Speech Acoustics and the Keyboard Telephone: Rethinking Edison's Discovery of the Phonograph Principle

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ERRATA

1. Figure 2 on page 16 isn't actually a Scott phonautogram recorded using a membrane. When I wrote this article, I hadn't yet seen any *real* Scott phonautograms and took a contemporary misidentification at face value.

2. As originally published, the **index numbers** in the text don't correspond correctly to the numbers of the endnotes (as I explained in the follow-up discussion with Oliver Berliner). I have included a *corrected set of endnotes* at the very end of this document.

3. My description of the **Reis receiver** at the bottom of page 12 is incorrect. Charles Bourseul had proposed the arrangement I described, but the Reis receiver never employed a membrane, and the vast majority of designs relied on electrostriction—see e.g. Silvanus Thompson's biography of Reis (http://books.google.com/books?id=7uQOAAAAYAAJ).

4. I claim in this article that the Scott phonautograph was used *only* to study the "shapes" of waveforms. I now know that this was not the case in Europe, where it was sometimes used to investigate straightforward questions about frequency (e.g., Cornu and Mercadier). However, the only studies I've found conducted *in America*, or written about *in English*, do center on the "shape" issue, about which Edison appears wholly ignorant throughout 1877.

PATRICK FEASTER

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The usual account of the 1877 invention of the phonograph fails to take into consideration the abstract ideas about speech acoustics that guided Edison's experimental work in that period. This article presents an alternative view of the origin of the "phonograph principle" centered on turning-points in the evolution of Edison's broader strategies toward mediating and manipulating articulate speech. It argues that the phonograph was largely a byproduct of Edison's unsuccessful plan to build a keyboard telephone, an instrument that would have allowed users to "play" individual speech sounds over a telephone line rather than speaking them into a mouthpiece.

In June 1889, a correspondent asked Thomas Edison whether there was "a reliable account published of your discovery of the Phonograph principle, and your early experiment connected with it," to which he flatly replied: "None yet."[1] This is not the response we should have expected. Many accounts of Edison's discovery of the principle behind the phonograph had appeared in print by then, and the story generally accepted today still centers on the same set of narratives found in them. Briefly, the usual explanation has been that Edison was working on developing a new model of telephone when he decided to try recording and reproducing its signals using something similar to his recent invention for recording and repeating telegraph messages, the embossing telegraph recorder/repeater (henceforward, his "embosser"). Sometimes the story has also incorporated one or another decisive eureka moment. In February 1878, the *New York Sun* quoted Edison as saying that he had been talking into a telephone receiver when a point attached to its diaphragm had pricked his finger, encouraging him to try recording and reproducing the vibrations of the point.[2] When Edison introduced his "perfected" phonograph a decade later, it came accompanied by a new official teleology: now he was supposed to have drawn his original inspiration from hearing the humming, vaguely speech-like noises his embosser had made when repeating Morse code at high speed, hinting to him that a similar device, with a different kind of record, might be able to generate intelligible speech.[3] All these details had already been published in some form as of June 1889 and so must be regarded as covered by Edison's "none yet" comment.

It is true that some new data has turned up in the meantime, allowing us to flesh things out a little further. Raymond R. Wile was the first researcher to refine the story through a methodical evaluation of primary documents (in 1982),[4] and additional relevant material has surfaced since then via the Edison Papers Project. Laboratory notes now reveal that Edison and his associates sketched out the principle of phonographic sound

recording and reproduction on 17 July 1877, that a successful experiment was documented the following day, and that the idea was pursued somewhat desultorily through a series of designs on paper until that November, when the tinfoil machine finally took shape, culminating in the phonograph craze of 1878. Paul Israel gives an up-to-date account of these developments in his 1998 Edison biography.[5] Still, the new information is limited to matters of timing and technical nuance and does not alter the fundamentals of the story, such as where Edison got the idea for the phonograph in the first place or what he first thought might be done with it. Overall, we are still left today with the same basic narratives that were available to the reading public in June 1889, and which Edison dismissed as unreliable. We might well ask, then, what shortcomings in the traditional account might have prompted the reply Edison gave to his correspondent's question.

Unfortunately, existing scholarship offers little guidance here. The conceptual origin of the phonograph has simply not been subjected in the past to the same kind of rigorous analysis as has been lavished on the conceptual evolution of the telephone,[6] which is arguably the most closely comparable case. Maybe critics have assumed that the steps involved are too self-evident or too well-established to warrant scrutiny. Maybe the telephone has been more closely examined than the phonograph in this regard because researchers have been obsessed for so long with proving that one or another party "really" invented it; one strategy is, of course, to document the favored candidate's sequence of reasoning in painstaking detail. Whatever the cause, the result is that very little has been written on those aspects of Edison's knowledge and cognitive processes that could shed real light on his path to the phonograph. In particular, we lack any serious examination of how his understanding of speech acoustics had evolved over the course of his work in telephony. The most ambitious published comment I can find on this topic comes from the literature on telephone development and is a negative one: "Edison showed little interest in the abstract idea of converting sound into electricity, perhaps because Bell had already stated it, but also because he was much more concerned with the practical task of improving the telephone."[7] Historians of the phonograph, on the other hand, have tended to take Edison's familiarity with the latest advances in acoustic science for granted. Consider the following statements about him in Andre Millard's *America on Record*:

He was well versed in the theories of the German scientist Hermann Helmholtz on the nature of sound waves. He was also aware of the work of Leon Scott in France, whose "phonautograph" used a stylus attached to a membrane diaphragm to trace out the undulations of sound waves on a cylinder covered with smoked paper.... All these pieces of information were to be brought together in the invention of the phonograph.[8]

Despite the unequivocal nature of these assertions, they are inferences and assumptions, not well established facts. As we will see, a closer look at the documentary record suggests that Edison was neither well versed in Helmholtz's acoustic theories nor aware of the phonautograph, and obviously the "pieces of information" Millard enumerates could not have been "brought together in the invention of the phonograph" if Edison did not in fact possess them.

Here I will pursue a different approach to the question of how Edison came to discover the phonograph principle. Rather than assuming he knew everything there was to know in 1877 about speech acoustics, I have surveyed his writings with the goal of determining

what he did in fact know and think about the subject. I find that the key insights that led to the phonograph were closely linked to shifts in Edison's abstract ideas about acoustics and that these ideas often differed markedly from those of his peers. Working from this perspective, I also find that the main impetus leading Edison to conceive of the phonograph principle probably came from his effort to develop a prospective invention that past historians of the phonograph have entirely overlooked: the *keyboard telephone*. The earliest history of the phonograph looks strikingly different when reexamined through this alternative lens; a few details and remarks that have formerly appeared puzzling or incomprehensible suddenly fall neatly into place. I will suggest, finally, that this new perspective on the origin of phonography helps to expose and remedy a mental block in the way most of us think and write about "recorded sound" in general.

Edison's Entry into Acoustics

Edison testified in 1880 that he had first begun reading up on acoustics in late 1874 or early 1875 not out of inborn curiosity but because the subject had turned out to be unexpectedly relevant to his work in telegraphy. Elisha Gray had just unveiled his "electric telephone," which transmitted multiple electrical signals at different frequencies over a telegraph wire, and he had already conducted some novelty concerts on this principle in which a single tympanum in a lecture hall received music played on a remote keyboard, complete with harmonies. Gray expected the practical end of his work to lie in separating out the different signals with receivers tuned to resonate at each of the respective frequencies, enabling telegraph companies to send several messages in Morse code over a single line at once – a commercially promising field known as acoustic or harmonic telegraphy. Edison was rightly worried that Gray's work might undermine the multiplex telegraphy systems he had been developing based on more straightforward differences in current strength and polarity. He first consulted his copy of J. Baillé's *The Wonders of Electricity*, which contained a brief section on acoustic telegraphy, and then took the matter up in earnest around July 1875 at the request of Western Union president William Orton. At the same time, he also began to develop a professional interest in the idea of an electric "speaking telegraph," or telephone, which he had first encountered through the work of Philip Reis.[9]

In the system of electric telephony Reis had worked out in the 1860s, sounds caused a transmitting diaphragm to vibrate against an electrical contact point, alternately closing and breaking a circuit. At the other end of a wire, an electromagnet switched on and off in response to the intermittent current, producing corresponding vibrations in a receiving tympanum and thereby generating a sound analogous in frequency to the original sound. The fatal flaw in Reis' approach to sound transmission was that a simple intermittent or "on/off" signal can accommodate only one frequency at a time, with no variation in intensity, whereas sounds in the natural world possess additional overtones superimposed at varying intensities. Our perception of timbre, which enables us (among other things) to differentiate among the phonemes of spoken language, depends upon our ears' built-in ability to analyze the spectra of these overtones. In order to preserve these spectra, a telephone must be able to accommodate the continual variation in the amplitude of a complex sound wave, the "waveform" which represents the mathematical sum of the amplitudes of all its component frequencies (and from which our ears can sort the

amplitudes of those component frequencies back out again) – thus, it requires a *variable* signal rather than a simple intermittent signal.[10] Three different solutions to this problem emerged in 1876-77. In the magneto transmitter, the vibrations of a bar magnet attached to a diaphragm induce weak electric pulses of varying strength in the coil of a nearby electromagnet. In the liquid transmitter, the vibrations of a diaphragm cause a wire dipped into a glass of liquid to approach and recede from another wire at the bottom, altering the resistance between the two wires and, hence, the strength of a current passing between them. Finally, there was Edison's major contribution, the carbon button transmitter. Having noticed that the electrical resistance of carbon in certain states varies proportionately with pressure, Edison arranged for a diaphragm to press against a carbon button so that its vibrations would create fluctuations in the strength of a current passing through the button. Because all three of these arrangements can in fact transmit speech sounds intelligibly, it is easy to assume that their inventors had correctly understood the acoustic principles responsible for their success. However, a closer look at the documentary record suggests otherwise.

23 March 1877: "Speaking Consists of Sound at One Rate of Vibration"

Edison brought a formidable understanding of electricity and chemistry with him to the field of telephony, but there is evidence that his knowledge of acoustics was initially quite weak. One of his first telephone sketches, drawn around July 1875, shows a couple of different ways to convey speech vibrations to one prong of a tuning fork, an arrangement that does not appear on the face of it to make much sense. The editors of his papers remark that he "seems not to have understood at this point that a given tuning fork responds strongly only to a particular frequency,"[11] and it would be hard to find a more basic piece of practical acoustic knowledge than that! However, Edison also appears to have had a curiously mistaken understanding of speech acoustics at the time he invented the carbon button transmitter, and one that may place his earlier "error" with respect to tuning forks in a different light.

Alexander Graham Bell's patent application and Elisha Gray's caveat, filed within a few hours of each other on 14 February 1876, both correctly stress the importance in "speaking" telephony of transmitting both amplitude *and* frequency.[12] Edison, by contrast, seems to have inferred from the failure of simple "on/off" signals to transmit speech intelligibly that frequency was irrelevant and that *only* amplitude mattered. One piece of evidence for this view dates from 23 March 1877, when Edison was preparing to apply for his first telephone patent. During a meeting with his attorney, Lemuel W. Serrell, he wrote at the top of a sheet of paper (Fig. 1) that "speaking consists of sound at one rate of vibration," meaning one frequency.[13] Three and a half years later, Serrell explained the significance of this document as follows:

Mr. Edison made all the sketches on that order, and explained to me the differences between musical sounds and articulate speech; his explanation was, that during his experiments, conducted through a long period of time, he had discovered that articulate speech was altogether different to music. That musical sounds had, as was well known, a regular rate of vibration; that speech had both a rate of vibration and a volume.... Mr. Edison wrote the words "Speaking consists of one rate of vibration," and explained that a person

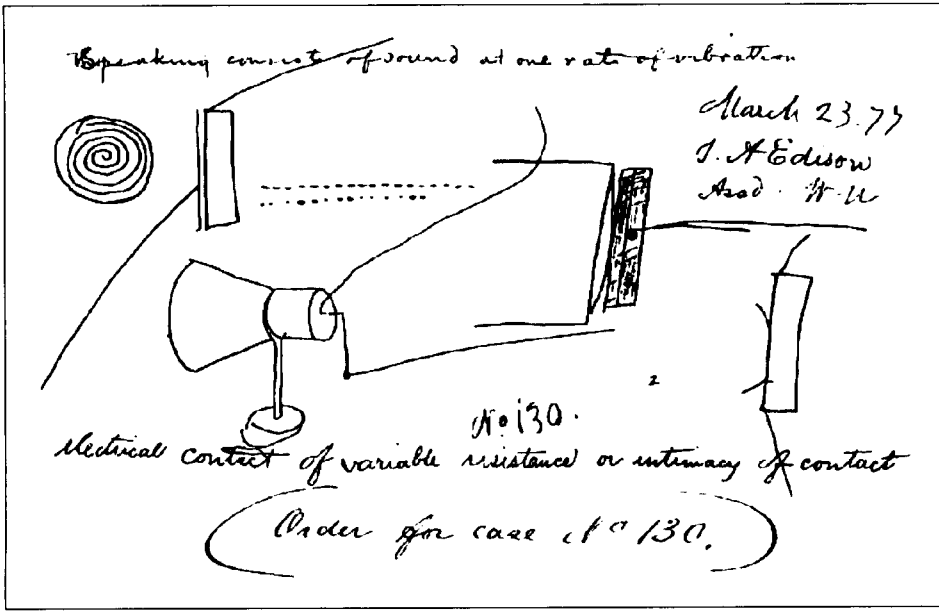

Figure 1. Edison's telephone drawings of 23 March 1877 (TAEM 3:927/TAED NV11028)

could speak in one musical key or another, and that the volume of the respective utterances determined the articulated sounds.[14]

The patent text which Serrell subsequently prepared, and which Edison signed on 18 April, also incorporates this view. Specifically, it states that because spoken words are "uttered in one key or tone, or nearly so," they are "not distinct and clear" when transmitted by Reis-style telephones, thereby justifying a focus on amplitude instead: "the diaphragm at the receiving-station will be influenced by the action of the electro-magnet in the same proportion *[i.e., amplitude]* as the rise and fall of electric energy produced by the vibrations of the voice, regardless of the musical key *[i.e., frequency]*."[15] Instead of acknowledging the complementary relationship between frequency and amplitude in the transmission of speech, Edison's statements from March and April 1877 consistently (and wrongly) represent the sounds of speech as a sequence of impulses varying meaningfully in their intensity but *not* in their rapidity.

It is unclear when Edison had first concluded that speech sounds consist of a single frequency, but if he had already done so as of mid-1875, he would have had good reason to deduce that a tuning fork would be useful in transmitting them. The "mistake" of his first telephone sketch would then have lain in his understanding of the acoustics of speech, not in his knowledge of the properties of tuning forks – an interpretation I consider more plausible and more consistent with the rest of his early work in the field.

Larger and Smaller Dots

Edison's unusual view of speech acoustics also manifested itself in his efforts to visualize the signals his telephone transmitted. Today we are accustomed to "seeing" sound in terms of a laterally modulated oscillogram, plotting time on an x-axis against amplitude on a y-axis. Edison himself had sketched some oscillographic representations of simple sound waves in December 1875 while working on acoustic telegraphy, so we know he was familiar with the format. However, his drawings treat sine waves and triangle waves as interchangeable,[16] whereas others had begun attributing significance to complex oscillographic shapes, particularly those produced by the human voice. The oscillogram was the format Léon Scott de Martinville had adopted for his phonautograph of the 1850s, the first instrument designed to record composite atmospheric sound waves for visual analysis, and scholars had been trying to make sense of its undulatory traces, such as those shown in Fig. 2, ever since.[17] Alexander Graham Bell had begun researching the oscillographic shapes of different speech sounds in 1874, having concluded that "each sound had its own appropriate curve" (see his illustration of this point in Fig. 3).[18] He later illustrated the differences between the intermittent signal of the Reis telephone and the variable signal of the successful "speaking" telephone using a similar laterally modulated format.[19]

When Edison met with Serrell on 23 March 1877 to work out the details of his first telephone patent, he drew up an analogous graphical representation in order, as he later explained, "to illustrate that which was essential to transmit articulate speech,"[20] but he approached the task quite differently. Underneath his statement that "speaking consists of sound at one rate of vibration," he drew a row of dashes of uniform size followed by a row of larger and smaller dots (Fig. 1). Edison had "illustrated his ideas and explanations by two rows of dots...the upper row of dots indicating musical tone vibrations, the lower row of dots the greater or less volume of the sounds in articulations, the rate of vibration being the same," Serrell later recalled.[21] Edison himself accounted for the sketch in similar terms: "The upper row of dots representing waves of invariable intensity, as sent from a Reiss *[sic]* transmitter and the lower line representing waves of variable intensity as sent by my instrument."[22] From his background in telegraphy, Edison was used to seeing electrical signals recorded as rows of dots and dashes by the striking of vertically mounted telegraph sounders against strips of paper, and he had understandably turned to this familiar format in trying to depict a telephone signal – but he was able to do so only because his idiosyncratic understanding of speech acoustics had misled him into believing it was capable of embodying all the necessary information. The telegraphic format was unable to show any detail about went on between the crests of waves, the data ordinarily embodied in the complex shape of an oscillogram, but that data had no place in Edison's conceptual framework. The only factor he considered important was the intensity of each impulse, and this could be represented by the size of the dots – an index of how forcefully or deeply the recording instrument (his pen) had pressed into the paper. This sketch reveals that Edison had then already thought of adapting the dot-and-dash format commonly employed for recording telegraph signals to represent the more complex signals of the telephone, and that his ability to do so was linked to a peculiar misconception about the acoustic properties of speech.

Edison's drawing of a telephone signal as a row of larger (i.e., deeper) and smaller (i.e., shallower) dots anticipates the vertical recording format his phonograph would

Figure 2. Record made by a Scott phonautograph
Rodolphe Radau, Wonders of Acoustics; or, the Phenomena of Sound, *rev. Robert Ball (New York: Charles Scribner & Co., 1870), 142.*

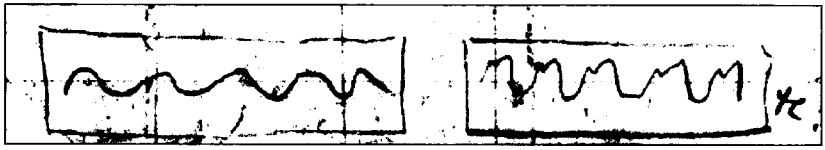

Figure 3. "Each sound had its own appropriate curve."
Alexander Graham Bell to Alexander Melville Bell et al., *6 May 1874, AGBFP.*

later use, and it is noteworthy that he had turned to this format by default even when the practical constraints of reproduction were not present. Of course, we cannot assume that Edison yet believed he could record *actual* telephone signals in this way or saw any reason to do so. His drawing was merely an illustration of what he thought the two types of signal would hypothetically look like on paper, intended to clarify the differences between them to his attorney. He certainly does not appear to have pursued the idea of applying telegraphic recording techniques to telephone signals any further at this time. I will assume he did not as yet perceive that anything useful could be done with such a record, presuming it could really be made in the first place.

An Alternative Approach to Speech Acoustics

On 4 April 1877, a week and a half after signing the paperwork for his first telephone patent, Edison found himself still wrestling with certain sounds: "We can get everything perfect except the lisps & hissing parts of speech, such as 'Sh' in shall= get only .o. in coach."[23] A group of sounds which he came to call "hissing sounds" or "hissing consonants" continued to elude his transmitters, including *s, sh, ch, t, v, k, j,* and *p*.[24] He had no idea why these sounds should be especially problematic, and this puzzle gave him a practical motive for reexamining speech acoustics literature on the chance that he might have missed something. The leading expert in the field at that time was Hermann Helmholtz ("von Helmholtz" following his ennoblement in 1882), who had developed a theory linking differences in timbre and vowel quality to different patterns of overtones. The book Edison had first consulted for information about acoustics, Baillé's *Wonders of Electricity,* had already summarized Helmholtz's idea that "each simple vowel is formed by one or more notes of the scale, accompanied by other and feebler notes which are harmonics of these,"[25] but, as we have seen, Edison had ignored this lead for a while in favor

of his own conviction about speaking consisting of sound at one rate of vibration. He had also obtained a copy of the first English edition of Helmholtz's *On the Sensations of Tone as a Physiological Basis for the Theory of Music* (1875), and his marginalia show that he had taken particular interest in an experimental apparatus Helmholtz describes there for synthesizing vowel sounds.[26] Still, it seems that Edison had initially missed the point of Helmholtz's experiment, since he exploited the apparatus only as a combination of interesting design elements, not as a source of insight into speech acoustics.

Helmholtz's vowel synthesis apparatus consisted of a system of resonators and tuning-forks. An "interrupting fork" tuned to the fundamental pitch was arranged so that a wire attached to one of its prongs dipped into and out of a cup of mercury as it vibrated, repeatedly making and breaking an electric circuit. The resulting intermittent current caused electromagnets to switch on and off at the same frequency, keeping both the interrupting fork and the other tuning-forks, which were tuned to successive harmonics and attached to resonators, in vibration together. This arrangement allowed Helmholtz to produce a fundamental pitch and its first seven harmonics in different combinations, replicating the characteristics of the mouth in different positions as a complex resonance chamber and thereby producing sounds he thought resembled those of different vowels.

We find Edison applying elements of Helmholtz's design to his work as early as 1875-76, but at that point he displayed no awareness of the implications of the experiment for speech acoustics, namely that vowels owe their different sounds to different patterns found in their overtones (although he might have mistaken Helmholtz's use of an interrupting fork tuned to a specific pitch to generate vowel sounds as evidence that "speaking consists of sound at one rate of vibration" – a possible source for that misconception). His first telephone document includes a sketch in which a mouthpiece conveys the vibrations of speech to a tuning fork with a contact dipping into a cup of "mercury like Helmholtz," an arrangement clearly based on Helmholtz's interrupting fork, but he shows its signal being received by a single tympanum, not a series of resonators, entirely defeating Helmholtz's purpose.[27] He did also employ "Helmholtz resonators" during this period, but apparently only as receivers for acoustic telegraphy.[28] Whatever uses Edison made of specific parts of Helmholtz's apparatus, he seems to have found the underlying explanations hard to grasp, judging from the frustrated note he jotted in the front of his copy of the book: "An immense mass of things stated in the most muddy manner. A masterpiece of incapacity of explaining simple things."[29] Nevertheless, he had finally picked up on one component of Helmholtz's theory by May 1877, when he concluded that he should expect frequency – or more specifically combinations of overtones – to be essential to the intelligibility of transmitted speech sounds after all. This is not to say that Edison was now "well versed" in Helmholtz's work. To the contrary, we find him once again basing his work on some faulty assumptions about speech acoustics, but this time he was at least in good company.

Helmholtz's vowel synthesis apparatus had already exercised a profound influence on the development of sound media by then, mainly because people had assumed it could do more than it actually could. Alexander Graham Bell had learned about it in the latter half of the 1860s, but he could not read German, and Helmholtz's writings had not yet been translated into English, so he had been forced to rely on imperfect summaries. In hindsight, Bell stated: "Without knowing much about the subject, it seemed to me, that if vowel sounds could be produced by electrical means so could consonants, so could articulate speech."[30] Helmholtz had in fact designed his apparatus only to investigate

vowel color and had recognized that parameters such as attack, which he did not even try to simulate, were likewise important in the perception of speech and other timbrally distinctive sounds.[31] Bell is thus sometimes said to have been led to imagine the possibility of the electrical transmission of speech through a *misunderstanding* of Helmholtz.[32] Perhaps Bell had exaggerated the implications of Helmholtz's experiment, but this "misunderstanding" was by no means an uncommon one. Elisha Gray had likewise concluded that human speech could be synthesized by "a mechanism which would employ such tones as needed, and would enable one to manipulate them in whatever manner was requisite to produce the desired effect," namely "a mechanism similar to the vocal organs of the throat, which would mould electrical waves into the same form that the air is moulded when a spoken word is uttered,"[33] and even Baillé's *Wonder's of Electricity*, the first book Edison had consulted on acoustics, contains a similar statement: "M. Helmholtz...thinks it would be possible to construct a human voice by artificially producing and combining the elementary sounds of which it is composed."[34] Of course, speech sounds *can* by synthesized in such a way, as we now know. The "misunderstanding," insofar as there was one, lay in the assumption that all speech sounds could be analyzed and synthesized using Helmholtz's specific approach to vowel synthesis, and that all one needed to know was which overtones combined in which proportions.

26 May 1877: "Harmonics of the Parts of Speech Can Easily Be Obtained"

Edison now fell into the same "misunderstanding" as Bell and the others by concluding that all speech sounds could easily be distinguished by and synthesized in terms of their resonant frequencies, a view that informs a fascinating set of laboratory notes all dated 26 May 1877. First, we find it applied to ordinary telephony: Edison remained frustrated by the inability of his transmitters to send "hissing sounds," but now he hypothesized that "notes having an exceedingly low rate of vibration p[*ro*]b[*ab*]ly 10 per second & weak at that" were responsible for the difficulty. The solution, he felt, was to add a second input device, a "hissing consonant tube" adjusted lengthwise until it was "in tune with" these supposedly very low frequencies.[35] Although this insight represents an improvement on Edison's earlier conviction that "speaking consists of sound at one rate of vibration," he was still on the wrong track. A vibration at ten cycles per second would have fallen below the threshold of human hearing; the frequencies of vibration that actually distinguish Edison's "hissing consonants" from one another were not too low but too *high*, or perhaps too aperiodic, for early telephone transmitters to handle. What is more significant for our purposes, however, is that Edison was inspired by his new understanding of speech acoustics to conceptualize a pair of inventions, one for recording telephone messages, the other for producing them.

The first of the proposed inventions was to be a telephone that "prints automatically *[sic]* the speech," the idea for which had actually arisen a day or two earlier, when Edison had met with General Benjamin Butler at the Fifth Avenue Hotel in New York. Butler had suggested that he invent a device for recording telephone transmissions, and they had hit upon the idea of recording the individual component frequencies of speech signals by causing them to set differently tuned sensors in sympathetic vibration, as in an acoustic or harmonic telegraph system. Butler's suggestion had been to use tuned

strings as receivers, but when Edison jotted the idea down back at the laboratory he observed that this was "ng" – no good – and settled on a series of Helmholtz resonators instead. As different speech sounds were transmitted through the telephone, the combinations of resonators corresponding to their distinctive spectra would respond, controlling either a typewriter, by opening and closing electrical circuits as needed, or a set of twenty-five points pressed against a strip of specially treated recording paper. In this way, a spoken message would be translated automatically into written "letters" of one kind or another.[36] In technical terms, what Edison and Butler were suggesting was a sound spectrograph for speech analysis, something that was not to be developed successfully until the 1940s.[37] Their practical aim was presumably to overcome a recognized drawback of the telephone, namely that its messages could not be recorded automatically as was possible in telegraphy.[3]

On the same day, Edison also proposed a second invention (Fig. 4) intended to produce speech sounds over the telephone artificially. The name he gave to it was the *keyboard talking telegraph*, but he used "talking telegraph" in his notes to mean what we would now call a "telephone," so for the sake of clarity I will refer to the hypothetical device as the *keyboard telephone.* Much as the proposed invention for "printing" telephone messages drew on the precedent of the harmonic telegraph, the keyboard telephone drew on another well-established inventive tradition, that of the *tonewheel.*

The Tonewheel and the Keyboard Telephone

The term "tonewheel" is associated primarily with the Hammond organ, but I will define it here more broadly as any wheel with a pattern laid out on its circumference that is translated into a sound wave of analogous pattern – often a particular frequency – as it rotates rapidly past a contact point. This branch of the prehistory of phonography has received little attention lately, but its significance was acknowledged as early as 1888, when Henry Edmunds marveled in a lecture on the graphophone that "the idea of simply mechanically reproducing the human voice" had "lain dormant" for so long after Robert Hooke's seventeenth-century tonewheel experiments.[39] Specifically, Hooke had "shewed an experiment of making musical and other sounds by the help of teeth of brass-wheels; which teeth were made of equal bigness for musical sounds, but of unequal for vocal sounds," before the Royal Society of London on 27 July 1681.[40] In spite of Edmunds' remark, the tonewheel idea had not really "lain dormant" since Hooke's day. In an article of 1829, Robert Willis describes using toothed wheels in connection with springs of variable length to synthesize vowel-like sounds.[41] About the same time, Félix Savart used a toothed wheel to study the frequency range of human hearing, and the device he employed is still known as the "Savart wheel" among acousticians today.[42] The teeth of early tonewheels had generated sound by plucking at quills, cards, and the like, but the same concept was later used for synthesizing sounds by electricity. Charles Delezenne of Lille used a toothed wheel to generate an intermittent current for producing musical pitches by electromagnetism in the 1830s.[43] Elisha Gray, Alexander Graham Bell, and Edison himself later pursued acoustic telegraphy systems employing similar "breakwheels,"[44] meaning wheels whose circumferences alternated between conductive and nonconductive regions and so would make and break a current when rotated past a contact point. In short, the tonewheel was well established as a means of synthesizing sounds by 1877, mostly in terms of single frequencies

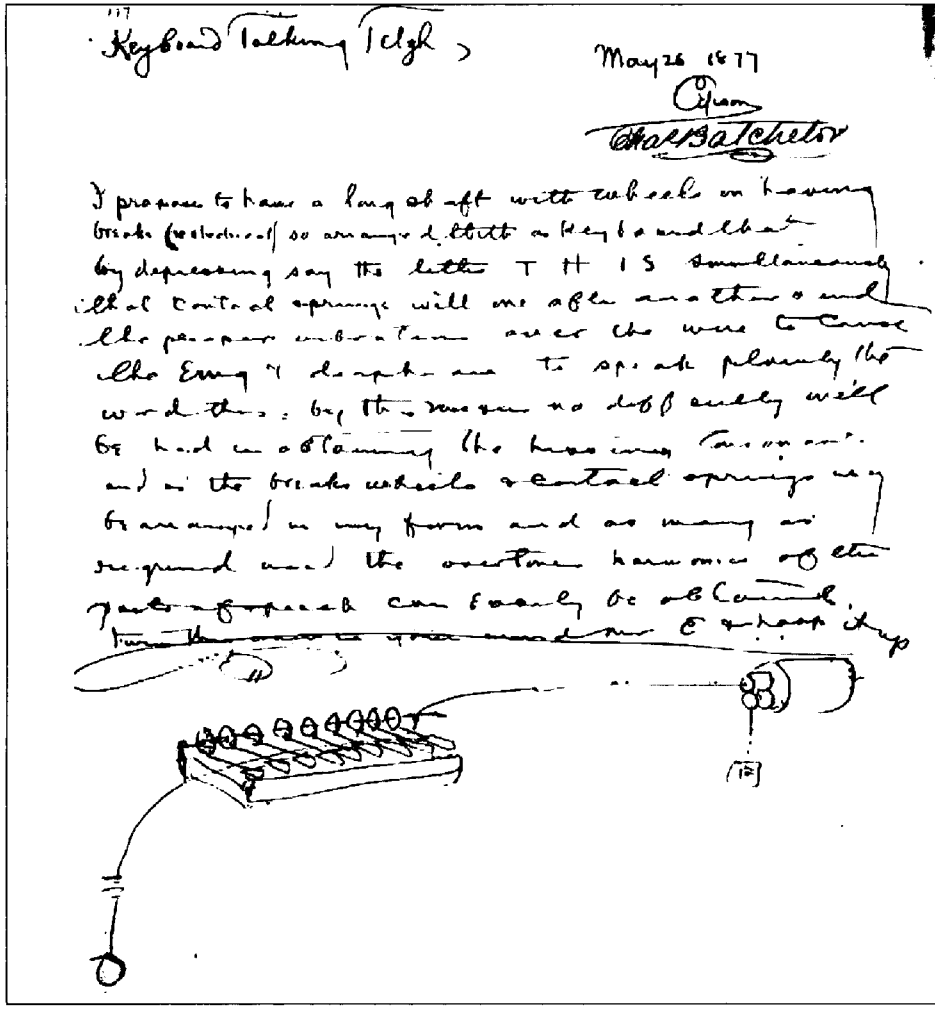

Figure 4. Keyboard telephone, design of 26 May 1877 (TAEM 3:981/TAED NV11109)

corresponding to regularly spaced teeth or electrical breakpoints.

The keyboard telephone plan of 26 May 1877 centered on the novel idea of using tonewheels to synthesize speech sounds. Edison recorded his inspiration as follows:

I propose to have a long shaft with wheels on having breaks (i.e., electrical) so arranged ~~th~~with a Key board that ~~is~~by depressing say the letters T H I S simultaneously that contact springs will one after another send the proper vibrations over the wire to cause the Emg [electromotograph receiver] *& diaphra*[g]*m to speak plainly the word this= by this means, no difficulty will be had in obtaining the hissing consonants and as the breaks*

wheels & contact springs may be arranged in any form and as many as required used the overtones harmonics of the parts of speech can easily be obtained[45]

Instead of speaking into the telephone, then, a user was supposed to type out a message on a keyboard connected with a set of electrical breakwheels, each of which would correspond to a different frequency. By pressing the T, H, I, and S keys, the user would set particular combinations of wheels in motion, making the apparatus transmit composite signals corresponding to the sounds that make up the word *this*. Edison writes of "letters," but he does not seem to distinguish these from what we would now refer to as phonemes and perhaps had not yet come to appreciate that English orthography does not correspond exactly to pronunciation (e.g., the *th* in *this* is not really a composite of *t* and *h*). I am not sure why all the keys were to be pressed simultaneously, which seems counterintuitive, but perhaps the plan was actually to hold down the keys of *adjacent* letters simultaneously – first T and H, then H and I, then I and S – so that the sounds would blend together. Instead of splitting speech apart into its simple vibrations like the telephone "printer," the keyboard telephone would have combined the same ingredients to produce synthetic speech; in this respect, the two proposals complemented each other nicely. We do not possess any document in which Edison explains the circumstances under which he thought his keyboard telephone might be used, or what its practical benefits might be. However, he emphasized its presumed ability to produce the elusive "hissing sounds," the word *this* being a good example of a problem word, so perhaps he thought of it as an alternative to the ordinary telephone transmitter, just in case the latter could never be made to work satisfactorily. In lieu of an explicit use scenario, we can infer that a telephone system in which people keyed in messages alphabetically on one end and heard them "spoken" on the other would still have been an improvement over telegraphy, since it would have freed them from the need to master Morse code.

Edison's notebook entries of 26 May 1877 show that he was then already eager to build both a speech recorder and a speech generator, both for use in connection with the telephone. A widespread misconception about speech acoustics had suggested to him a way to realize these aspirations, and he had immediately seized on it. The phonograph was, therefore, actually to be Edison's *second* attempt to devise a technology capable of serving these two ends. Whatever the phonograph may have owed to an accidental discovery or sudden flash of insight, therefore, it was also the answer to a pair of problems Edison had already formulated: he had in mind what it should do, at least in part, before he knew how it would do it.

11 July 1877: "Sufficient Number of Teeth and of Different Heights"

Edison's new understanding of speech acoustics must not have yielded very gratifying results, since he seems quickly to have abandoned it. Having unsuccessfully sought the key to successful speech transmission in two different acoustic parameters – sheer amplitudes (in March) and straightforward combinations of frequencies (in May) – he began speculating on June 6 that the "stress of air" accompanying the elusive "hissing" sounds "carries the diaphragm forward and holds it from vibrating freely,"[46] and he continued to focus on the practical implications of such "wind pressure" through the middle of July.[47] On 11 July he

signed a new telephone patent application in which he justified his approach as follows: "By this arrangement it is sought to produce such undulations of the electric currents passing over the line that they will represent the inflections of the human voice speaking into the transmitting-resonator."[48] His choice of such words as "undulations" and "inflections" seems to betray a new appreciation for the complexity and mystery of the phenomenon he was proposing to transmit, but it reveals little about the specifics of his latest thoughts.

On 11 July 1877, the same day Edison executed his new telephone patent application, he also sketched out a second model of keyboard telephone (Fig. 5). The revised model incorporated a vitally important innovation: "30 wheels each having sufficient no of teeth & of dif heighths *[sic]* to give proper vibration of spring & contact against plumbago & proper pressure by teeth being low & high to send letter over wire & have it reproduced = each key sends letter & words may be sent by proper depression of several letters."[49] Again, although Edison writes of "letters," he really appears to mean what we would now refer to as phonemes; after all, he acknowledges the need to provide for thirty of them, whereas there are only twenty-six "letters" in our alphabet. To produce these thirty speech sounds, Edison was now proposing to rely on the use of individual wheels with more complicated patterned surfaces, not on combinations of single-frequency breakwheels. Specifically, he would give the wheels teeth in varying numbers and heights, corresponding to both frequency and amplitude. Despite acknowledging (at last) that frequency and amplitude were both significant parameters, Edison still does not seem to have recognized that the overall "shape" of a composite waveform was essential for mediating overtone patterns – after all, his wheels were to contain discrete teeth, not complex undulatory shapes. His vague talk of "undulations" and "inflections" thus appears to mask a continued treatment of speech sounds as comprised of simple impulses of varying force.

On the other hand, Edison's plan for producing speech sounds from individual wheels with complex surfaces does presuppose an insight which he later attributed to one of his eureka experiences. When running dots and dashes through his embosser at high speed, he had noticed that it "gave off a humming and musical sound, which varied according to the characters in the record, apparently talking in a language which could not be understood,"[50] or "a musical, rhythmic sound resembling that of human talk heard indistinctly,"[51] and if this process was able to generate speech-like sounds from an embossed record, he reasoned, then with a different kind of record it might also be able to generate the sounds of actual speech. The tooth is merely the inverse of the embossed dot, so I believe we can see in the toothed wheels of the revised keyboard telephone Edison's first effort to incorporate this flash of inspiration into a workable design – always presuming there is some truth to this particular eureka story.

Tonewheels for "Reproducing" Sound

It is also noteworthy that Edison used the verb "reproduce" to refer to what his keyboard telephone would do. This term had appeared in his first telephone patent in connection with the transmission of speech,[52] and he had also used it when writing about his embosser in connection with the retransmission of a Morse code record,[53] but he had never before applied the word to "speech" without any human speaker. In following up the analogy with the embosser, Edison may have found it conceptually useful to imagine his new method for generating sounds as "reproduction" even in the absence of a "record-

ed" original to reproduce. Indeed, he told a *Strand Magazine* reporter in 1905 that, as a result of hearing the artificial humming, he had imagined using complex surfaces to "reproduce" sounds before thinking of recording as a method for inscribing the surfaces:

Simply as a matter of inspiration *the idea of a talking machine occurred to Mr. Edison, and, remembering his experiences with the automatic telegraph transmitter, he concluded that, if the undulations on the strip could be given the proper form and arrangement, a diaphragm could be vibrated so as to reproduce any desired sounds. The next step was to* form *the proper undulations on the strip, and the idea was then suggested to Mr. Edison's mind that these undulations could be produced by* sounds themselves, *which could then be reproduced.... It is, therefore, rather an interesting fact that in the development of the phonograph the reproduction of the sounds* preceded *the original production of the record.*[54]

This interview took place almost three decades after the events it describes, but I take the fact that the reporter expressed surprise about this assertion as evidence in favor of its truthfulness – it is not a detail likely to have been interpolated into the story on the basis of presumed common sense.[55] Edison's keyboard telephone design of 11 July embodies the concept of sound "reproduction" from complex surfaces without setting forth any method of recording and so is likely to mark the brief interlude between Edison's two eureka experiences.

In mid-July, the keyboard telephone project suddenly drew an enthusiastic response from outside the laboratory. Edison's colleague Edward Johnson was then busy conducting a series of telephone exhibitions in Philadelphia, and the organizers had assigned him the task of contributing material to the newspapers calculated to stir up interest in Edison and his work. "Hence I want you to give me every day or so often as you can some little Scientific note or observation that you have made that is new," Johnson had written to Edison. "I think it is the very finest kind of an opportunity for you to inform the world what you have been doing – These little squibs will be copied by papers the Country over as well as by papers abroad." The lectures themselves were to be given by George Barker of the University of Pennsylvania.[56] Unfortunately, we do not possess any of Edison's "little scientific notes or observations," but we do have Johnson's replies to them. From these, we know that Johnson received a letter from Edison on 10 July with a "record" enclosed, apparently made by the embosser; that Johnson wrote back that same day, asking for a new telephone transmitter;[57] that Edison responded by promising to send one by 12 July; and that Johnson wrote back on 17 July fretful that it had not yet arrived. The second of Edison's aforementioned letters, presumably sent on or before 12 July, must also have included an update on progress towards the keyboard telephone, judging from Johnson's reply: "Now as to the latest Idea of mechanically speaking the Letters of the alphabet. Prof. B. *[i.e., George Barker]* is delighted & says it looks as if you might reach by a short cut the end sought by scientists for ages, viz – the ascertainment 1st of what constitutes a vocal sound of a letter & 2 – How to mechanically reproduce it – It was that Letter which decided him to take his guests to Menlo Park."[58] What Barker probably meant was that if a toothed wheel could successfully simulate the sound of a given letter, as proposed in Edison's new keyboard telephone design of 11 July, this would prove that its pattern of teeth truly corresponded to the letter's distinctive acoustic properties. But an enormous practical obstacle would have remained: how could Edison "ascertain" the properties of

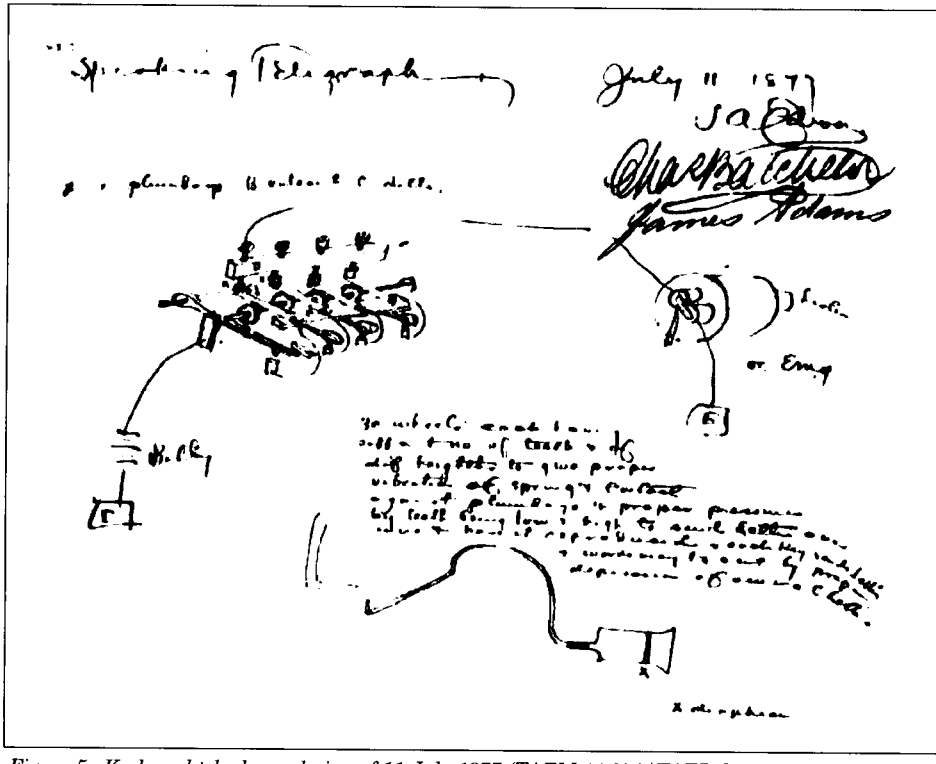

Figure 5. Keyboard telephone, design of 11 July 1877 (TAEM 11:356/TAED TI2186)

given speech sounds in the first place? It was one thing to imagine wheels with elaborately toothed surfaces generating the various sounds of articulate speech, but quite another to determine, for each sound, how many teeth would be necessary and how high or low each tooth would have to be. Perhaps Edison had already hinted at a method for "ascertaining" this elusive information "by a shortcut" in his lost letter to Johnson, written on 11 or 12 July. Unfortunately, we have no way of knowing – but we do know where he is supposed to have got the idea when he *did* get it.

"Many Sore Fingers"

Edison is supposed to have been inspired to try recording sound by his other eureka story, the one in which he felt the vibrations of a telephone diaphragm. He later recalled that he had adopted the practice of testing the sensitivity of diaphragms by touch because his partial deafness made it difficult for him to hear experimental results in the ordinary way, and that he had attached needles to diaphragms to heighten the tactile effect (although sources differ widely as to the rationale behind affixing a needle to the diaphragm).[59] The decisive moment is supposed to have come when one of these needles pricked Edison's finger hard enough to cause physical injury: the invention of the phonograph "cost me many sore fingers," he later joked.[60] Sometimes the significance of this episode is held to be that it had

made Edison aware of the sheer mechanical force of the vibrations: "If the disc has power enough to prick my finger,' thought 'The Wizard,' 'it has power enough to make a record which can be reproduced."[61] However, some early accounts claimed that the needle had actually scratched Edison's finger, leaving visible dots and dashes of blood.[62] In that version of the story, he would have just inadvertently made a short "record" looking remarkably like the sketch of telephone signals he had drawn for his attorney on 23 March – but this time produced automatically, and with his own skin as the medium.

In retrospect, we naturally associate Edison's eureka stories with the invention of the phonograph, since that is the big success to which they ultimately led. At first, however, it seems Edison and his colleagues must have interpreted them from a very different perspective – as breakthroughs in a specific project they already had in the works. Edison had first imagined the keyboard telephone in May, when a brief flirtation with Helmholtz's theory of overtones had led him to believe that speech sounds ought to be easy to synthesize, but he had since abandoned the relevant view of speech acoustics as unhelpful. To pursue the idea further, he would have needed to find a new approach to the task of producing speech sounds artificially, and the speech-like humming of his embosser had suggested just that: a single surface embossed with dots of different depth, or fitted out with teeth of different heights, moved past a contact point at high speed. The next logical step would have been to identify the impulse patterns characteristic of each sound, and the finger-pricking incident had suggested a means of doing so: he could record some samples of actual speech sounds and then search for patterns in the inscriptions. The goal of developing a keyboard telephone had thus furnished Edison with a compelling reason to seek out the phonograph principle. It would not have struck him as a random discovery of uncertain application, but as a solution to a problem already formulated.

17 July 1877: Speech "Reproduced Slow or Fast"

The first document among Edison's papers that refers unambiguously to the concept of recording and reproducing sounds phonographically is dated 17 July 1877 – and it is tantalizingly incomplete. Here is what appears on the page we have:

Sp[ea]*k*[in]*g telephone*
reproduced slow or fast by a copyist & written down This can be applied telegraphically thus [illustration shows a telephone receiver at the end of a line, with "Telephone transmitter same as my Talker Transmitter" written at the other end; a point attached to the receiver touches the circumference of a circle, presumably representing a wheel-shaped or cylindrical recording surface of some kind, and this circle is also in contact with a reproducing diaphragm.] *Sheet after received is sent to Copyist whole* [sic, presumably "who'll"] *pass it in machine similar to that shewn on other page & copied at rate of 25 words per minute whereas it was sent at rate of 100 per minute thus Saving all skilled op*[e]*r*[ator]*s & 5 persons doing work of .8. Emg* [electromotograph] *might be used instead of magnet to receive it might be done in other ways besides indenting – such as perforating with needle or by a friction ink=* [illustration shows the spiral groove of the embosser with two tonearms.] *Revolving plate two telephone tubes=*[63]

Edison has now clearly decided to use the mechanism of his embosser to *record* the

sounds of speech: the medium would be indented not by telegraphic dots and dashes, but by the impulse patterns of the human voice, which could be reproduced from the record in turn. Beyond that, the fragmentary nature of this document makes it challenging to interpret. The opening line seems to start in mid-sentence, since it does not make sense as a continuation of the heading (the "speaking telephone" was certainly not being "reproduced"), and the reference to the "other page" appears to confirm that something is missing. We must accordingly bear in mind not just what is on the page we have, but also that it once formed part of a larger whole whose full scope we cannot now assess.

Let's try to reconstruct at least some of what the lost "other page" must have contained. First, it evidently depicted a "machine" through which messages could be "passed" for reproduction. It must also have ended with some phrase equivalent to "the message can be..." that could appropriately have continued "...reproduced fast or slow," but "message" is not a viable antecedent for "this," as in "this can be applied telegraphically," so "this" must instead refer to a broader concept set forth on the missing page – one that corresponds to the idea illustrated by the telephonic or "telegraphic" arrangement, but which lacks the extra element of transmission over a distance. The illustration shows a telephone signal being recorded phonographically, so "this" should refer to a means of recording an equivalent signal *not* transmitted over a distance, which could only have been the immediate human voice. We can therefore infer that the page break occurred while Edison was in the middle of proposing that records made directly from speech could be "reproduced slow or fast by a copyist & written down," presumably using the "machine" he had depicted. Of course, we do not know how he framed this proposal or what other jottings might have preceded it, but I believe my reconstruction is defensible as far as it goes.

Paul Israel reproduces the note of 17 July in facsimile in his Edison biography with the caption: "Edison's first conception of the phonograph was as a way to record telephone messages so they could be played back and transcribed at a slower speed in a manner similar to his Morse recorder practice instrument."[64] As we have seen, a closer analysis of the document suggests that Edison was actually proposing to capture speech *directly* in addition to recording incoming telephone signals, but the goal of slowing messages down for transcription was central to both cases. The "practice instrument" Israel mentions dated back to Edison's sojourn in Indianapolis in 1864-65, when he had recorded press reports on an old Morse register at their usual breakneck speed of forty words per minute and had then run the indented tape through a second register at a reduced rate of twenty-five or thirty words per minute to activate a telegraph sounder. This device had enabled him to take press reports by ear at a more manageable speed, at first just for practice, but later to produce actual press copy for newspapers.[65] As Israel observes, the document of 17 July can be understood as an effort to adapt this same use scenario to the human voice. However, the plans outlined in this document would not actually have worked. To put the proposal in terms of the standard turntable speeds of the mid-twentieth century, it would have been equivalent to playing back a 78 r.p.m. record at 16 r.p.m. The slowed-down speech would have been unintelligible, though neither Edison nor anyone else would yet have been in a position to know this.

"The Phonographic Alphabet Was Impossible"

The other surviving laboratory notes from 17 July show that Edison and his colleagues spent much of the day grappling with the perennial challenge of trying to get telephone transmitters to pick up "hissing" sounds, composing such appropriate test utterances as "hemidemisemiquaver," "the vibration of the oscillation," "physicists and sphynxes in majestical mists," and "the majestical myth which physicists seek" in the process.[66] This work continued on 18 July, when they recorded their first new hypothesis regarding the cause of the difficulty since the beginning of June: namely, that "vocal or vowel vibrations" emerge from the mouth in a straight line, right into a telephone transmitter, whereas "hissing vibrations" do not.[67] "I have experienced great difficulty in reproducing the sound of the hissing consonants, such as *s*," Edison later explained; "this appears to arise from the fact that this sound is deflected downwardly in leaving the mouth, and does not act distinctly upon the diaphragm."[68] Another idea advanced on 18 July was that of introducing "a hiss sound produced by a tuning fork arranged to give a number of Contacts 1 after the other," and Edison drew a row of irregular dots and dashes to illustrate the sound in question, using the same proto-phonographic format he had chosen when illustrating telephone signals for his patent attorney back in March.[69] Finally, at the bottom of one of these pages of telephone notes, we find this oft-quoted statement: "Just tried experiment with a diaphra*[g]*m having an embossing point & held against para*ff[f]*in paper moving rapidly the ~~nam~~ sp*[ea]*k*[in]*g vibrations are indented nicely & there*[']*s no doubt that I shall be able to store up & reproduce automatically at any future time the human voice perfectly."[70] Edison had now demonstrated that it was in fact possible to record speech sounds using the phonograph principle, and he assumed he would be able to reproduce them as well (though he did not specify whether or not he had yet tried to do so). We have a fragmentary record of some use scenarios he had associated with this process the day before. But how did he *actually* try to apply his discovery in the short term?

It is easy to assume that Edison must immediately have realized that he had "invented the phonograph," since it is so blatantly obvious to us in retrospect. However, he appears at first to have continued to prioritize the keyboard telephone project as the most exciting application for his discovery: at last he could determine what patterns he needed to emboss on wheels in order to synthesize the individual phonemes of articulate speech. Around 19 July, he finished preparing a British provisional patent specification covering improvements in telephony, and he introduced his newfound ability "to make a record of the atmospheric sound waves, or the electric waves, or pulsations corresponding thereto or resulting therefrom" among the topics to be covered. The final specification, which Edison signed on 24 December, sets forth some designs we can easily recognize today as "phonographic," but the only potentially relevant passage in the remainder of the provisional document from July describes the keyboard telephone:

For transmitting and receiving letter by letter, I employ a shaft with 30 wheels, and contact springs resting upon them; the wheels are provided with teeth of such number and character that they will cause the springs to be vibrated against a plumbago point the necessary number of times, and with proper pressure to transmit the letter, which is rendered audible at the distant station by the magnet or frictional surface. Each wheel is controlled by a key of a key board.[71]

The connection with phonography is not made explicit here, but the only method Edison had conceived for determining the patterns required for the thirty "letters" or phonemes of the keyboard telephone was that of phonographic recording. Furthermore, Edison did not simply choose utterances for testing experimental sound media at random – for instance, "the majestical myth which physicists seek" had consciously targeted the problem of "hissing" sounds – and his early choices of utterance for testing the phonograph principle point towards a goal of gathering the specific sound samples he would have needed for the keyboard telephone: individual "letters" rather than words. A 1904 account states that his first experiments had aimed specifically at the recording and reproduction of the letters of the alphabet:

He placed a strip of yellow paper under the steel point, replaced it in the mouthpiece and said the alphabet. The steel, while he spoke, ran over the paper, and for each letter of the alphabet it made a different mark or scratch.

This was what Mr. Edison had hoped for. He now held the steel point still and drew the paper scratches slowly over it. There was given forth, very faintly, the alphabet as he had repeated it.[72]

In terms of the keyboard telephone project, the results of such an experiment would have been encouraging. Each letter had made "a different mark or scratch," and the fact that these marks and scratches could "reproduce" the letters implied that they would also be able to generate the necessary sounds if converted into teeth on the wheels of the keyboard telephone. Difficulties arose only when Edison attempted to discern consistent patterns in the inscriptions. Not only did each letter make "a different mark or scratch," but so, unfortunately, did repetitions of the *same* letter, as he acknowledged during an interview in the spring of 1878:

"How long ago did you get the idea of the phonograph?"

"Only last July. It is a mechanical invention, begotten out of an attempt to emboss an alphabet for telegraphy [i.e., the keyboard telephone project]. *I found that repeating the letter 'A' many times produced an ever varying puncture, all of unlike depth or size under the microscope. Then it was plain that the voice was its own recorder and measurer. The phonographic alphabet was impossible, but articulation was easy."*[73]

Edison claimed to have recorded the letter A over and over and to have examined the results under a microscope, hoping to find regular patterns. Finding no rhyme or reason to the "punctures," he had concluded it was impossible to "measure" the "phonographic alphabet" and that he had not discovered the means of synthesizing speech sounds he had been looking for after all. Years later, during the hearings that culminated in the 1909 Copyright Act, an attorney confirmed that Edison had once "examined with a microscope each particular indentation" produced by uttering the letter A and "made a drawing of it," and that the results had utterly defied analysis.[74]

"Halloo!"

Early accounts agree that the first utterance Edison recorded experimentally was "Halloo! Halloo!," disagreeing only in their spellings of it.[75] This would have been a natural choice. Surely a rousing "halloo," a shout traditionally used to summon a person's attention at a distance, was powerful enough to make a record if anything was. Indeed, Edison later revealed his association of the word with sheer volume and carrying power in his comment on one tinfoil phonograph arrangement: "I can *speak* into it from a distance of six feet and can *halloo* into it twelve feet."[76] The connection of such a shout to the keyboard telephone project may not be immediately apparent. However, Edison did later refer to the "halloo" test as having "made an alphabet,"[77] reflecting the association of his early experiments in general with "alphabets," and determining whether the voice could make an intelligible record *at all* would necessarily have preceded more specific studies of individual speech sounds. Later on, Edison repeatedly chose "hello" (a variant of "halloo") to illustrate his argument that phonographic records could not be read visually, as he does in an interview published in 1889: "Suppose I say 'hello' in a full chest voice, 'hello' in a squeaky nasal tone and again 'hello' in ordinary conversational voice, what is the result. Three entirely different records are made."[78] A correspondent suggesting a plan for recording telephone messages visually received a reply along similar lines in 1891: "Mr. Edison has instructed me to say to you that, if ten men were to speak any particular word into the phonograph, 'hello' for example, there would be no resemblance whatever in their records."[79] Furthermore, the *Scientific American* published an "enlarged tracing of the phonographic record of the word 'hello'" to accompany an article on Edison's new wax cylinder phonograph in February 1888 (Figure 6).[80] Judging from these cases, it seems that Edison favored "hello" as a test utterance when he wanted to produce traces mainly for visual apprehension, and also that he had come to link the word "hello" to his argument that phonographic records of speech were visually undecipherable. All this is consistent with the view that Edison thought of his first experimental "halloo" mainly as part of the failed keyboard telephone project – and that he remembered its lesson well.

"It's a Talking Machine, and None of Us Realized It"

It was a week and a half into August 1877 before Edison is known to have drawn up any further notes based on the phonograph principle, and then he returned specifically to the idea of slowing speech down to a speed at which it could easily be transcribed. The "phonograph," by that name, was to be used to record incoming telephone signals, such as speeches transmitted to New York from the Senate in Washington, so that the words could be played back at low speed for transcription – perhaps even over the telephone. This was still the only use scenario Edison and his colleagues had spelled out in laboratory notes by the start of November.[81] However, they did also draft a tentative press release on 7 September, noting that Edison

has gone into a new and entirely unexplored field of acoustics which is nothing less than an attempt to record automatically the speech of a very rapid speaker upon paper; from which he reproduces the same Speech immediately or year's [sic] *afterwards preserving the characteristics of the speakers voice so that persons familiar with it would at once recognize it.*[82]

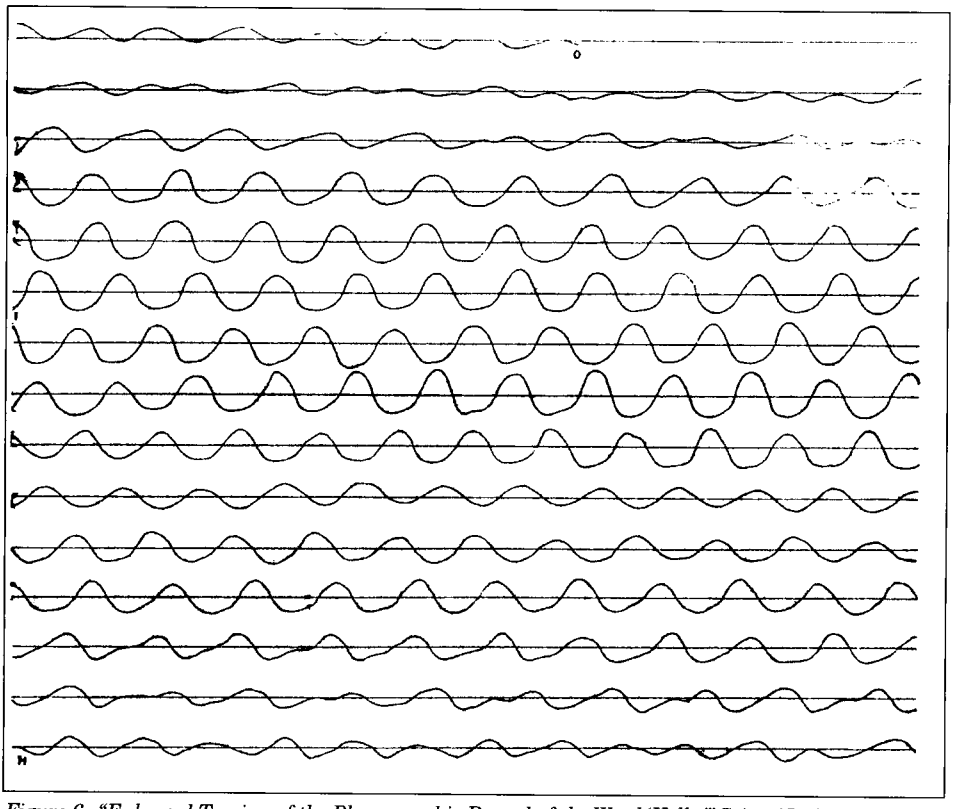

Figure 6. "Enlarged Tracing of the Phonographic Record of the Word 'Hello,'" Scientific American Supplement *1888; 632 (11 Feb.): 10097.*

Here we have evidence of two cognitive breakthroughs: first, that Edison's discovery had significance for acoustic science in the abstract; and second, that the phonograph would capture the paralinguistic "characteristics" of speech rather than uniform "letters" and words. The latter point had an eminently practical application: during 1878, the ability of listeners to recognize individual recorded voices was celebrated as a better safeguard against forgery in legal and business documents than distinctive styles of handwriting or signatures,[83] and Edison and his colleagues may already have thought of this advantage, leading them to foreground the possibility of such recognition.

Edward Johnson was to play an important role in the further development of these concepts. He had received another note from Edison by 25 July, prompting him to reply: "Your last letter was simply astounding – I am already getting anxious to pay you a visit to see these things for myself."[84] As usual, Edison's letter is lost, so we do not know what "these things" were, but it had probably contained some reference to sound recording, judging from Johnson's follow-up letter on August 4, describing his latest Philadelphia telephone exhibition: "Green *[i.e., C. W. Greene]* of the Exhibition Co did the speechifying the other night & told the audience what you proposed to do in the way of recording

speech – I am sorry it is not a little later in the season so that Barker & some more of the Scientific Cusses could be here." He then set off to give some telephone lectures on his own, the first of which took place at Cape May, New Jersey on 12 August.[85] One of these events was reported in the *Philadelphia Record* as follows:

CAPE MAY, August 14, 1877. – Professor Johnson, the right-hand man of Professor Edison, treated the guests at the Stockton to a sensation by the announcement that Edison had also invented an instrument by which a speech can be recorded while it is being delivered, on prepared paper, by the simple articulation of speaking, and from the same paper the speech can at any time be redelivered automatically.[86]

It is unclear how prominently the phonograph principle featured in Johnson's presentations over the next couple of months. At some point after mid-October, however, he produced a print edition of his talk, "offered as a substitute for extended remarks in the course of an entertainment, in order that the demonstration of the working of the instruments be more full and complete,"[87] in which he explains of the principle behind Edison's "translating phonograph," including its preservation of paralinguistic features of speech. Still, he cites only the limited use scenario involving the playback of recorded telephone signals:

The idea being to record speech, and at any time – five, ten or fifty years subsequently – to redeliver it with all the vocal characteristics of the original speaker.... [H]*e will be able to transmit a speech from Washington to New York, and automatically record it for immediate or future redelivery. A speech delivered on the floor of the Senate could be transmitted to New York, there automatically recorded, and, by the application of telephones, redelivered in the respective editorial ears of the New York dailies.*[88]

Johnson does not explicitly mention Edison's plan of slowing recorded speech down for transcription, but the telephonic "redelivery" of Senate oratory to New York's "editorial ears" would only have been practically useful if it had somehow facilitated the job of getting the speeches into print.

The *Scientific American* for 3 November 1877 contained an item that may have worried Johnson that Edison's idea was about to be scooped by foreign rivals. The next issue, it stated, would contain an account of an instrument devised in France by Dr. Rosapelly and Professor Marey to make a visible record of "the movements of the lips, those of the veil of the palate, and the vibrations of the larynx" in order to help deaf mutes learn to speak. The writer speculated that a further use for this "automatic phonography" would be

vocal speech translated into phonographic short hand at any distance from the speaker. It appears quite possible with the apparatus of M. Marey aided by well known electrical appliances for the words of a speaker in New York to be taken down in legible short hand in San Francisco. This is an application scarcely anticipated by the inventors and their apparatus is perhaps not the best adapted to that particular end, but still it possesses none the less the "promise and potentiality" of that wonderful result.[89]

In fact, Rosapelly and Marey had designed an intrusive device that had to be in direct physical contact with a speaker's mouth, and nothing in the upcoming article had even

hinted at using the results for telegraphy or telephony; it only envisioned teaching deaf mutes to talk.[90] However, it must have seemed to encroach on the one use scenario Edison and Johnson had thus far envisioned for the phonograph principle – apart from the keyboard telephone – because Johnson fired off a letter in response, ostensibly with Edison's permission. In opening, he cites the editors' "prophesy *[sic]*" that Marey's work "may lead possibly to the application of electricity for the purpose of transferring these records to distant points by wire" (they had actually suggested that speech might be recorded *at* distant points). He then goes on to describe the phonograph in much the same terms as his *Telephone Hand Book,* with one significant and fanciful departure: "A speech delivered into the mouthpiece of this apparatus may fifty years hence – *long after the original speaker is dead* – be reproduced audibly to an audience with sufficient fidelity to make the voice easily recognizable by those who were familiar with the original."[91] The fifty-year duration had not changed, but the implications for the affective value of sound recordings certainly had.

Just over ten years before, the *Scientific American* of 4 May 1867 had contained an essay on the possibility of "photographing" sound so that it could be "given back" in a manner analogous to the development of photographic negatives: "the speech of an orator would be handed down to all time and all mankind exactly as it sounded from the lips. All books worth reading *verbatim* would be read to the phonograph by elocutionary experts, and thenceforth read by the phonograph to the hearing (not reading) public, who would thus be saved the labor of reading, and perhaps the art itself would go out of fashion."[92] Johnson's letter finally supplied a means for accomplishing this end. The *Scientific American* of 17 November 1877 – actually sent out to subscribers about 6 November – accordingly prefaced Johnson's announcement with an editorial rhapsodizing about the promise of hearing the familiar voices of the dead, substituting recorded oratory for books, and disseminating prerecorded musical performances.[93] Newspapers across the country picked up the story and speculated about the potential of the invention, often adding some new ideas of their own.[94] This media frenzy, in turn, inspired new brainstorming sessions at Menlo Park: on 23 November, Edison drew up a tentative list of additional use scenarios including phonographic toys, musical boxes, and public advertising.[95] Until this time he appears to have had only a very limited sense of the phonograph's potential scope of application.

Two of Edison's colleagues were later to tell two very different stories when asked how the phonograph came to be invented. Charles Batchelor, focusing on *how* the instrument worked, recalled that Edison's flash of inspiration with the telephone diaphragm had led immediately and inexorably to the tinfoil phonograph, even though we know that these developments really took half a year to unfold.[96] On the other hand, Edward Johnson, focusing on *why* the phonograph had seemed like a good idea, repeatedly claimed that Edison had not realized the potential of his discovery until public feedback had alerted him to it. Johnson's story centers on a lecture he remembered giving at Buffalo, New York, but the details vary from version to version. In a version from 1887, he recalls that his audience had reacted with such enthusiasm to a vague plan for a "talking machine" that he had rushed back to urge Edison to carry it out,[97] but in versions from the 1890s he states that he had merely described a "telephone repeater" and that the very notion of a "talking machine" had been new to him:

My audience seemed to have a much clearer appreciation of the value of the invention than we had ourselves. They gave me such a cheer as I have seldom heard. I did not comprehend the importance of the device at the time: but the next morning the Buffalo papers announced in glaring headlines, "A Great Discovery: A Talking Machine by Professor Edison. Mr. Edison's Wonderful Instrument will Produce Articulate Speech with all the Perfections of the Human Voice." I realized for the first time that Edison had, as a matter of fact, invented a talking machine.[98]

A Buffalo paper of the following morning published in large headlines:

Edison's Latest Marvel – A Talking Machine.
The Wonder of the Age.
Described Last Night in Buffalo.
By Prof. Edward H. Johnson.

Mr. Johnson, on reading this, realized for the first time what Edison had invented, and canceling the dates for his remaining lectures, hurried back to Menlo Park. "Well, what brought you back so soon?" said Mr. Edison, in surprise. "This," he said, pointing to the newspaper account. "What's wrong with it?" asked Mr. Edison. "Wrong with it? Nothing. It will make your fortune. See here!" handing to his amazed superior the newspaper. "Do you see what this thing is? It's a talking machine, and none of us realized it."[99]

Past historians of the phonograph have been dismissive of Johnson's account. "It seems very unlikely that a man with Edison's quick turn of mind would remain insensible to the potentialities of his experimentations until a headline writer had pointed them out," writes Roland Gelatt.[100] Furthermore, my search of the *Buffalo Evening News* and *Buffalo Express* between August and November 1877 has failed to turn up any reference to a lecture by Johnson, although similar local events were routinely announced. Still, Johnson's account does contain a kernel of truth, since it was not until his letter to the *Scientific American* had inspired a trickle of popular speculation that Edison's notes began to display a real awareness of the possibilities of the phonograph.

Edison and the Phonautograph

Numerous commentators have claimed that Edison must have known about Léon Scott's phonautograph at the time he invented the phonograph, and that his method for recording sound was not, therefore, an independent discovery. "Mr. Edison was well acquainted with Mr. Scott's phonautograph," stated the Count du Moncel in 1878, dismissing as an implausible "American romance" the story about the pricked finger.[101] "The phonautograph, by Leon Scott, was a sound recorder, and gave Edison the idea of the phonograph," noted an Ohio newspaper twenty years later.[102] In 1933, R. D. Darrell complained of "an irritating tendency of the Edison biographers to ignore the fact that Edison must have been familiar with the work of Scott, whose theories were fairly common knowledge at the time, particularly among telephonic experimenters, or to imply that he first became acquainted with the phonautograph after the 1877 invention" (this remark came in the context of a broader argument challenging the value of Edison's overall contribu-

tion to the development of sound recording).[103] Despite the repeated insistence that "the American inventor was undoubtedly familiar with the older device,"[104] I do not find that there has been any serious effort to muster evidence in support of such a claim – it has simply been taken for granted.

On the other hand, Edison himself is supposed explicitly to have denied that his invention of the phonograph owed anything to the phonautograph. "I never heard about Scott until years after I invented the phonograph," his colleague Alfred Ord Tate later quoted him as having said.[105] "Years" was certainly an exaggeration, but the statement is otherwise likely to have been true. In 1878, a journalist reported Edison's comment upon seeing a phonautograph on display at the Smithsonian: "Wise men, these were, not to see that they could put a hard point and a piece of tinfoil in front of it and there was the phonograph."[106] Of Scott himself, Edison is reported to have said: "Why the deuce didn't he think of substituting a sheet of tin foil for his carbon film?"[107] In other words, Edison is represented as having expressed astonishment that anyone who had known about the phonautograph had not also thought of adapting it so that it could reproduce the sounds it recorded – hardly the reaction we should have expected from him if *he* had formerly known about the phonautograph but not made such a connection himself. Even more significant, however, is the absence of any step along Edison's path to the phonograph that could conceivably reflect the influence of Scott's work. To the contrary, Edison seems to have remained unaware throughout 1877 that composite sound waves had distinctive "shapes" – the one phenomenon acousticians had been using Scott's phonautograph to record and illustrate.

The phonautograph was not as widely known in the 1870s as we might think, and its existence would have been easy for anyone but a dedicated acoustician to miss. When Edison was asked how he had kept abreast of developments in science and technology during the period 1875-77, he replied: "My habit was to read a few of the ordinary scientific works, containing subject matter which I desired to understand, and to read the *Scientific American* and *American Journal of Science*, for current scientific literature."[108] He would have been unlikely to learn anything useful about the phonautograph from such sources. The *American Journal of Science* had published an account of a proposed improvement to Scott's instrument in 1874, together with three sample oscillograms, but the author had not bothered to explain what the basic instrument was supposed to do or how it worked.[109] The *Scientific American* had not mentioned the phonautograph since 1863, when the editors had dismissed it as indistinguishable from Lancelot Hope Everitt's "phonographic locmanaud" – a device with which it actually had nothing in common.[110] The same publication's 1867 essay on the idea of "photographing" sound further betrays an ignorance of Scott's work: the author admits to having "scarce a hint of the process" that would be required for recording sound waves.[111] Edison can hardly be expected to have known about an instrument that even the editorial staff of the *Scientific American* failed to understand. Even Helmholtz's *On the Sensations of Tone as a Physiological Basis for the Theory of Music* associates the phonautograph only with the recording of straightforward tuning-fork vibrations.[112]

Contrary to received wisdom, I believe that a fixation on the phonautograph's oscillographic method of representation may actually have impeded others' ability to develop the phonograph, since it is so much more technically challenging to work out a method for "playing back" a laterally modulated inscription than a vertically modulated one. On

30 April 1877, Charles Cros famously deposited a sealed package with the Academy of Sciences in Paris describing a method for recording and reproducing sounds. He would begin, he wrote, by recording the movements of a stylus vibrating laterally on a smoked glass plate (a medium also employed by Scott). After the record was made, in the form of a spiral, it was to be used as a negative for photoengraving. This step would produce a copy of the record on a hard substance such as steel, either as a ridge or a groove, from which the sounds could finally be reproduced.[113] Although this process should theoretically have worked, it would have been extraordinarily difficult for Cros to put into practice, as Emile Berliner found out a decade later when he pursued the same idea: it took him at least weeks, and perhaps over a year, to "get an articulate speech" from a record photoengraved in this way.[114] In March 1878, Alexander Graham Bell wrote to his father-in-law, expressing chagrin that Edison had beaten him to the phonograph:

In showing to an audience the tracings produced by the Phonautograph I had said if the motions indicated by the curves could be produced mechanically in any way the sounds would be audible. For instance I have said in my lectures that if I were to move my hand in the way indicated by these curves articulate sounds would proceed from the hand. And yet in spite of this the thought never occurred to me to indent a substance and from the indentations to reproduce sound.

In other words, Bell had thought of reproducing lateral modulations but never vertical ones, and from a practical standpoint that had made quite a difference. He goes on in his letter to criticize Edison's phonograph for controlling motion "only in one direction *[i.e., downward]*," noting that "the shape of one half of the vibration *[i.e., upward]* will be distorted,"[115] another instance in which his familiarity with the oscillographic paradigm seems to have made him less receptive to Edison's approach – and hence also less likely to have come up with it himself. Edison seems to have labored under no such cognitive constraints. All along he had been visualizing telephone signals not in terms of the wavy lines of the phonautograph but as rows of "deeper" and "shallower" dots and dashes, consistent with his peculiar belief about speech consisting of sound at one rate of vibration. For him, I believe knowledge of the phonautograph would have been a liability rather than an asset – it becomes easier to account for his invention of the phonograph if he was *not* familiar with it.

Even after the first tinfoil phonograph had been completed and exhibited in early December, Edison does not really seem to have understood the acoustic principles by which it worked. The patent application he signed on 15 December 1877, states: "I have discovered, after a long series of experiments, that a diaphragm or other body capable of being set in motion by the human voice does not give, except in rare instances, superimposed vibrations, as has heretofore been supposed, but that each vibration is separate and distinct, and therefore it becomes possible to record and reproduce the sounds of the human voice."[116] In other words, Edison thought his phonograph was viable as a transducer of speech only because Helmholtz's theory of speech acoustics was wrong. It seemed he was able to record speech in the form of embossed dots, and he assumed that each dot had to correspond to a "separate and distinct" vibration of greater or lesser amplitude, which left no room for "superimposed vibrations" or overtones. In fact, it was Edison who was wrong, not Helmholtz: overtone spectra manifest themselves in the com-

plex "shapes" of composite sound waves, and the phonograph recorded these shapes through fluctuations in depth that were not readily apparent to the eye. But Edison's error may have been a fortunate one. If he had been more thoroughly immersed in Helmholtz's theories, he might have taken it for granted that the phonograph would not work. Instead, he had embraced a hypothesis that speech consisted of simple impulses of varying intensity, encouraging him to try to record and reproduce it in those terms. Nor had he yet abandoned the doomed idea of slow-speed playback for transcription. As late as April 1878, the clerk of the future was expected to copy off a dictator's letters by "setting the clockwork to go more slowly,"[117] and it was not until May that Edison switched to the plan of instead having him write out dictation by "causing as many words to be uttered at one time as his memory was capable of retaining until he had written them down,"[118] constantly starting and stopping the machine as needed. This change in approach marked Edison's abandonment of the one clear advantage he had seen in the phonograph principle back in July 1877, outside of the keyboard telephone project.

Discussion

Let me summarize my argument here as follows: Edison's discovery of the phonograph principle did not result merely from the idea of combining two earlier inventions (the embosser and the telephone) or from a pair of fortuitous eureka experiences (hearing his embosser make speech-like sounds and feeling the vibrations of a telephone diaphragm against his finger). Rather, it emerged out of a misconception about speech acoustics (that speech consists of simple impulses of variable intensity), a corresponding format for visualizing telephone signals ("deep" and "shallow" dots and dashes), and a prospective invention that failed to materialize (the keyboard telephone, originally inspired by a different but equally wrong notion of speech acoustics). Edison appears not only to have been uninfluenced by the precedent of Léon Scott's phonautograph but to have remained ignorant of the principle acousticians had been using it to illustrate: namely, that differences in timbre correlate to differences in oscillographic shape. Indeed, I believe the phonautograph may have saddled those who knew about it, such as Cros and Bell, with a disadvantageous cognitive framework, since it is so much more logistically challenging to reproduce a sound from a lateral inscription than from a vertical one. Finally, the broader potential of the phonograph principle was not immediately obvious to Edison once he had discovered it. Until journalists had indulged in some heady speculation, the only specific use scenario he had articulated for it, apart from the keyboard telephone, was that of slowing spoken messages down to quarter speed for transcription – which would not have worked!

One obstacle that may have impeded prior efforts to trace the origins of the "phonograph principle" as I have tried to do here is that the principle itself is more challenging to define than we tend to realize. The phonograph is almost always equated with "sound recording and reproduction," but a little reflection will show that this definition does not encompass all the territory it should. Much of today's "recorded sound" is no more "recorded" than a Hollywood movie replete with computer-generated special effects; it is largely the stuff of illusion, used to generate new sounds in new contexts rather than to "reproduce" old ones faithfully. Furthermore, the phonograph cannot "reproduce" a person's voice any more holistically than photography "reproduces" a person's face; rather, it

can at most represent sounds in two dimensions from a given perspective (or from a few select perspectives, as in stereo or quadraphonic sound).[119] And yet the language of "reproduction" traps us into speaking and thinking along certain lines when it comes to phonography, since there is no more neutral terminology in common use – "playback" likewise implies an anterior playing. In fact, what we colloquially call phonographic "reproduction" or "playback" can be defined more precisely as a specific kind of illusion: artificially causing a surface to vibrate according to the pattern embodied in an inscription (a "phonogram") as though that surface were a point through which atmospheric sound waves were passing and thereby introducing a sound wave based on those vibrations into the surrounding atmosphere. This concept, which I like to call sound *eduction*, neatly fits everything from the wax cylinder of 1890 to the most heavily edited, quantized, and synthesized pop hit of 2006. And it also fits the keyboard telephone.

Researchers who have seen the phonograph only as an instrument for "recording and reproducing" sound have understandably overlooked the significance of Edison's keyboard telephone project, which does not seem on the face of it to involve "reproducing" a "record" of anything. However, once we recognize that phonographic eduction is a form of acoustic illusion (analogous to the optical trick that binds cinema to such precursors as the phenakistoscope and zoetrope), the trajectory linking the phonograph to the keyboard telephone, and to earlier manifestations of the tonewheel, becomes apparent. Furthermore, we can see that phonography did not start out as simple "reproduction" and only later inspire creative efforts to manipulate and synthesize its "records," as has generally been assumed. Instead, Edison's earliest plans for the phonograph principle turn out to have depended on speed manipulation (quarter-speed transcription), synthesis, and montage (the keyboard telephone would have spliced painstakingly inscribed phonographic "letters" together into words on the fly). In this light, such seeming anomalies as Augustus Stroh's "automatic phonograph" for the artificial synthesis of speech sounds and William M. Jewell's sampling "musical instrument" of 1891 can be recognized as developments in precisely the same direction Edison's own thoughts had originally taken.[120]

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Endnotes

1. John L. Butterfield to Edison, 24 Jun. 1889, in Thomas E. Jeffrey, ed. *Thomas A. Edison Papers: A Selective Microfilm Edition* (Frederick, Maryland: University Publications of America, 1985–), henceforth "TAEM," 128:79.
2. "Marvellous Discovery," *New York Sun*, 22 Feb. 1878 (TAEM 94:115-16).
3. Thomas Edison, "The Perfected Phonograph," *North American Review* 1888;379(June):642-3; speech of Ezra Gilliland at Electrical Club, New York City, 12 May 1888, quoted in "Edison's Perfected Phonograph," from *Electrical Review*, in *Invention*, 16 Jun. 1888 (TAEM 146:262).

4. Raymond R. Wile, "The Edison Invention of the Phonograph," *ARSC Journal* 1982;14:5-28.

5. Paul Israel, *Edison: A Life of Invention* (New York: John Wiley & Sons, 1998), 142ff.

6. The invention of the telephone has served as a central example in the study of invention as a cognitive process more generally; see Michael E. Gorman and W. Bernard Carlson, "Interpreting Invention as a Cognitive Process: The Case of Alexander Graham Bell, Thomas Edison, and the Telephone," *Science, Technology, & Human Values* 1990;15(Spring):131-64; Michael E. Gorman, "Mind in the World: Cognition and Practice in the Invention of the Telephone," *Social Studies of Science* 1997;27:583-624.

7. Gorman and Carlson, "Interpreting Invention," 156.

8. Andre Millard, *America on Record: A History of Recorded Sound* (Cambridge: Cambridge University Press, 1995), 24.

9. *The Speaking Telephone Interferences: Evidence for Thomas A. Edison* (TAEM 11:3ff), 1:3ff, 105; Elisha Gray, *Experimental Researches*, in *Electro-Harmonic Telegraphy and Telephony, 1867-1878* (New York: Russell Brothers, 1878), reprinted in *The Telephone: An Historical Anthology*, ed. George Shiers (New York: Arno Press, 1977).

10. I wish to thank Cornelia Fales for her helpful feedback on my explanations of acoustic matters, here and elsewhere in this article; of course, responsibility for anything that remains unclear or technically suspect rests with me.

11. Reese Jenkins, Robert A. Rosenberg, Paul Israel, *et al.*, eds., *The Papers of Thomas A. Edison* (Baltimore: Johns Hopkins University Press, 1989–), henceforth "TAEB," 2:526, n. 6.

12. Alexander Graham Bell, "Improvement in Telegraphy," U. S. Patent 174,465, executed 20 Jan. 1876, filed 14 Feb. 1876, granted 7 Mar. 1876; Gray's caveat is reproduced in Gray, *Experimental Researches*, 79.

13. Document dated 23 Mar. 1877 (TAEM 3:927), stating: "This is a duplicate of the order and sketch furnished to L. W. Serrell when Case 130 was ordered"; see also TAEM 11:633. In *Speaking Telephone Interferences*, 1:47, Edison states that the sketch had been "made in his [*Serrell's*] office at the time he was preparing case 130...made for his information," and that it was "dated, probably by Mr. Serrell, March 23, 1877." Edison clearly uses the phrase "rate of vibration" for frequency elsewhere, as in *Speaking Telephone Interferences*, 1:4.

14. *Speaking Telephone Interferences*, 1:263-4.

15. T. A. Edison, "Speaking Telegraph," U. S. Patent 474,230, executed 18 Apr. 1877, filed 27 Apr. 1877, granted 3 May 1892.

16. Technical note, 10 1875 (TAEB 2:685).

17. See e.g. "Sound Recording Itself," from *London Review*, in *The Living Age* 1861;70(21 Sept.):726-7.

18. Alexander Graham Bell to Alexander Melville Bell *et al.*, 6 May 1874, *Alexander Graham Bell Family Papers*, http://memory.loc.gov/ammem/bellhtml/, henceforth "AGBFP." See also drawings of the shapes produced by Koenig's manometric flames in response to vowel sounds in Alexander Graham Bell to Alexander Melville Bell *et al.*, Apr. 1874, AGBFP.

19. See e.g., the patent cited in note 12; also the illustration in the *Scientific American* 1877;36(31 Mar.):191.

20. *Speaking Telephone Interferences*, 1:47.

21. *Speaking Telephone Interferences*, 1:263-4. Serrell also explains the significance of the other drawings on the page, including the volute spiral.

22. *Speaking Telephone Interferences*, 1:47.

23. Notebook entry, 4 Apr. 1877 (TAEB 3:299-301).

24. In addition to the source just cited, Edison lists "th sh ch s" (Technical note, 26 May 1877, TAEB 3:359) and "S, T, V, P, C J etc" (Technical note, 18 Jul. 1877, TAEB 3:443).

25. J. Baile [sic, Baillé], *Wonders of Electricity,* transl. John W. Armstrong (New York: Scribner, Armstrong, and Co., 1872), 141.

26. Israel, *Edison,* 110.

27. H. Helmholtz, *Die Lehre von der Tonempfindungen als physiologische Grundlage für die Theorie der Musik* (Braunschweig: Friedrich Vieweg und Sohn, 1863), 163-80, 183-90, 582-6; for the same passages in English, see Hermann Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music,* transl. Alexander J. Ellis (New York: Dover Publications, 1954), 103-18, 120-4, 398-400. He used a slightly different configuration when using another set of higher-pitched forks, in which both prongs of the interrupting fork were used to complete the circuit.

18. Technical drawing, ca. Jul. 1875 (TAEB 2:526).

29. See e.g. Edison's proposal to use Helmholtz resonators in a caveat of 13 Jan. 1876, Document 708, TAEB 2:713; also Batchelor's testimony about Edison's use of Helmholtz resonators "to find out how much the resonator increased the volume of sound of the fork when applied to it" in *Speaking Telephone Interferences,* 1:260.

30. I am indebted to Jerry Fabris for providing this quotation.

31. "Autobiography of A. G. Bell," 6 Feb. 1879, p. 4 (AGBFP).

32. For instance, Helmholtz acknowledged that his analogous synthesis of the timbre of organ pipes was missing certain features: "doch fehlt den nachgeahmten Tönen das scharfe sausende Geräusch, welches der an der Lippe der Pfeife gebrochene Luftstrom giebt" (*Lehre von der Tonempfindungen,* 190), or in English: "of course the whizzing noise, formed by breaking the stream of air at the lip, is wanting in these imitations" (*Sensations of Tone,* 124). If he felt his system could "of course" not replicate the whizzing of an organ pipe, it is unlikely he thought it could produce, say, consonant sounds.

33. Robert V. Bruce, *Bell: Alexander Graham Bell and the Conquest of Solitude* (Boston, Toronto: Little, Brown and Co., 1973), 51. Bruce does not draw out the implications of this "mistake," for which see John M. Picker, *Victorian Soundscapes* (Oxford and New York: Oxford University Press, 2003), 100.

34. Gray, *Experimental Researches,* 36.

35. Baile, *Wonders of Electricity,* 141.

36. Notebook entry, 26 May 1877 (TAEB 3:359; TAEM 3:982).

37. Notebook entry, 26 May 1877 (TAEB 3:361; TAEM 3:980). Robert Conot, *A Streak of Luck* (New York: Seaview Books, 1979), 98, incorrectly describes the proposed format as oscillographic (like the phonautograph) rather than spectrographic.

38. W. Koenig, H. K. Dunn, and L. Y. Lacy, "The Sound Spectrograph," *Journal of the Acoustical Society of America* 1946;18:18-49.

39. A reporter once asked Thomas Watson, "Won't the receiving operators have to learn shorthand?" Watson replied: "Yes, I suppose they will. In our experiments we have generally paused after saying a sentence, so that the receiver had time to write out in long hand" ("Prof. Bell's Telephone," *New York Sun,* 23 Feb. 1877 [TAEM 94:29]). "If this verbal communication should be used for telegraphic purposes," echoed the *Scientific American,* "the messages would have to be taken down by the receivers in short hand" ("The Telephone," *Scientific American* 1877;36[31 Mar.]:200). See also TAEB 3:441, n. 1.

40. Henry Edmunds, "The Graphophone," paper read 7 Sept. 1888 at Section G of the British Association for the Advancement of Science, http://history.sandiego.edu/gen/recording/ar312.html, accessed 4 Jan. 2007.

41. Thomas Birch, *The History of the Royal Society of London* (London: A. Millar, 1756-7), 4:96.

42. Robert Willis, "On the Vowel Sounds, and on Reed Organ-Pipes," *Transactions of the Cambridge Philosophical Society* 1830;3:249-50.

43. Thomas L. Hankins and Robert J. Silverman, *Instruments and the Imagination* (Princeton, New Jersey: Princeton University Press, 1995), 275, n. 17.

44. Stanley Sadie, ed., *New Grove Dictionary of Music and Musicians,* 2nd ed. (New York: Grove, 2002), 8:78.

45. Gray, *Experimental Researches,* 27; illustration at 26; Alexander Graham Bell, *Experiments Made by A. Graham Bell (Vol. 1)*, entry for 19 Feb. 1876, p. 14-5, digitized as part of the Alexander Graham Bell Notebooks Project, http://www3.iath.virginia.edu/id/AGB/, accessed 17 Dec. 2006; T. A. Edison, "Improvement in Telephonic Telegraphs," U. S. Patent 198,087, filed 16 May 1876, granted Dec. 11, 1877, concerns "a series of revolving circuit-closing break-wheels with varying contact teeth and notches, so that each wheel produces a different number of pulsations per minute than the others, in combination with finger-keys." See also technical note, 10 Dec. 1875 (TAEB 2:684-5), esp. n. 2.

46. Technical note, 26 May 1877 (TAEB 3:360; TAEM 3:981). Despite the fact that the entry concludes with "turn this over in your mind Mr E & hoop it up," the entry is in Edison's own handwriting.

47. Technical note, 6 Jun. 1877 (TAEB 3:379-80).

48. See e.g. technical note, 18 Jul. 1877 (TAEB 3:443-6).

49. T. A. Edison, "Speaking-Telegraph," U. S. Patent 203,014, executed 11 Jul. 1877, filed 20 Jul. 1877, granted 30 Apr. 1878.

50. Technical note, 11 Jul. 1877 (TAEB 3:430-1; TAEM 11:356).

51. Speech of Ezra Gilliland at Electrical Club, New York City, 12 May 1888, quoted in "Edison's Perfected Phonograph," from *Electrical Review,* in *Invention,* 16 Jun. 1888 (TAEM 146:262).

52. Thomas Edison, "The Perfected Phonograph," *North American Review* 1888;379(Jun.):643.

53. T. A. Edison, "Speaking Telegraph," U. S. Patent 474,230, executed 18 Apr. 1877, filed 27 Apr. 1877, granted 3 May 1892.

54. Technical note, 7 Sept. 1876 (TAEB 3:128).

55. Francis Arthur Jones, "Illustrated Interviews," *Strand Magazine* 1905;29(Jan.-Jun.):421, italics in original.

56. A piece published in the *Phonogram* in 1901 places the finger-pricking anecdote "a day or two previous" to Edison's observation about the humming embosser: see "The Reverie of a Phonograph," *Phonogram* 1901;2 (Mar.): 182. However, this piece is written in the first person from the phonograph's point of view and appears more likely than the *Strand* interview to have incorporated fanciful inferences.

57. Edward Johnson to Edison, 5 Jul. 1877 (TAEB 3:416-7).

58. Edward Johnson to Edison, 10 Jul. 1877 (TAEB 3:426-7).

59. Edward Johnson to Edison, 17 Jul. 1877 (TAEB 3:437; TAEM 14:819). An archival note at the top classifies this letter as a phonograph-related document. Conot, *Streak of Luck,* 100 incorrectly identifies Johnson's letter with the "concept of printing sounds" Edison had worked out with Butler.

60. The standard explanation appears in Alfred O. Tate, *Edison's Open Door: The Life Story of Thomas A. Edison, a Great Individualist* (New York: E. P. Dutton, 1938), 115. For some alternatives, see "The Phonograph," *Boston Times,* 22 Sept. 1889 (TAEM 146:531); Charles Batchelor's memoirs in TAEB 3:445, 699; and "The Phonograph," *Iowa City Daily Press* (Iowa City, Iowa), 3 Oct. 1904, p. 6.

61. "Edison's Lucky Scratch," from *Saturday Evening Post,* in *Twin City News* (Uhrichsville, Ohio), 17 Aug. 1899, p. 4.

62. Oliver Read and Walter L. Welch, *From Tin Foil to Stereo: Evolution of the Phonograph* (Indianapolis: Howard W. Sams & Co., 1959), 17.

63. W. H. Preece, "The Phonograph," *Journal of the Society of Arts,* 10 May 1878, 536 (TAEM 25:205); *Daily Telegraph,* 22 May 1878 (TAEM 25:230).

64. Technical note, 17 Jul. 1877 (TAEB 3:440-1, TAEM 4:8). The format of this document is consistent with second pages: compare TAEM 11:386 (with similar header, date, signatures, and opening sentence fragment) and TAEM 11:387, of which it is a continuation (see TAEB 3:463-9 for a reconstruction of the original order of pages).

65. Israel, *Edison,* 143.

66. Israel, *Edison,* 26-8; TAEB 1:36-7, 659.

67. Technical notes, 17 Jul. 1877 (TAEB 3:439-40).

68. Technical notes, 18 Jul. 1877 (TAEB 3:443-6).

69. Specification for British patent 2909, filed 30 Jan. 1878, executed 24 Dec. 1877 (TAEM 92:58ff).

70. Technical note, 18 Jul. 1877 (TAEM 11:366).

71. Technical note, 18 Jul. 1877 (TAEB 3:444; TAEB 11:367). TAEB has "new" for the crossed-out word, which is hard to decipher; my best guess (and I admit that it is only a guess) is that Edison had started to write "names of the letters of the alphabet" but interrupted himself partway through.

72. Thomas Alva Edison, "Controlling by Sound the Transmission of Electric Currents, and the Reproduction of Corresponding Sounds at a Distance," British Patent 2909, filed 30 Jul. 1877, provisional document only in TAEB 3: 447; whole document in TAEM 92:56.

73. "The Phonograph," *Iowa City Daily Press* (Iowa City, Iowa), Oct. 3, 1904, p. 6; *Fitchburg Sentinel* (Fitchburg, Massachusetts), 17 Aug. 1904, p. 4; "Edison's Lucky Accident," from *Kansas City Journal,* in *Washington Post,* 16 Oct. 1904, p. 4.

74. Gath, "A Visit to Edison," *Philadelphia Weekly Times,* 27 Apr. 1878 (TAEM 25:189).

75. Statement of Frank Dyer in E. Fulton Brylawski and Abe Goldman, eds., *Legislative History of the 1909 Copyright Act* (South Hackensack, New Jersey: F. B. Rothman, 1976), 4:J:286-7.

76. "Halloo" in "Marvellous Discovery," *New York Sun,* 22 Feb. 1878 (TAEM 94:115-16) and "Phonograph," *Brooklyn Daily Eagle,* 26 Feb. 1878 (TAEM 94:117); "halloa" in W. H. Preece, "The Phonograph," *Journal of the Society of Arts,* 10 May 1878, 536 (TAEM 25:205) and *Daily Telegraph,* 22 May 1878 (TAEM 25:230).

77. "The Morning's News: Edison's Laboratory," *Boston Evening Transcript,* 23 May 1878 (TAEM 25:208), italics added.

78. W. K. L. Dickson and Antonia Dickson, *The Life and Inventions of Thomas Alva Edison* (New York and Boston: Thomas Y. Crowell & Co., 1892-4), 122.

79. "How it Grew," *Telegraph* (Pittsburgh, Pennsylvania), 24 May 1889 (TAEM 146:429).

80. Alfred O. Tate to B. W. Childs, 3 Apr. 1891 (TAEM 142:124).

81. "The New Phonograph," *Scientific American Supplement* 632 (11 Feb. 1888), 10097.

82. Technical note, 12 Aug. 1877 (TAEB 3:494); technical note, 17 Aug. 1877 (TAEB 3:502-9).

83. "Edison's Phonograph," 7 Sept. 1877 (TAEB 3:533).

84. See in particular "The Phonograph," *The Public,* 2 May 1878 (TAEM 25:182).

85. Edward Johnson to Edison, 25 Jul. 1877 (TAEB 3:460).

86. Edward Johnson to Edison, 4 Aug. 1877 (TAEB 3:482); for the identity of "Green" see 3:483, n. 11; "Telephone at the Stockton," *Daily Star* (Cape May, New Jersey), 13 Aug. 1877 (TAEM 94:69).

87. "Edison 'At Home,'" *Philadelphia Record,* 6 Jun. 1878 (TAEM 94:223).

88. Edward Johnson, *Telephone Hand Book* (New York: Russell Brothers, 1877; TAEM 162:1032ff), 17.

89. Johnson, *Telephone Hand Book,* 11-2. The last testimonial is dated 20 Oct. 1877 (on page 24), so the date of publication must be later than that.

90. "Speech automatically transmitted in short hand by the telegraph," *Scientific American* 1877;37(3 Nov.):273.

91. "Graphic Phonetics," *Scientific American* 1877;37(17 Nov.):307.

92. Letter from Edward Johnson, in "A Wonderful Invention," *Scientific American* 1877;37(17 Nov.):304, italics added.

93. "Phonography and Photo-Phonography," *Scientific American* 1867;16(4 May):285.

94. "A Wonderful Invention," *Scientific American* 1877;37(17 Nov.):304. For the date on which this issue of the *Scientific American* actually became available, see TAEB 3:617, n. 1.

95. See e.g. "The Phonograph," *New York Times,* 7 Nov. 1877, p. 4.

96. "Phonograph," 23 Nov. 1877 (TAEB 3:629-30).

97. TAEB 3:445, 698-700.

98. "A Story of Edison," *Electrical World,* 12 Nov. 1887 (TAEM 146:216); "Edison's Phonograph," *American Settler,* 14 Jan. 1888 (TAEM 146:229).

99. Edward H. Johnson, "Edison's Phonograph, Its History and Development," *Scientific American Supplement* 1890;743(29 Mar.):11872.

100. "'The News' and Edison. How an Article Published in 1877 Brought the Phonograph Into Existence. Prof. Johnson's Surprise. A Newspaper Man's Name For His Machine Showed Him What He Had Discovered," *News* (Buffalo, New York), 7 May 1898 (TAEM 146:1172).

101. Roland Gelatt, *The Fabulous Phonograph: 1877-1977,* 2nd ed. (New York: Collier Books; London: Collier Macmillan Publishers, 1977), 20. See also Wile, "Edison Invention," 22, n. 7.

102. Th[eodose-Achille-Louise], Comte du Moncel, *The Telephone, The Microphone, and the Phonograph* (New York: Harper & Brothers, 1879), 238; translation of *Le téléphone, le microphone, et le phonographe* (Paris: Hachette et cie, 1878).

103. "Miscellaneous Notes," *Daily Herald* (Delphos, Ohio), 16 Aug. 1898, p. 2.

104. R. D. Darrell, "Mr. Edison's Phonograph: A Post-Mortem," *Sewanee Review* 1933;41(Jan.-Mar.):95.

105. Hankins and Silverman, *Instruments and the Imagination,* 135; also Raymond R. Wile, "Etching the Human Voice: The Berliner Invention of the Gramophone," *ARSC Journal* 1990;21:3.

106. Tate, *Edison's Open Door,* 115

107. "Washington ... Wonders of Edison's Inventions." *New York Herald,* 24 Apr. 1878 (TAEM 25:171).

108. *Evening Journal,* 15 Jun. 1878 (TAEM 94:237).

109. *Speaking Telephone Interferences,* 1:319.

110. Chas. A. Morey, "The Phonautograph," *American Journal of Science and Arts* 1874;8(Aug.):130-1.

111. "Fixing Sounds," *Scientific American* 1863;37(12 Dec.):371.

112. "Phonography and Photo-Phonography," *Scientific American* 1867;16(4 May):285.

113. See Helmholtz, *Lehre von der Tonempfindungen*, 33, or *Sensations of Tone*, 20.

114. Charles Cros, "Procédé d'enregistrement et de reproduction des phénomènes perçus par l'ouïe," *Comptes Rendus Hebdomaires des Séances de l'Académie des Sciences* 1877;85(Jul.-Dec.):1082.

115. Berliner technical note of 17 May 1887, quoted in Wile, "Etching the Human Voice," 5. He first showed the device to his attorney in "March or April of 1887" (ibid., 4), but no firm evidence seems to exist as to when he began his work: Wile guesses 1886 but acknowledges that a contemporary source gives the year 1885 (ibid., 19, n. 7).

116. Alexander Graham Bell to Gardiner Greene Hubbard, 18 Mar. 1878 (AGBFP), italics added.

117. T. A. Edison, "Phonograph or Speaking Machine," U. S. Patent 200,521, executed 15 Dec. 1877, filed 24 Dec. 1877, granted 19 Feb. 1878.

118. "Washington... Wonders of Edison's Inventions," *New York Herald*, 24 Apr. 1878 (TAEM 25:171).

119. Thomas Edison, "The Phonograph and its Future," *North American Review* 1878;262(May-Jun.):532; on Edward Johnson's authorship of this article, see TAEB 4:224-5.

120. For expanded versions of these arguments, see Evan Eisenberg, *The Recording Angel: Explorations in Phonography* (New York: McGraw Hill, 1987), 109; and Alan Williams, "Is Sound Recording Like a Language?" Yale French Studies 1980;60:51-66.

121. Timothy C. Fabrizio and George F. Paul, "Augustus Stroh: Forgotten Scientist of Sound," *ARSC Journal* 2001;32:1-10; W. M. Jewell, "Musical Instrument," U. S. Patent 460,688, filed 27 Apr. 1891, granted 6 Oct. 1891.

Rethinking Edison's Discovery of the Phonograph Principle

The Editor of the ARSC Journal *encourages letters from readers. When the printed word, however, is challenged or a different point of view expressed about what has been stated, the conventions that govern other publications do not readily apply to the* ARSC Journal. *Given its frequency, readers cannot reasonably be expected to have to wait upwards of six months between issues to read the next installment of any exchange between, say, an author and reader. When appropriate, the Editor attempts to facilitate an exchange between the parties involved with a view to publishing the reader's initial letter together with the author's rebuttal or response. The intent is not necessarily to restrict discussion in any way, but to avoid long, drawn out correspondence in the pages of the* ARSC Journal.

In 'Speech Acoustics and the Keyboard Telephone: Rethinking Edison's Discovery of the Phonograph Principle' (Feaster, P. *ARSC Journal* 2007;38(1):10-43) Edison is quoted as denying knowledge of Leon Scott's phonautograph, which is typical of the many deceptions uttered over his lifetime, all calculated to let the willing, gullible public believe that all his creations originated with him, unaided. Yet it is transparently clear that he'd not only copied Scott's creation in all ways, save a very important one, but he even appropriated Scott's name for his invention by merely removing the letters a-u-t from Scott's word and coming up with the word phonograph.

Interestingly, he wasn't the first to use that word; for as Prof. Ray Wile has pointed out, the inventor of a form of stenography had designated that which the secretaries wrote as a "phonograph," meaning a visual display of a sound – the sound being the dictator's words and the graph being what the stenographers wrote down. The shorthand developer attempted to persuade Edison to stop using the word. Edison ignored him.

What aspect of Scott's invention had "the wizard" overlooked? It was the use of lateral modulation. Edison's incorporation of vertical modulation was either 1) an oversight on his part; 2) a belief that vertical modulation was more appropriate; or, 3) a desire to not be accused of copying from Scott. Just as he later stubbornly resisted the necessity for alternating current, Edison refused to recognize the scientific fact that doubling the depth of a groove requires much more than double the amount of force ...one reason for the increased distortion in cylinder recordings.

Oliver Berliner
Bozman, MD

Author's Response...

This letter is not alone in insisting that Thomas Edison *must* have known about Léon Scott's phonautograph at the time he invented the phonograph. However, my article doesn't just cite Edison's claim to the contrary, as if to imply we should accept his word on the matter as fact. It also advances some new arguments in support of that claim based largely on evidence Edison himself never made public, such that we cannot reasonably dismiss it as part of a deliberate campaign of deception.

At the risk of repeating myself, let me summarize the three main counterarguments I see to Mr. Berliner's view.

First, laboratory notes reveal that the vertically modulated phonogram format originated in Edison's efforts to synthesize speech sounds for his "keyboard talking telegraph," based on a fanciful combination of Helmholtz's vowel theory and the tonewheel. Thus, it seems Edison did not initially associate the format with recording speech sounds at all, but only with simulating them artificially. If the idea of recording in this format came to him only after the idea of using it for simulation, then Scott's approach to recording sound can hardly have inspired the format in the first place.

Second, when Edison first sketched out an automatic method of recording speech for visual apprehension, in May 1877, it was spectrographic, not oscillographic like Scott's phonautograph. This demonstrates that Edison was quite capable of conceiving methods of sound recording that were not anchored in Scott's prior work, and also that he perceived automatic speech recording as a puzzle that, at the time, had yet to be solved – not as an accomplished fact.

Third, Edison's theoretical statements and drawings throughout 1877 betray a conspicuous ignorance of the relationship between timbre and complex waveforms. This was the one principle acousticians had been using Léon Scott's phonautograph to study and illustrate, and I maintain it is the one basic idea nobody could realistically have missed who also understood the phonautograph well enough to see any advantage in "copying" it.

In order to be persuasive, any future argument to the effect that Edison knowingly "copied" Scott should need to find some means of countering these three points, which I do not find addressed in Mr. Berliner's letter.

One additional note for those who might wish to check the sources on which I base these arguments: when my article was reformatted for publication, the index numbers in the text became unlinked from the numbers of the endnotes. They're correctly matched up through endnote 26; however, endnote 27 at the end should refer to the first full paragraph on page 17, and the reader would need to add one to each index number in the text from 27 onward to find the correct endnote. I regret any confusion the misnumbering may cause.

Patrick Feaster
Bloomington, Indiana

Comments on the Author's Response...

After impliedly agreeing with me (and myriad others) that Edison had to have known about Edouard Leon Scott de Martinville's *phonautograph*, author Feaster criticizes me for citing that Edison's *phonograph* didn't copy Scott in every single respect; thus he shoots

down my, in effect, giving the "wizard" some "benefit of the doubt". And in his challenge of the reasons I volunteered as possibly being the basis for Edison's departure from Scott's lateral cut recording principle, he ignores my reason #2, which states, in different words, Mr. Feaster's own position as articulated in his above response to my letter. ***OB***

And...

I refer Mr. Berliner to pages 11, 34, and 35 of my article, where he will see that I explicitly reject the very position he claims I have 'impliedly' espoused. With that in mind, I believe the other points, including the fundamental difference between my position and his 'reason #2' are clear. ***PF***

Corrected Endnotes

1. John L. Butterfield to Edison, 24 Jun. 1889, in Thomas E. Jeffrey, ed. *Thomas A Edison Papers: A Selective Microfilm Edition* (Frederick, Maryland: University Publications of America, 1985—), henceforth "TAEM," 128:79.
2. "Marvellous Discovery," *New York Sun*, 22 Feb. 1878 (TAEM 94:115-16).
3. Thomas Edison, "The Perfected Phonograph," *North American Review* 1888;379(June):642-3; speech of Ezra Gilliland at Electrical Club, New York City, 12 May 1888, quoted in "Edison's Perfected Phonograph," from *Electrical Review*, in *Invention*, 16 Jun. 1888 (TAEM 146:262).
4. Raymond R. Wile, 'The Edison Invention of the Phonograph," *ARSC Journal* 1982;14:5-28.
5. Paul Israel, *Edison: A Life of Invention* (New York: John Wiley & Sons, 1998), 142ff.
6. The invention of the telephone has served as a central example in the study of invention as a cognitive process more generally; see Michael E. Gorman and W. Bernard Carlson, "Interpreting Invention as a Cognitive Process: The Case of Alexander Graham Bell, Thomas Edison, and the Telephone," *Science, Technology, & Human Values* 1990;15(Spring):131-64; Michael E. Gorman, "Mind in the World: Cognition and Practice in the Invention of the Telephone," *Social Studies of Science* 1997;27:583-624.
7. Gorman and Carlson, "Interpreting Invention," 156.
8. Andre Millard, *America on Record: A History of Recorded Sound* (Cambridge: Cambridge University Press, 1995), 24.
9. *The Speaking Telephone Interferences: Evidence for Thomas A Edison* (TAEM 11:3fl), 1:3ff, 105; Elisha Gray, *Experimental Researches, in Electro-Harmonic Telegraphy and Telephony, 1867-1878* (New York: Russell Brothers, 1878), reprinted in *The Telephone: An Historical Anthology*, ed. George Shiers (New York: Arno Press, 1977).
10. I wish to thank Cornelia Fales for her helpful feedback on my explanations of acoustic matters, here and elsewhere in this article; of course, responsibility for anything that remains unclear or technically suspect rests with me.
11. Reese Jenkins, Robert A. Rosenberg, Paul Israel, et al., eds., *The Papers of Thomas A. Edison* (Baltimore: Johns Hopkins University Press, 1989—), henceforth "TAEB," 2:526, n. 6.
12. Alexander Graham Bell, "Improvement in Telegraphy," U. S. Patent 174,465, executed 20 Jan. 1876, filed 14 Feb. 1876, granted 7 Mar. 1876; Gray's caveat is reproduced in Gray, *Experimental Researches*, 79.
13. Document dated 23 Mar. 1877 (TAEM 3:927), stating: "This is a duplicate of the order and sketch furnished to L. W. Serrell when Case 130 was ordered"; see also TAEM 11:633. In *Speaking Telephone Interferences*, 1:47, Edison states that the sketch had been "made in his [Serrell's] office at the time he was preparing case 130...made for his information," and that it

was “dated, probably by Mr. Serrell, March 23, 1877.” Edison clearly uses the phrase “rate of vibration” for frequency elsewhere, as in *Speaking Telephone Interferences*, 1:4.
14. *Speaking Telephone Interferences*, 1:263-4.
15. T. A. Edison, “Speaking Telegraph,” U. S. Patent 474,230, executed 18 Apr. 1877, filed 27 Apr. 1877, granted 3 May 1892.
16. Technical note, 10 1875 (TAEB 2:685).
17. See e.g. “Sound Recording Itself,” from *London Review*, in *The Living Age* 1861;70(21 Sept.):726-7.
18. Alexander Graham Bell to Alexander Melville Bell et al., 6 May 1874, Alexander Graham Bell Family Papers, http//memory.loc.gov/ammem/bellhtml/, henceforth “AGBFP.” See also drawings of the shapes produced by Koenig's manometric flames in response to vowel sounds in Alexander Graham Bell to Alexander Melville Bell et al., Apr. 1874, AGBFP
19. See e.g., the patent cited in note 12; also the illustration in the *Scientific American* 1877;36(31 Mar.):191.
20. *Speaking Telephone Interferences*, 1:47.
21. *Speaking Telephone Interferences*, 1:263-4. Serrell also explains the significance of the other drawings on the page, including the volute spiral.
22. *Speaking Telephone Interferences*, 1:47.
23. Notebook entry, 4 Apr. 1877 (TAEB 3:299-301).
24. In addition to the source just cited, Edison lists “th sh ch s” (Technical note, 26 May 1877, TAEB 3:359) and “S, T, V, P, C J etc” (Technical note, 18 Jul. 1877, TAEB 3:443).
25. J. Baile [sic, Baillé], *Wonders of Electricity*, transl. John W. Armstrong (New York: Scribner, Armstrong, and Co., 1872), 141.
26. Israel, *Edison*, 110.
26a [***refers to the first full paragraph on page 17***]. H. Helmholtz, Die Lehre von der Tonempfindungen als physiologische Grundlage für die Theorie der Musik (Braunschweig: Friedrich Vieweg und Sohn, 1863), 163-80, 183-90, 582-6; for the same passages in English, see Hermann Helmholtz, On the Sensations of Tone as a Physiological Basis for the Theory of Music, transl. Alexander J. Ellis (New York: Dover Publications, 1954), 103-18,120-4, 398-400. He used a slightly different configuration when using another set of higher-pitched forks, in which both prongs of the interrupting fork were used to complete the circuit.
27. Technical drawing, ca. Jul. 1875 (TAEB 2:526).
28. See e.g. Edison's proposal to use Helmholtz resonators in a caveat of 13 Jan. 1876, Document 708, TAEB 2:713; also Batchelor's testimony about Edison's use of Helmholtz resonators “to find out how much the resonator increased the volume of sound of the fork when applied to it” in *Speaking Telephone Interferences*, 1:260.
29. I am indebted to Jerry Fabris for providing this quotation.
30. “Autobiography of A. G. Bell,” 6 Feb. 1879, p. 4 (AGBFP).
31. For instance, Helmholtz acknowledged that his analogous synthesis of the timbre of organ pipes was missing certain features: “doch fehlt den nachgeahmten Tonen das scharfe sausende

Gerausch, welches der an der Lippe der Pfeife gebrochene Luftstrom giebt" (*Lehre von der Tonempfindungen*, 190), or in English: "of course the whizzing noise, formed by breaking the stream of air at the lip, is wanting in these imitations" (*Sensations of Tone*, 124). If he felt his system could "of course" not replicate the whizzing of an organ pipe, it is unlikely he thought it could produce, say, consonant sounds.

32. Robert V. Bruce, *Bell: Alexander Graham Bell and the Conquest of Solitude* (Boston, Toronto: Little, Brown and Co., 1973), 51. Bruce does not draw out the implications of this "mistake," for which see John M. Picker, *Victorian Soundscapes* (Oxford and New York: Oxford University Press, 2003), 100.

33. Gray, *Experimental Researches*, 36.

34. Baile, *Wonders of Electricity*, 141.

35. Notebook entry, 26 May 1877 (TAEB 3:359; TAEM 3:982).

36. Notebook entry, 26 May 1877 (TAEB 3:361; TAEM 3:980). Robert Conot, *A Streak of Luck* (New York: Seaview Books, 1979), 98, incorrectly describes the proposed format as oscillographic (like the phonautograph) rather than spectrographic.

37. W. Koenig, H. K. Dunn, and L. Y. Lacy, "The Sound Spectrograph," *Journal of the Acoustical Society of America* 1946; 18:18-49.

38. A reporter once asked Thomas Watson, "Won't the receiving operators have to learn shorthand?" Watson replied: "Yes, I suppose they will. In our experiments we have generally paused after saying a sentence, so that the receiver had time to write out in long hand" ("Prof. Bell's Telephone," *New York Sun*, 23 Feb. 1877 [TAEM 94:291). "If this verbal communication should be used for telegraphic purposes," echoed the *Scientific American*, "the messages would have to be taken down by the receivers in short hand" ('"he Telephone," *Scientific American* 1877;36131 Mar.1:200). See also TAEB 3:441, n. 1.

39. Henry Edmunds, "The Graphophone," paper read 7 Sept. 1888 at Section G of the British Association for the Advancement of Science, http://history.sandiego.edu/gen/recording/ar312.html, accessed 4 Jan. 2007.

40. Thomas Birch, *The History of the Royal Society of London* (London: A. Millar, 1756-7), 4:96.

41. Robert Willis, "On the Vowel Sounds, and on Reed Organ-Pipes," *Transactions of the Cambridge Philosophical Society* 1830;3:249-50.

42. Thomas L. Hankins and Robert J. Silverman, *Instruments and the Imagination* (Princeton, New Jersey: Princeton University Press, 1995), 275, n. 17.

43. Stanley Sadie, ed., *New Grove Dictionary of Music and Musicians*, 2nd ed. (New York: Grove, 2002), 8:78.

44. Gray, *Experimental Researches*, 27; illustration at 26; Alexander Graham Bell, *Experiments Made by A. Graham Bell* (Vol. 1), entry for 19 Feb. 1876, p. 14-5, digitized as part of the Alexander Graham Bell Notebooks Project, httpJ/www3.iath.virginia.edu/id/AGB/, accessed 17 Dec. 2006; T. A. Edison, "Improvement in Telephonic Telegraphs," U. S. Patent 198,087, filed 16 May 1876, granted Dec. 11,1877, concerns "a series of revolving circuit-

closing break-wheels with varying contact teeth and notches, so that each wheel produces a different number of pulsations per minute than the others, in combination with finger-keys." See also technical note, 10 Dec. 1875 (TAEB 2:684-5), esp. n. 2.

45. Technical note, 26 May 1877 (TAEB 3:360; TAEM 3:981). Despite the fact that the entry concludes with "turn this over in your mind Mr E & hoop it up," the entry is in Edison's own handwriting.

46. Technical note, 6 Jun. 1877 (TAEB 3:379-80).

47. See e.g. technical note, 18 Jul. 1877 (TAEB 3:443-6).

48. T. A. Edison, "Speaking-Telegraph," U. S. Patent 203,014, executed 11 Jul. 1877, filed 20 Jul. 1877, granted 30 Apr. 1878.

49. Technical note, 11 Jul. 1877 (TAEB 3:430-1; TAEM 11:356).

50. Speech of Ezra Gilliland at Electrical Club, New York City, 12 May 1888, quoted in "Edison's Perfected Phonograph," from *Electrical Review*, in *Invention*, 16 Jun. 1888 (TAEM 146:262).

51. Thomas Edison, "The Perfected Phonograph," *North American Review* 1888;379(Jun.):643.

52. T. A. Edison, "Speaking Telegraph," U. S. Patent 474,230, executed 18 Apr. 1877, filed 27 Apr. 1877, granted 3 May 1892.

53. Technical note, 7 Sept. 1876 (TAEB 3:128).

54. Francis Arthur Jones, "Illustrated Interviews," *Strand Magazine* 1905;29(Jan.-Jun.):421, italics in original.

55. A piece published in the *Phonogram* in 1901 places the finger-pricking anecdote "a day or two previous" to Edison's observation about the humming embosser: see "The Reverie of a Phonograph," *Phonogram* 1901;2 (Mar.): 182. However, this piece is written in the first person from the phonograph's point of view and appears more likely than the Strand interview to have incorporated fanciful inferences.

56. Edward Johnson to Edison, 5 Jul. 1877 (TAEB 3:416-7).

57. Edward Johnson to Edison, 10 Jul. 1877 (TAEB 3:426-7).

58. Edward Johnson to Edison, 17 Jul. 1877 (TAEB 3:437; TAEM 14:819). An archival note at the top classifies this letter as a phonograph-related document. Conot, *Streak of Luck*, 100 incorrectly identifies Johnson's letter with the "concept of printing sounds" Edison had worked out with Butler.

59. The standard explanation appears in Alfred 0. Tate, *Edison's Open Door: The Life Story of Thomas A. Edison, a Great Individualist* (New York: E. P. Dutton, 1938), 115. For some alternatives, see "The Phonograph," *Boston Times*, 22 Sept. 1889 (TAEM 146:531); Charles Batchelor's memoirs in TAEB 3:445, 699; and "The Phonograph," *Iowa City Daily Press* (Iowa City, Iowa), 3 Oct. 1904, p. 6.

60. "Edison's Lucky Scratch," from *Saturday Evening Post*, in *Twin City News* (Uhrichsville, Ohio), 17 Aug. 1899, p. 4.

61. Oliver Read and Walter L. Welch, *From Tin Foil to Stereo: Evolution of the Phonograph*

(Indianapolis: Howard W. Sams & Co., 1959), 17.
62. W. H. Preece, 'The Phonograph," *Journal of the Society of Arts*, 10 May 1878,536 (TAEM 25:205); *Daily Telegraph*, 22 May 1878 (TAEM 25:230).
63. Technical note, 17 Jul. 1877 (TAEB 3.440-1, TAEM 4:8). The format of this document is consistent with second pages: compare TAEM 11:386 (with similar header, date, signatures, and opening sentence fragment) and TAEM 11:387, of which it is a continuation (see TAEB 3:463-9 for a reconstruction of the original order of pages).
64. Israel, *Edison*, 143.
65. Israel, *Edison*, 26-8; TAEB 1:36-7, 659.
66. Technical notes, 17 Jul. 1877 (TAEB 3:439-40).
67. Technical notes, 18 Jul. 1877 (TAEB 3:443-6).
68. Specification for British patent 2909, filed 30 Jan. 1878, executed 24 Dec. 1877 (TAEM 92:58f1).
69. Technical note, 18 Jul. 1877 (TAEM 11:366).
70. Technical note, 18 Jul. 1877 (TAEB 3:444; TAEB 11:367). TAEB has “new” for the crossed-out word, which is hard to decipher; my best guess (and I admit that it is only a guess) is that Edison had started to write “names of the letters of the alphabet” but interrupted himself partway through.
71. Thomas Alva Edison, “Controlling by Sound the Transmission of Electric Currents, and the Reproduction of Corresponding Sounds at a Distance,” British Patent 2909, filed 30 Jul. 1877, provisional document only in TAEB 3: 447; whole document in TAEM 92:56.
72. “The Phonograph,” *Iowa City Daily Press* (Iowa City, Iowa), Oct. 3,1904, p. 6; *Fitchburg Sentinel* (Fitchburg, Massachusetts), 17 Aug. 1904, p. 4; “Edison's Lucky Accident,” from *Kansas City Journal*, in *Washington Post*, 16 Oct. 1904, p. 4.
73. Gath, “A Visit to Edison,” *Philadelphia Weekly Times*, 27 Apr. 1878 (TAEM 25:189).
74. Statement of Frank Dyer in E. Fulton Brylawski and Abe Goldman, eds., *Legislative History of the 1909 Copyright Act* (South Hackensack, New Jersey: F. B. Rothman, 1976), 4:J:286-7.
75. “Halloo” in “Marvellous Discovery,” *New York Sun*, 22 Feb. 1878 (TAEM 94:115-16) and “Phonograph,” *Brooklyn Daily Eagle*, 26 Feb. 1878 (TAEM 94:117); “halloa” in W. H. Preece, “The Phonograph,” *Journal of the Society of Arts*, 10 May 1878, 536 (TAEM 25:205) and *Daily Telegraph*, 22 May 1878 (TAEM 25:230).
76. “The Morning's News: Edison's Laboratory,” *Boston Evening Transcript*, 23 May 1878 (TAEM 25:208), italics added.
77. W. K. L. Dickson and Antonia Dickson, *The Life and Inventions of Thomas Alva Edison* (New York and Boston: Thomas Y. Crowell & Co., 1892-4), 122.
78. “How it Grew,” *Telegraph* (Pittsburgh, Pennsylvania), 24 May 1889 (TAEM 146:429).
79. Alfred O. Tate to B. W. Childs, 3 Apr. 1891 (TAEM 142:124).
80. “The New Phonograph,” *Scientific American Supplement* 632 (11 Feb. 1888), 10097.
81. Technical note, 12 Aug. 1877 (TAEB 3:494); technical note, 17 Aug. 1877 (TAEB 3:502-

9).
82. “Edison's Phonograph,” 7 Sept. 1877 (TAEB 3:533).
83. See in particular “The Phonograph,” *The Public*, 2 May 1878 (TAEM 25:182).
84. Edward Johnson to Edison, 25 Jul. 1877 (TAEB 3:460).
85. Edward Johnson to Edison, 4 Aug. 1877 (TAEB 3:482); for the identity of “Green” see 3:483, n. 11; “Telephone at the Stockton,” *Daily Star* (Cape May, New Jersey), 13 Aug. 1877 (TAEM 94:69).
86. “Edison ‘At Home,’” *Philadelphia Record*, 6 Jun. 1878 (TAEM 94:223).
87. Edward Johnson, *Telephone Hand Book* (New York: Russell Brothers, 1877; TAEM 162:1032ff), 17.
88. Johnson, *Telephone Hand Book*, 11-2. The last testimonial is dated 20 Oct. 1877 (on page 24), so the date of publication must be later than that.
89. “Speech automatically transmitted in short hand by the telegraph,” *Scientific American* 1877;37(3 Nov.):273.
90. “Graphic Phonetics,” Scientific American 1877;37(17 Nov.):307.
91. Letter from Edward Johnson, in “A Wonderful Invention,” *Scientific American* 1877;37(17 Nov.):304, italics added.
92. “Phonography and Photo-Phonography,” *Scientific American* 1867;16(4 May):285.
93. “A Wonderful Invention,” *Scientific American* 1877;37(17 Nov.):304. For the date on which this issue of the *Scientific American* actually became available, see TAEB 3:617, n. 1.
94. See e.g. “The Phonograph,” *New York Times*, 7 Nov. 1877, p. 4.
95. “Phonograph,” 23 Nov. 1877 (TAEB 3:629-30).
96. TAEB 3:445, 698-700.
97. “A Story of Edison,” *Electrical World*, 12 Nov. 1887 (TAEM 146:216); “Edison's Phonograph,” *American Settler* 14 Jan. 1888 (TAEM 146:229).
98. Edward H. Johnson, “Edison's Phonograph, Its History and Development,” *Scientific American Supplement* 1890;743(29 Mar.):11872.
99. “The News' and Edison. How an Article Published in 1877 Brought the Phonograph Into Existence. Prof. Johnson's Surprise. A Newspaper Man's Name For His Machine Showed Him What He Had Discovered,” *News* (Buffalo, New York), 7 May 1898 (TAEM 146:1172).
100. Roland Gelatt, *The Fabulous Phonograph: 1877-1977*, 2nd ed. (New York: Collier Books; London: Collier Macmillan Publishers, 1977), 20. See also Wile, “Edison Invention,” 22, n. 7.
101. Th[eodose-Achille-Louise], Comte du Moncel, *The Telephone, The Microphone, and the Phonograph* (New York: Harper & Brothers, 1879), 238; translation of *Le telephone, le microphone, et le phonographe* (Paris: Hachette et cie, 1878).
102. “Miscellaneous Notes,” *Daily Herald* (Delphos, Ohio), 16 Aug. 1898, p. 2.
103. R. D. Darrell, “Mr. Edison's Phonograph: A Post-Mortem,” *Sewanee Review* 1933;41(Jan.-Mar.):95.
104. Hankins and Silverman, *Instruments and the Imagination*, 135; also Raymond R. Wile,

“Etching the Human Voice: The Berliner Invention of the Gramophone,” *ARSC Journal* 1990;21:3.
105. Tate, *Edison's Open Door*, 115
106. “Washington ... Wonders of Edison's Inventions,” *New York Herald*, 24 Apr. 1878 (TAEM 25:171).
107. *Evening Journal*, 15 Jun. 1878 (TAEM 94:237).
108. *Speaking Telephone Interferences*, 1:319.
109. Chas. A. Morey, “The Phonautograph,” *American Journal of Science and Arts* 1874;8(Aug.):130-1.
110. “Fixing Sounds,” *Scientific American* 1863;9(12 Dec.):371.
111. “Phonography and Photo-Phonography,” *Scientific American* 1867;16(4 May):285.
112. See Helmholtz, *Lehre von der Tonempfindungen*, 33, or *Sensations of Tone*, 20.
113. Charles Cros, “Procédé d'enregistrement et de reproduction des phénomènes perçus par l'ou”ie,” *Comptes Rendus Hebdomaires des Séances de l'Académie des Sciences* 1877;85(Jul.-Dec.):1082.
114. Berliner technical note of 17 May 1887, quoted in Wile, “Etching the Human Voice,” 5. He first showed the device to his attorney in “March or April of 1887” (ibid., 4), but no firm evidence seems to exist as to when he began his work: Wile guesses 1886 but acknowledges that a contemporary source gives the year 1885 (ibid., 19, n. 7).
115. Alexander Graham Bell to Gardiner Greene Hubbard, 18 Mar. 1878 (AGBFP), italics added.
116. T. A. Edison, “Phonograph or Speaking Machine,” U. S. Patent 200,521, executed 15 Dec. 1877, filed 24 Dec. 1877, granted 19 Feb. 1878.
117. “Washington... Wonders of Edison's Inventions,” *New York Herald*, 24 Apr. 1878 (TAEM 25:171).
118. Thomas Edison, “The Phonograph and its Future,” *North American Review* 1878;262(May-Jun.):532; on Edward Johnson's authorship of this article, see TAEB 4:224-5.
119. For expanded versions of these arguments, see Evan Eisenberg, *The Recording Angel: Explorations in Phonography* (New York: McGraw Hill, 1987), 109; and Alan Williams, “Is Sound Recording Like a Language?” *Yale French Studies* 1980;60:51-66.
120. Timothy C. Fabrizio and George F. Paul, “Augustus Stroh: Forgotten Scientist of Sound,” *ARSC Journal* 2001;32:1-10; W. M. Jewell, “Musical Instrument,” U. S. Patent 460,688, filed 27 Apr. 1891, granted 6 Oct. 1891.