Prince Fowler, "The Newer Tests for Hearing with Demonstration of Methods," *Laryngoscope* 37 (April 1927): 285–298.

68. "How Much Is an Earfull?" *Western Electric News* 12, no. 3 (1923): 8; and Thompson, 147.

69. R.V.L. Hartley, "TU Becomes Decibel," *Bell Laboratories Record* 7 (December 1928): 137.

70. Following Weber's Law, the TU and the decibel were logarithmic: as a stimulus increased in intensity, its perception increased at a slower rate.

71. Bijsterveld, 105.

72. Jont Allen, "The Articulation Index Is a Shannon Channel Capacity," in *Auditory Signal Processing: Physiology, Psychoacoustics, and Models*, ed. D. Pressnitzer et al. (Berlin: Springer Verlag, 2004), 319.

73. Ena G. MacNutt, "The Three Million," *Public Health Nursing* (1932): 39. See also Untitled Memorandum, in DOC-0115-004297, "The Development of Audiometers" file, 444-05-01-07, AT&T Archives, Warren, NJ.

74. The phono-audiometer used a phonograph record on which a voice recited numbers at intensities decreasing incrementally from thirty decibels to three decibels. Fowler dismissed the poor fidelity of the machine in terms that belied the circular logic of ears and telephone receivers improving one another: "As in all telephone instruments, the voice sounds somewhat distorted; but everyone is now accustomed to the telephone voice, and unconsciously disregards its peculiari-

ties." Edmund Prince Fowler, "Tests for Hearing," in *Medicine of the Ear*, ed. Edmund Prince Fowler, Jr. (New York: Thomas Nelson and Sons, 1947), 381.

75. "Hearing Tests Made in Public School #43 Using 4A Audiometer," Memorandum, 9 January 1926, p. 2, in DOC-0015-004297, "The Development of Audiometers" File, 444-05-01-07, AT&T Archives.

76. Mrs. James F. Norris, "Committee on the Survey of Hard of Hearing Children," *The Volta Review* 28 (1926): 451.

77. Fletcher, *Speech and Hearing*, 213.

78. Norris, "Committee," 455. Emily Thompson has noted that noise reformers in the next decade similarly acted in the name of efficiency; noise intruded into work and home, distorting intended communications. Thompson, *Soundscape*, 123.

79. United States Division of Public Health Methods, *The National Health Survey, 1935–1936* (Washington, DC: United States Federal Security Agency, Public Health Service, 1951).

80. Robert Thayer Sataloff and Joseph Sataloff, *Occupational Hearing Loss* (Boca Raton: CRC Press, 1993), 73.

81. F.A. Coles, "Hearing-Test Machines at the World's Fairs," *Bell Laboratories Record* 18 (June 1940): 291.

82. The U.K. studies were laboratory based. L.J. Wheeler and E.D.D. Dickson, "The Determination of the Threshold of Hearing," *Journal of Laryngology and Otology* 66 (1952): 379–395; and R.S. Dadson and J.H. King, "A Determination of the Normal Threshold of Hearing and Its Relation to the Standardization of Audiometers," *Journal of Laryngology and Otolaryngology* 66 (1952): 366–378. Dadson, for instance, tested only "normal" subjects in the 18–25 age range. In 1964, the International Organization for Standardization selected an arbitrary intensity to serve as the reference zero; it continues to be referred to as "normal hearing."

83. William G. Noble, *Assessment of Impaired Hearing: A Critique and a New Method* (New York: Academic Press, 1978), 183–184.

84. *Western Electric No. 5-A Audiometer* (pamphlet), in folder 1, box 3006, 154-02-03-01, AT&T Archives.

85. Susan Burch has shown that at first both Deaf and oralist groups supported the audiometric classification movement. Susan Burch, "Reading between the Signs: Defending Deaf Culture in Early Twentieth-Century America," in *The New Disability History: American Perspectives*, ed. Paul K. Longmore and Lauri Umansky (New York: NYU Press, 2001), 226.

86. Fletcher, "Audiometric Measurements," 10.

87. Rogers H. Galt, "Methods and Apparatus for Measuring the Noise Audiogram," *Journal of the Acoustic Society of America* 1 (1929): 147.

88. See Thompson, 155–168. The noise audiometer was eventually replaced by the "objective" sound meter; however, this new device continued to use a decibel scale based on human perception. T.G. Castner, "A Portable Sound Meter," *Bell Laboratories Record* 10 (May 1932): 334.

89. Fletcher, *Speech and Hearing*, 99. On noise as irregular, see Hermann von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (1885; New York: Dover Publications, 1954), 7–8, 67–69.

90. Fletcher, *Speech and Hearing*, 100–101.

91. "Society Transactions: Chicago Laryngological and Otological Society," 19 October 1925, p. 4, in DOC-0115-004299, "Development of Audiometers," AT&T Archives.

92. N.R. French and J.C. Steinberg, "Factors Governing the Intelligibility of Speech Sounds," *Journal of the Acoustic Society of America* 19 (January 1947): 92.

93. For more on this topic, see Jonathan Sterne, *MP3: The Meaning of a Format* (Durham, NC: Duke University Press, forthcoming). Researchers also discovered that "noise" generated as the result of coding could be "hidden" by taking advantage of the ear's susceptibility to masking.

94. Allen, "The Articulation Index," 314. Allen describes the index as "a widely recognized method of characterizing the information bearing frequency regions of speech."

95. Leo Beranek, "The Design of Speech Communication Systems," *Proceedings of the IRE* (September 1947): 880.

96. Norbert Wiener, *Cybernetics: Or Control and Communication in the Animal and the Machine* (Cambridge: MIT Press, 1965), 87.

97. Fowler and Wegel, "Presentation of a New Instrument," 110; and Wiener, 87.

98. Lev Manovich, "The Engineering of Vision from Constructivism to Computers" (PhD diss., University of Rochester, 1993), 184.