Early use of the Scott-Koenig phonautograph for documenting performance

George Brock-Nannestad[a] and Jean-Marc Fontaine[b]

[a]Patent Tactics, Resedavej 40, DK-2820 Gentofte, Denmark
[b]Université UPMC - Ministère de la Culture - CNRS - IJRA - LAM, 11, rue de Lourmel, F-75015 Paris, France
pattac@image.dk

Acoustics of phenomena in the air in the 1850s combined listening, observation and tabulation. This was "real-time", catching any phenomenon as it appeared. If it was repeatable, one could be prepared. Continuous, rather than tabular data enabled a very different analysis from observation plus notebooks.

Édouard-Léon Scott's invention of the *phonautograph* enabled this. A surface moved below a stylus vibrated by sound in air. Originally the surface was a blackened glass plate, and it became a sheet of blackened paper. The scientific instrument maker Rudolph Koenig contributed his craftsmanship by building a very professional apparatus. A two-dimensional representation of the individual vibrations was obtained.

Scott deposited a sealed letter with the Paris Academy of Sciences in January, 1857 and filed a patent application in April, 1857. Later he deposited a further sealed letter and in 1859 he filed an application for patent of addition. Analyzing the thoughts expressed and documented in his manuscripts and by Koenig's licensed production it is feasible to see how they were dependent on each other, although they had different purposes in mind. The paper concentrates on Scott's interests in performance vs. Koenig's in partials, and the structure of original tracings are discussed.

1 The men and the apparatus

1.1 Fundamental considerations

Édouard-Léon Scott had the intention of using a simulated middle ear construction to register sound for analysis. This statement will be qualified in the following under the premise that this permits analysis of performance. Acoustic performance is any action that carries a sound with it; the focus will be on voluntary sound, i.e. the emitted sound is intentional, it is intended to represent information. This information may be part of communication to create a specific reaction or it may merely set the mind of a listener. The voluntary acoustic communication may be verbal, i.e. it has a phonetic and semantic content or it may be musical which obeys other rules, but which enables both analytic listening and aesthetic listening.

Performance of music and speech share many features [1, 2]. The objectivity in approach to their analysis did not change much for a century - consider for instance Seashore's "performance scores" [3] still referred to in 1947, comprising pitch, loudness, time, and timbre. This means that any method of observation must be able to provide reliable results for any of these features, preferably for their combination, repeatability if an identical sound complex is presented for analysis and differentiability if different sound complexes are presented. The acoustic energy must be represented in way that permits these analyses.

1.2 The phonautographic trace

Looking at the graphical image given by phonautograms, they appear far from what we have grown used to regarding oscillographic traces. This was noticed very early. Radau [4] wrote: "..... it is unlikely that ..... one could write via the membrane more complicated things ... [... than a seven-tone tune...], because its tracings show in general very little fidelity", Gutzmann [5] quotes Hugo Pipping: "Large differences in the tension and the little spring modify the relative values of the amplitudes of the various partials". Catchpool [6] says "..... its movements correspond in frequency, though not in any other respect, with those from the air". Phillips [7] provides a very lucid explanation for these observations.

Pisko [8] brings the most systematic contemporary discussion of the qualities of the phonautographic traces. He identifies the membrane and its complex oscillations as the cause of most of the confusion of the traces.

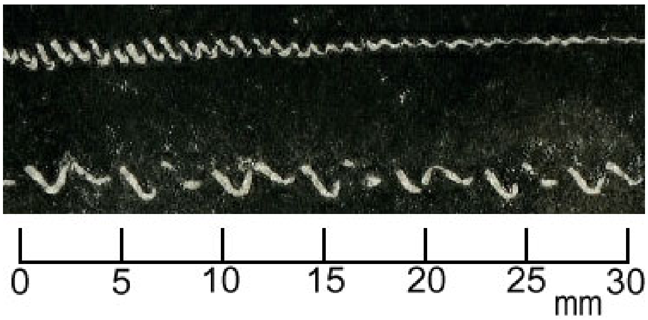

Figure: an extract from the phonautogram attached to [15]

1.3 Historical setting

Physical measurement and tabularization of results was standard practice in astronomy, physics and chemistry and it was entering into the field of physiology. As regards acoustics, one may consider that measurements were reported since the late 17th century [9], perhaps even since 1636 [10], and the ear was used as a good universal instrument, but it had to rely on an agreed terminology for the phenomena.

Primarily to demonstrate the waveform of vibrations, Young (1807), Weber (1830), Duhamel (ca. 1837), and Koenig used a rotating cylinder with an inscribable smooth surface that passed perpendicular to the vibration underneath the inscribing stylus. To calibrate a time axis, impulses inscribed in a parallel trace by a chronometer (Weber, Koenig) or the corresponding vibrations a tuning fork with a known frequency (Wertheim) was used. This enabled measurement of an unknown frequency of mechanical vibration.

1.4 The basic idea of Édouard-Léon Scott

Completely independently of this, the typographer and proof-reader Édouard-Léon Scott had occupied himself with stenography and logography. He had written a major book on the subject [11]. The strong relations to writing motivated the direction of development strictly towards writing of sound, an in particular of the spoken word. Scott himself gave a coherent account of this development in 1878 [12, 13] to defend his reputation as the originator of recorded sound. However, the original documents were those that influenced contemporary development.

1.5 The development and reduction to practice of Scott's idea: the Phonautograph

In the References section below a chronology of Scott's communications is given as numbers [14-20]. The complete descriptions of the patents were translated in [21] in 2007. Notable is Scott's overlooked second deposit of a sealed letter [16] with the president, Isidore Geoffroy Saint-Hilaire, of the Academy of Sciences in July 1857. Scott himself had forgotten this in 1878 ([12] p. 72) and only remembered a correspondence with an academy member, Pouillet. In this sealed letter Scott reports observations on membranes, and he suggests that tactile detection of their vibrations might be used in training the deaf-mute. This was an idea that was not further elaborated until teaching of the deaf-mute aided by apparatus became the target for experiment in various European countries about ca. 1900.

Particular effort was spent on the construction of the tracing stylus. Scott was quite explicit in his patent of addition: "... provided at its end with a barb of a feather, cemented to an inelastic stick taken in the middle part of a flexible organ that may be found in certain crustaceans, for instance big shrimp" ([19] at 5º). However, he did not limit himself in the patent. In [12] p. 73, notes (X) and (Y) Scott indicates that the "inelastic stick" would dry out, and that he had performed innumerable experiments. Valérius [22] performed experiments with the length of stylus that would make particular notes register well, and he concludes that in reality, it would be impossible to obtain a true phonautographic tracing of two simultaneous sounds, because they would require different lengths. Pisko [8] makes similar remarks.

A few researchers used the phonautograph in its original form for researches into phonetics; Donders [22] is a good example. Pisko [8] discusses Koenig's as well as Donders' experiments and conclusions. Other researchers used modified apparatus based on the phonautograph principle, and when mechanical recording for reproduction had been demonstrated twenty years later, methods were devised for converting such recordings to tracings. It is, however, not here the place for discussing these later developments.

1.6 Instructions for the use of the Scott-Koenig Phonautograph

The earliest written version of the instructions can be found in the application for patent of Addition filed 29 July 1859 by Scott [19]. The patent text has a close correspondence to the instructions given as a prospectus in Koenig's 1859 catalogue. The patent of addition appears as handwritten, but most of the text is actually lithographed, and it is this part which contains phrasing identical to the prospectus (dated 20 July 1859) in Koenig's 1859 catalogue of instruments. The explanation may be found in a licence agreement between Scott and Koenig dated 30 April 1859, predating the both the prospectus and the patent application. Scott states [12] p. 17 that the lithographed text of the patent was printed in 100 copies and provided with each phonautograph delivered. Koenig took responsibility to develop the phonautograph into an instrument for studying air-borne vibrations.

It is interesting to compare this to the handwritten description given by Koenig to Donders after 1862 [24] and the English-language descriptions signed by Koenig, and provided to the Seminaire de Quebec (October 1865) [25] and to professor Joseph Henry at the Smithsonian Institution in November 1865 [26]. Again, lithography was used in the latter texts, but they were dated and signed by Koenig.

The blackening of the paper quickly became a standard procedure, and essentially identical to that used for multichannel recording by Marey and others [27]. Our analysis of these texts is ongoing.

1.7 Koenig's requirements for registration

There is no doubt that Koenig had a different use in mind than had Scott, and the differences in handwriting in the patent of addition demonstrates this quite clearly. Koenig's intention is obvious from the lithographed part; Scott in his own handwriting explained how his invention could assist in the objective description of the performed language. This is evidenced by his demonstration of actual declamation recorded. The interpretation that his examples are not merely statements of principle but most likely taken from veritable tracings is supported by the fact that the examples are drawn on lines that are at essentially the same angle to the edges of the paper as the angle of the zero line on an original phonautograph trace (due to the helical registration on a sheet folded around a cylinder). A source-critical use of these historic tracings is demonstrated in the accompanying paper "Prosody in French theatrical declamation traced backwards in time", this volume.

Hence, to Scott it was basically immaterial whether the tracing was distorted, as long it consistently reproduced his phenomena of study. However, he did want to avoid disturbances in the form of resonances in the sound collector. Such a *qualitative* approach was not helpful to Koenig, who needed *quantification* of the phenomena. We may hence conclude that Koenig intended to use the phonautograph for musical research and the mathematical relations between partials, whereas Scott was interested in the spoken word and had no use for mathematics. The opposing views resulted in a breaking up of the cooperation [28]. It was probably not helpful either that Scott neglected the maintenance of the patent ([12] pages 5 and 13). In practice, this meant that the content of the patent was printed and published already in 1867 [29], well before the normal term 1872.

2 Léon Scott rehabilitated

2.1 The first device for recording air-borne sound

Following his aim of making the spoken word visible, Léon Scott conceived and reduced to practice the first device for collecting and for obtaining a graphical representation of phenomena of sound in air.

1857: an extraordinary technological leap of a baffling simplicity was brought about due to the talent of our inventor, guided by the consecutive elements of human audition that were most accessible for observation (ear canal, tympanum, and the bones of the middle ear; oval window). The device created by L. Scott for the first time realized the mechanical transformation of the variations of the soundwave that propagates in air.

By trade a typographer, he put all his energies towards the realization of a process for automatic writing of sound on a paper carrier. He was a man of letters, and he had been engaged in speed-writing (stenography) [11]. The representations provided by the phonautograph as traces would be recognized by experience; the traces furthermore would permit imagining the study of the structure of spoken words, of phonetics.

The improvements provided by Scott and by Koenig had no other motive than to improve the legibility of traces: at the time no validation of the results by listening was possible.

Because while the device quite well shows the basic principle of the conversion between acoustic pressure/vibration of a membrane/activation of a transducer (displacement of a stylus united to the membrane, as it were), it suffers from deficiencies that can only create strong distortions.

The presence of two membranes connected by intermediary pieces for adjustment. The temptation to imitate the mode of functioning of the middle ear would make the capturing of acoustic energy and its transformation to vibrations of a marking stylus particularly complex. Many points of adjustment remained possible, but the elastic characteristics of membranes constituted one of the principal obstacles to a possible less complex representation of the aural event.

The structure of the "response" of the vibrating membrane is undefined, the stylus, demonstrating the properties of a writing pen was fixed at an anti-node of vibration, its length is such that it adds a movement of oscillation whose components with respect to the plane perpendicular to the membrane ("vertical") and the parallel plane ("horizontal") are variable according to the vibration modes excited. In other words, the pen moves in three dimensions, draws circular forms and presses against the carrier. Perhaps this is a writing that is looked for with heavy and light strokes, but also a fact that makes the relationship with the soundwave particularly complex.

Even though it is filled with distortion, the trace represents the sound phenomenon quite well, and the reciprocity could be obtained. However, despite the improvements brought to the device by in particular Koenig, there had been no attempts to recreate the sound from the traces. It had not entered into their minds ([28] p. 132).

Looking for means for obtaining graphical representations of the spoken word, any adaptations that could relate to the "repetition" of sound were definitely not envisaged before C. Cros and T.A. Edison attacked this question directly. Science was quick to grasp the significance [30].

The phonautograph took advantage of a certain number of improvements by Scott himself and by Koenig. It is likely that less than 100 copies of complete Phonoautographs were made by Koenig (and later Max Kohl in Chemnitz to the same design) in the period 1859-1911 for equipping phonetics laboratories in Europe and in the US. This is an educated guess based on the number of institutions of higher learning. The procedure was taken up again and improved (manometric capsule and recording cylinder), in particular by Rousselot and Marey, mostly for multichannel recordings - still on sooted paper as originally devised by Scott. Such apparatus was still in use in the 1930s.

2.2 The arrival of the Phonograph

Towards the end of his life Scott was to encounter, with a certain bitterness, the phonograph that offered a possibility of recording and to reproduce an acoustic event [12].

Edison's device did apparently not display the slightest originality, and yet in a system that was very close to that of Scott he realised the reversibility of the process: production of sound from a marking (in relief) of a carrier. Scott had been the first to use a removable surface (paper instead of glass), and Edison's use of another removable surface - tinfoil - must have been seen as particularly frustrating.

Although the phonograph did not have any pretensions as regards the representation of sound, the tracings resulting from the impression on the cylinder would enable the study of the spoken word to the same degree as the other systems of visualization (phonautographic traces, flames, deviation of an optical ray) The validation of the traces could be made to work.

In other words, there is an end - posthumously - of a misunderstanding: Scott is truly the inventor of sound recording.

The misunderstanding came about because of the focus on the restitution of sound from tracings. But the convergence of the two approaches - Scott and Edison - was complete. Only the technology of extraction of a sound signal from tracings could attribute the status as a carrier for recording to the phonautograph.

2.3 Transforming an optical contrast to a sound signal

The photographic representation of sounds: it was necessary to wait until ca. 1920 for the demonstration of "optical sound", by Engl, Vogt & Masolle (Germany) [31] and by Axel Petersen & Arnold Poulsen (Denmark) [32], and only after electronic development tracing back to Bell & Tainter, Lauste, Lee de Forest and many others were the processes commercialized.

It is interesting to note here how much optical readout of mechanical records has occupied researchers since the 1980s. To date, only one optical record player (laser) is accessible on the market, and yet this construction is not able to reproduce lacquer records that are originals in the same sense as a phonautographic tracing or a tinfoil. To overcome this difficulty, yet another project, but using white light, is being developed in a European initiative.

2.4 Optical readout of Phonautograph traces

From the digitized images, getting back to an acoustic signal p(t) can present a number of challenges. The first step is to convert the traces (greyscales images) to parametrized trajectories (x(t), y(t)) that represent the displacement of the stylus. This is usually done by tracking the maximum greyscale values along the traces. On the earliest drawings, this task can be extremely difficult, as the stylus is often squashed on the cylinder, so that its trace becomes a rather large blob, where trajectory tracking is nearly impossible. It also happens that the stylus jumps, leading to a discontinuous trace : here again, x(t) and y(t) can only be estimated by interpolation. The second step is to convert the trajectories (x(t), y(t)) into a one-dimensional signal p(t). Without any reverse-engineering and calibration on replicas, one can only make a number of simplifying hypotheses. When the traces do not make loops, as is the case with small amplitudes (x(t) is monotonously increasing), one can simply assume that p(t) is proportional to y(t), up to a rescaling in time due e.g. to variations in the speed of rotation of the cylinder. However, when loops are present, the bi-dimensional nature of the stylus' displacement cannot be ignored : here a full mass-spring mechanical model of the writing device must be designed, simulating the displacement of the stylus attached to the membrane.

If we assume that we need at least ten harmonics to keep the intelligibility of the voice at medium pitches, then 20 measurements per period is a strict minimum, and in practice more points are needed to lower the noise level. Depending on the cylinder speed of rotation, scans of more than 1000 ppi are often necessary.

The recent presentation of sound obtained from Phonautograph traces demonstrates that in fact to write sound, such as conceived by Scott is also a machine for recording sound, and not merely a tool for analysis. At the time it was impossible to make a reverse operation functional, but the principle was absolutely correct; the trace had the potential for restitution. History must be corrected as to attributing inventorship to recording.

The traces attached to Scott's fundamental patent and the improved versions attached e.g. to his presentations at the French Academy of Sciences attest to an undeniable success, albeit rudimentary. His invention has definitely shown the way for all the researches regarding the mechanical-graphical recording of sonic phenomena until the moment when an electrical signal became obtainable.

R. Koenig's simplification of the device consisted in the elimination of several mechanical items that were inspired by the middle ear bones, but for a while the secondary membrane persisted, being vibrated by resonance.

Acknowledgements

We are grateful to the French Patent Office, INPI, and the assistance of Mr. Gerard Winter in providing access to the original French patents of Scott. We are also appreciative of the assistance given by the Archives of the French Academy of Sciences, and its Chief Conservator Mme. Florence Greffe in providing access to the complete file of Léon Scott. We thank Laurent Daudet of LAM, Paris, for his discussion of the conversion of phonautograph tracings into signals representing sound that we have been able to make use of in the present text. Furthermore, we thank Dr. David Pantalony for having made his doctoral thesis available for consultation.

References

[1] G. Brock-Nannestad, ""An Evaluation of Early Use of Sound Recordings In the Analysis of Performance Practice and in Phonetics", 'Internationaler Musikwissenschaftlicher Kongress zum Mozartjahr 1991 Baden-Wien. Bericht', Ed. Ingrid Fuchs, Bd.II, Tutzing 1993, pp. 505-514

[2] G. Brock-Nannestad, B. Elverdam, "Pierre Schaeffer's *Objets Musicaux* and Their Relationship to Phonetic Research", in: Proc. Inaug. Int. Conf. on Music Comm. Sci., 5-7 December 2007, Sydney, Australia, pp. 23-27

[3] C.E. Seashore, "In Search of Beauty in Music", Ronald Press 1947, p. 29f

[4] R. Radau, "L'acoustique ou les phénomenes du son" Paris 1867, p. 185

[5] H. Gutzmann, "Physiologie der Stimme und Sprache", Braunschweig 1909, p. 80

[6] E. Catchpool, "A Text-Book of Sound", London 1918, p. 131

[7] V. J. Phillips, "Waveforms. A History of Early Oscillography", Bristol 1987, pp. 46-47

[8] F. J. Pisko, "Die neueren Apparate der Akustik", Wien 1865, pp. 71-92

[9] A. Cohen, "Music in the French Royal Academy of Sciences", Princeton University Press 1981, p. 8

[10] F. V. Hunt, "Origins in Acoustics. The Science of Sound from Antiquity to the Age of Newton", Acoustical Society of America 1992, p. 87ff

[11] É.-L. Scott de Martinville, "Histoire de la sténographie depuis les temps anciens jusqu'á nos jours ....", Charles Tondeur, Paris 1849

[12] É.-L. Scott de Martinville, "Le probléme de la parole s'écrivant elle-même", Paris 1878

[13] E. Gautier, "Le Phonographe, son passé, son présent, son avenir", Paris 1905, pp. 20-28

[14] É.-L. Scott, "Principes de Phonautographie", Sealed Letter No. 1639 to Académie des Sciences, Paris, dated 26 January 1857. 7pp. including 2 small phonautograms

[15] É.-L. Scott, "Application for Patent No. 31470" dated 25 March 1857. 6 pp. including certificate and one phonautogram

[16] É.-L. Scott, "Graphie du son", Sealed Letter No. 1688 to Académie des Sciences, Paris, dated 22 (29) July 1857. 7 pp.

[17] É.-L. Scott, "Fixation graphique de la voix", printed statement to Société d'Encouragement pour l'Industrie Nationale, Paris, dated 28 October 1857. 1 sheet in 3 columns

[18] F. Moigno, ”Phonautography; Or the Graphic Fixing of the Voice”, The Photographic News, Vol. 1, April 15, 1859, pp. 62-64 {adapted translation of [17]}

[19] É.-L. Scott, "Application for patent of addition to Patent No. 31470", dated 29 July 1859, 10 pp. including certificate and one phonautogram

[20] É.-L. Scott, "Inscription automatique des sons de l'air au moyen d'une oreille artificielle" manuscript ca. September 1860 presented in session 15 July 1861 in Academie des Sciences, Paris. 4 pp plus 9 phonautogram plates. Printed in Comptes Rendus de l'Académie des Sciences, Vol. 53, 1861 pp. 108-111 (no figures)M.

[21] G. Brock-Nannestad, "150 years of time-base in acoustic measurement and 100 years of audio's best publicity stunt - 2007 as a commemorative year", Audio Engineering Society Convention Paper No. 7007, May 2007, pp. 8, 12

[22] H. Valérius, ”Memoire sur les vibrations de fils de verre”, in ‘Mémoires Couronnés et autres mémoires”, Vol. 17, Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, June 1865, p. 21

[23] F. C. Donders, "On the speed of mental processes" [translated from 1869 Dutch original], Acta Physiologica, Vol. 30, 1969, pp. 412-431

[24] R. König, “Letter to Franciskus Donders concerning phonautograph and Helmholtz resonators“, deposited in University Museum Utrecht Archive, No. 1626

[25] R. Koenig, ”Instruction pour le maniement du Phonautographe”, deposited at Museum of Civilization, from the Seminary of Quebec, accessed 01012008 at http://www.talkingmachine.org/phonautograph.html

[26] R. Koenig, ”Instruction pour le maniement du Phonautographe”, deposited at the Smithsonian Institution, typed copy in Library of Congress, Berliner Papers, Motion Picture, Broadcasting and Recorded Sound Division

[27] E. J. Marey, ”La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine”, 2nd ed., Paris 1885, p. 444ff

[28] D. A. Pantalony, ”Rudolph Koenig (1832-1901), Herrmann von Helmholtz (1821-1894) and the birth of modern acoustics”, Thesis University of Toronto 2002, pp. 9-53 and 125-142

[29] "Descriptions des machines et procédés", vol. 60, pp. 358-363, and plate XXXI, Paris 1867

[30] F. Jenkin & J.A. Ewing, "On the Harmonic Analysis of Certain Vowel Sounds", in: Transactions of the Royal Society of Edinburgh, Vol. 28, 1878, pp. 745-777

[31] H. Lichte & A. Narath, “Physik und Technik des Tonfilms“, 2nd ed., Leipzig 1943, p. 15

[32] U. Lomholt Madsen, ”Preservation of early sound films”, in: “Preserve Then Show”, Danish Film Institute 2002, pp. 146-151