CHRISTIAN GOTTLIEB KRATZENSTEIN: PIONEER IN SPEECH SYNTHESIS

John J. Ohala

University of California, Berkeley, USA
ohala@berkeley.edu

ABSTRACT

C. G. Kratzenstein (1723-1795) is known in phonetics as the first to publish details of his attempt to synthesize speech – in his case, the "five" (sic) vowels *a, e, i, o, u*. He was, however, "a man of many parts", making contributions in such fields medicine, exploration, navigation, and physics, among others. Although when his principal phonetic work, was published in 1781 and 1782 there was no clear understanding of acoustic resonance, his accomplishment – via trial and error – was remarkable and contributed to accumulating 'existence proofs' that speech could be understood in physical and physiological terms.

Keywords: C. G. Kratzenstein, speech synthesis, history of phonetics, speech physiology, physics of speech

1. INTRODUCTION

Although the history of phonetics can be said to go back at least to the time of Paṇini, the 5th c BPE grammarian who described the sounds and sound patterns of Sanskrit, a breakthrough occurred in the 17th and 18th c. – the "Enlightenment" – when the accumulated lore about speech resulted in the ultimate validation of that knowledge via the mechanical synthesis of speech by, among others, the polymath Christian Gottlieb Kratzenstein (1723-1795). From the present perspective his accomplishment might seem modest but its true importance was conceptual: it contributed to the 'existence proofs' that speech could be understood, that is, deduced from many of the same physical principles that governed the generation of the sound of musical instruments and birds' cries. Moreover it heralded potential applications: the mechanical synthesis of speech as well as suggesting ways to diagnose and correct various speech pathologies.

2. KRATZENSTEIN'S LIFE STORY[1]

Christian Gottlieb Kratzenstein was born in 1723 in the small town of Wernigerode in Saxony-Anhalt, Germany. He studied the Natural Sciences at the University of Halle starting in 1742, earning a doctorate in 1746. At Halle he worked with Professor J.G. Krüger, regarded as 'the father of electrotherapy' – the, therapeutic uses of electricity. It was Kratzenstein, however, who authored what is regarded as the pioneering work on electrotherapy [13]. Then, at the recommendation of Leonhard Euler, (yet another polymath) he was appointed professor of mathematics and mechanics at the St. Petersburg Academy of Sciences (one of the forerunners of the current University of St. Petersburg) from 1748 to 1753. From 1753 to his death in 1795 he had the appointment as professor of Experimental Physics at the University of Copenhagen.[2]

3. HIS RESEARCH IN AREAS OTHER THAN PHONETICS

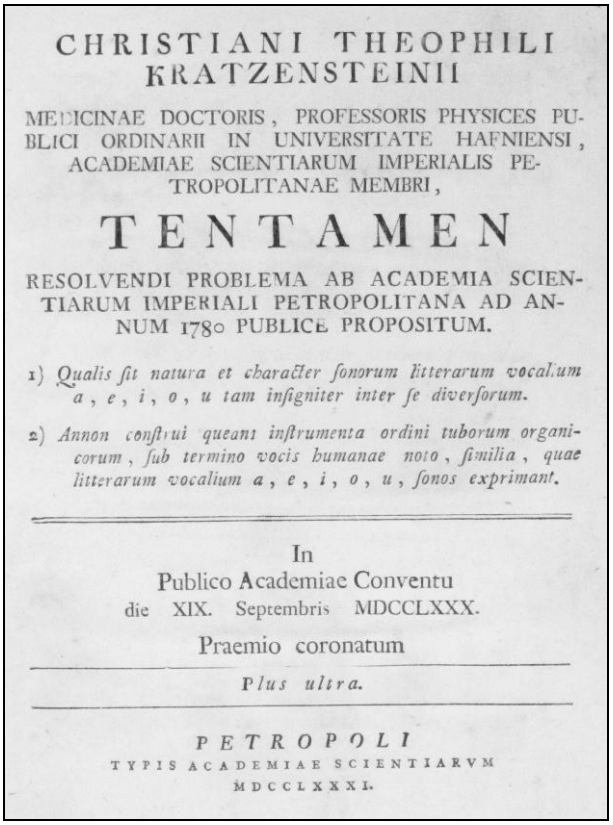
In the history of science Kratzenstein's fame rests primarily on his work in electrotherapy where he gave accounts of curing or ameliorating paralysis by passing electric currents (administered via electrostatic generators or Leyden jars) through the diseased part.[3] In his student days at Halle he promoted the now discredited "two fluid theory" of electricity. But Kratzenstein is also recognized as the first to make the "free reed" in the West (it had a quite ancient presence in East and Southeast Asian musical instruments, e.g., in the Chinese *sheng*). This was the "voice source"[4] in his vowel synthesizer and is now the sound source in such instruments as the harmonica and accordion. Additionally in this age when scientific disciplines were not so rigid as they are today, he merits at least a footnote in the history of accomplishments in navigation [13], computing, robotics (a "rowing machine"), chemistry, geology, exploration, aeronautics, to mention a few. A notable thread

through many of these endeavors, including of course his work with his vowel synthesizer, is that he demonstrated his skill as an instrument maker, i.e., a craftsman – and one informed by physical, physiological, and mathematical principles.

4. HIS PHONETICS

In 1780 the St. Petersburg Academy of Sciences, in a scientific competition, offered a prize for answers to the questions (paraphrased) 'what is the nature of and the difference between the vowels *a, e, i, o, u* and how can they be instrumentally produced?' Kratzenstein indicates that he had been working on this problem for some 10 years prior to the competition and submitted the winning entry.[5] It was initially published in Latin in St. Petersburg [15] (Fig. 1) and a French translation appeared in *J. Physique* in the following year [16].

Figure 1: The title page of Kratzenstein's monograph on vowel synthesis.



CHRISTIANI THEOPHILI
KRATZENSTEINII

MEDICINAE DOCTORIS, PROFESSORIS PHYSICES PUBLICI ORDINARII IN UNIVERSITATE HAFNIENSI, ACADEMIAE SCIENTIARUM IMPERIALIS PETROPOLITANAE MEMBRI,

TENTAMEN

RESOLVENDI PROBLEMA AB ACADEMIA SCIENTIARUM IMPERIALI PETROPOLITANA AD ANNUM 1780 PUBLICE PROPOSITUM.

1) *Qualis sit natura et character sonorum litterarum vocalium a, e, i, o, u tam insigniter inter se diversorum.*

2) *Annon construi queant instrumenta ordini tuborum organicorum, sub termino vocis humanae noto, similia, quae litterarum vocalium a, e, i, o, u, sonos exprimant.*

In
Publico Academiae Conventu
die XIX. Septembris MDCCLXXX.
Praemio coronatum

Plus ultra.

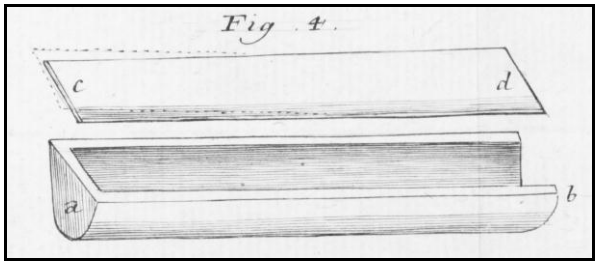
PETROPOLI
TYPIS ACADEMIAE SCIENTIARVM
MDCCLXXXI.

4.1. Anatomical details

His monograph starts with an account of the anatomical structures involved in speech production. This was not entirely original given the earlier publications of Amman, [1] Dodart [3], Ferrein [4], and Haller [5], all of whom he refers to. What is somewhat original is that he bolsters his account of how these structures and surfaces function in speech by mentioning how speech is adversely affected if the speaker is afflicted by some pathology. What was also original – and incorrect – was his rejection of the theory of Ferrein that it is the vibration of the vocal cords which gives rise to the tone (pitch) of voice. Instead he claimed it was the vibrations of the epiglottis. His apparent reason for this idea was that he judged the vocal cords to be too massive and thick (in the vertical dimension) to be able to vibrate at the frequencies, especially the high frequencies, encountered in speech and singing. In addition he conceived of the epiglottis serving as a valve at the upper end of the trachea and positioned to vibrate with the egress of air out of the lungs. (The vibrating part of the free reed he invented was, according to him, the analogue of the epiglottis.)

Kratzenstein devotes a considerable portion of his monograph to the voice source – actually he specifies two designs Both, free reeds, function quite well as a human-like sound source, since they produce a pulse-like, harmonic-rich, excitation that is a reasonable approximation to the glottal sound. The simpler design is shown in Fig. 2.

Figure 2: Kratzenstein's free reed which was the "voice" of his vowels. The 'lid' (cd) should be of some flexible material, e.g., a thin metal sheet, and should be attached to the right end of the tube (db) in a way that leaves the left end (ca) unattached and free to vibrate (see dotted outline). Air is pumped in at the open end (db). The vibrations at the 'free' end (cd) create a pulse-like, harmonic-rich, sound wave.



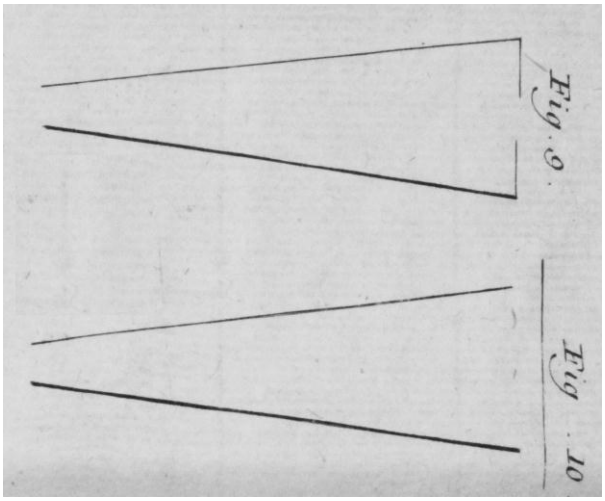
4.2. The vowel resonators

Kratzenstein's achievement in synthesizing the sound of the five vowels is a testament to his craftsmanship, ingenuity, and his desire -- characteristic of the Enlightenment -- to explain natural phenomena through empirical and rational means. It does not, however, constitute a significant scientific achievement. His account of the articulatory basis for these vowels is reasonable,

taking into account that it was not possible then to access much of the vocal tract during speech beyond what could be seen directly. He even gives detailed measurements of jaw positions, and the height and width of the lip openings –, but the articulation of vowels was previously known, at least in broad outline, e.g., [1, 2, 3, 4, 11, 20]. His account of the acoustic properties of vowels and, in fact, his conception of how sound quality is transmitted in general, strikes the modern reader as very strange. He proposes a geometric theory of vowels' different qualities in terms of different elliptical shapes.[16][6].

It seems evident that the shapes of the resonators – "flutes" he call them – that Kratzenstein made were largely found by trial and error. With the possible exception of the resonator for the vowel [ɑ], Fig. 3, the shapes bear little resemblance to actual the vocal tract shapes.

Figure 3: His shapes for the vowel [ɑ]. Here and in the following figures, these are sections showing the varying diameter through the longitudinal axis of cylindrical tubes. The sound source is at the left, the point of radiation at the right.



The resonator for the vowel [o] – see Fig. 4 -- is the same as that for [ɑ] with a cylindrical "hood" that evidently functioned as what we now recognize as a low-pass filter.

His resonator for the vowel [e] is shown in Fig. 5.

The resonators for the vowels [u] and [i] are variations on those for [o] and [e], respectively, except that in the latter case he found it necessary to force an airstream across the input end of the resonator (i.e., at a right angle with respect to the long axis of the tube).

I have experimented with cardboard resonators approximating these shapes and although I accept that those for [ɑ] and [o] sound more or less like the intended vowel, that for [e] does not. It is possible that what he was aiming for is that the sounds emitted through these resonators at least *sounded* different.

Figure 4: His resonator for the vowel [o]. It is similar to that for [ɑ] with the addition of a cylindrical "hood" that must have functioned as a low-pass filter.

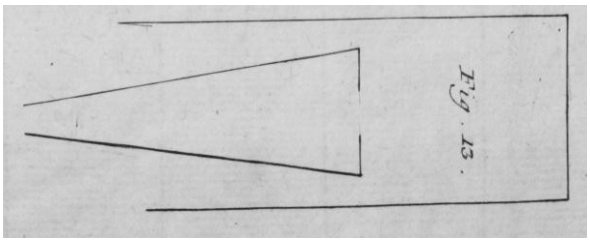
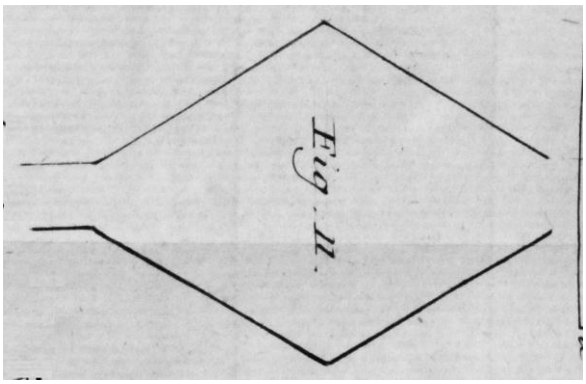


Figure 5: His resonator for the vowel [e].



5. CONCLUSION

What can we learn from Kratzenstein's efforts at speech synthesis? I think it is that he took great pains to understand speech in its physical and physiological aspect. We should value his work for his intentions and efforts. That we may find the science on which this was based and that the science that he derived from this work does not conform to our current understanding is not relevant. He did not have the benefit of the discoveries that came in the 19th century regarding resonance, e.g., by Helmholtz [6]. No doubt behind almost all modern scientific conceptualizations of the world as it is there has been much trial-and-error and some false leads. In Kratzenstein's writings we find a detailed and frank admission of such and a forthright presentation of his disagreements with the arguments and evidence of others of his time. It is his honesty and the originality of his ideas and his persistence in pursuing the goals he set for himself that is inspiring. It is these traits and what he accomplished with them that allows us to recognize him as a pioneer in speech synthesis.

6. REFERENCES

[1] Amman, J.C. 1700. *Dissertatio de Loquela.* Amstelæ dami: Joannem Wolters.

[2] Darwin, E. 1803. *The Temple of Nature*. London: Printed for Johnson, J. by Bensley, T., 119-120.

[3] Dodart, D. 1703. Mémoire sur les causes de la voix de l'homme et de ses différents tons. Extract from *Mémoires de l'Academie Royale,* 244-293.

[4] Ferrein, A. 1741. De la formation de la voix de l'homme. *Mémoires de l'Academie Royale*, 409-432.

[5] Haller, A.V. 1761. Elementa physiologiae corporis humani. *Respiratio, Vox*, Bousquet: Lausanne, Bd. III.

[6] Helmholtz, H. 1863. *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik.* Braunschweig: Friedrich Vieweg u. Sohn.

[7] van Helmont, F.M. 1667. *Alphabeti verè Naturalis Hebraici Brevissima Delineatio.* Sulzbach: A. Lichtenthaler.

[8] Herries, J. 1968 [1773]. *The Elements of Speech.* London: Printed for Edward and Charles Dilly.

[9] Holder, W. 1669. *Elements of Speech: An Essay of Inquiry into the Natural Production of Letters.* London: J. Martyn.

[10] Kaplan, P.W. 2002. The real Dr Frankenstein: Christian Gottlieb Kratzenstein? *J. R. Soc. Med.* 95, 577-578.

[11] ten Kate H.L. 1723. *Aenleidning tot de Kennisse van het verhevene Deel der nederduitsche Sprake.* Vols 2. Amsterdam: Rudolph en Gerard Wetstein.

[12] von Kempelen, W. 1791. *Mechanismus der Menschlichen Sprache*. Wien: Degen, J.B.

[13] Kratzenstein, C.G. 1744. *Abhandlung von dem Nutzen der Electricität in der Arzneywissenschaft.* Halle, Hermann Hemmerde.

[14] Kratzenstein, C.G. 1750. Mechanicae coelestis specimen primum continens: Novam tubos longiores commodissime tractandi methodum. *Novi Commentarii Acad. Scient. Petropolitane 1747-1748*. St, Petersburg. 1, 291-304.

[15] Kratzenstein, C.G. 1781. *Tentamen Resolvendi Problema ab Academia Scientiarum Imperiali Petroplitana ad annum 1780 Publice Problema.* Petropoli: Typis Academiae Scientiarum.

[16] Kratzenstein, C.G. 1782. Sur la formation et la naissance des voyelles. *Journal de Physique* 21, 358-380.

[17] Pompino-Marschall, P. 2005. von Kempelen, et al. – Remarks on the history of articulatory-acoustic modeling *ZAS Papers in Linguistics* 40, 145-159.

[18] Reyher, S. 1679. *Mathesis Mosaica, sive loca Pentateuchi Mathematica Mathematicè explicata*. Kiel: Joachim Reumann.

[19] Snorrason, E. 1974. *C.G. Kratzenstein*. Odense Universitetsforlag.

[20] Wallis, J. 1653. *Grammatica Lingua Anglicanae* [with an appendix: De loquela, sive sonorum formatione, tractus grammatico-physicus.] London: Leon Lichfield.

[1] Snorrason [19] provides accurate and well documented details on Kratzenstein's life and works.

[2] There is considerable misinformation about Kratzenstein on the internet and in printed works with some sites identifying him as Russian and others as Danish. By birth he was German.

[3] A convincing case has been made [10] that Kratzenstein,, who showed how "dead" limbs could be revivified by the application of an electric current, was at least in part the inspiration for Mary Shelley's 1818 novel "*Frankenstein; or, The Modern Prometheus*".

[4] Moreover, it had been some 36 years earlier that he had first examined the larynx in detail, presumably via dissection.

[5] Kratzenstein is often credited with being the first to demonstrate speech synthesis. But there is credible evidence that Abbé Mical of France constructed and demonstrated a "talking head" some years before. Unfortunately, Mical didn't publish anything on this. So Kratzenstein is at least the first to *publish* a detailed account of his work. As for other near-contemporaneous efforts in mechanical speech synthesis, see [2] and [12].

[6] As far as the acoustics of vowels are concerned, Kratzenstein account falls short of that of Reyher [18], though it is possible he did not know of this work.