Von Kempelen et al. – Remarks on the history of articulatory-acoustic modelling

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The contribution of von Kempelen's "Mechanism of Speech" to the 'phonetic sciences' will be analyzed with respect to his theoretical reasoning on speech and speech production on the one hand and on the other in connection with his practical insights during his struggle in constructing a speaking machine.
Whereas in his theoretical considerations von Kempelen's view is focussed on the natural functioning of the speech organs – cf. his membraneous glottis model – in constructing his speaking machine he clearly orientates himself towards the auditory result – cf. the bag pipe model for the sound generator used for the speaking machine instead. Concerning vowel production his theoretical description remains questionable, but his practical insight that vowels and speech sounds in general are only perceived correctly in connection with their surrounding sounds – i.e. the discovery of coarticulation – is clearly a milestone in the development of the phonetic sciences: He therefore dispenses with the Kratzenstein tubes, although they might have been based on more thorough acoustic modelling.
Finally, von Kempelen's model of speech production will be discussed in relation to the discussion of the acoustic nature of vowels afterwards [Willis and Wheatstone as well as von Helmholtz and Hermann in the 19th century and Stumpf, Chiba & Kajiyama as well as Fant and Ungeheuer in the 20th century].

1. The person

Wolfgang von Kempelen (1734-1804), civil servant – in later years in the rank of a privy councillor – at the Royal Hungarian Court at Preßburg (today's Bratislava), protégé of Maria Theresa, is present in public memory foremost because of his geniously constructed chess playing 'Turk' (although it was based on deception), an 'automaton' that defeated – among others – the Russian empress, Catherine the Great, at this royal game (cf. Figure 2). Napoleon's stepson, Prince Eugène de Beauharnais, later bought this 'machine' (but, alas, without the chess champion hidden inside).

Figure 1: Self portrait of Wolfang von Kempelen
(charcoal drawing; Szépmüvészeti Múzeum, Budapest) and signature

But, typical son of his times, Wolfgang von Kempelen was a multitalented person, experimenting in quite different fields of science and engineering.

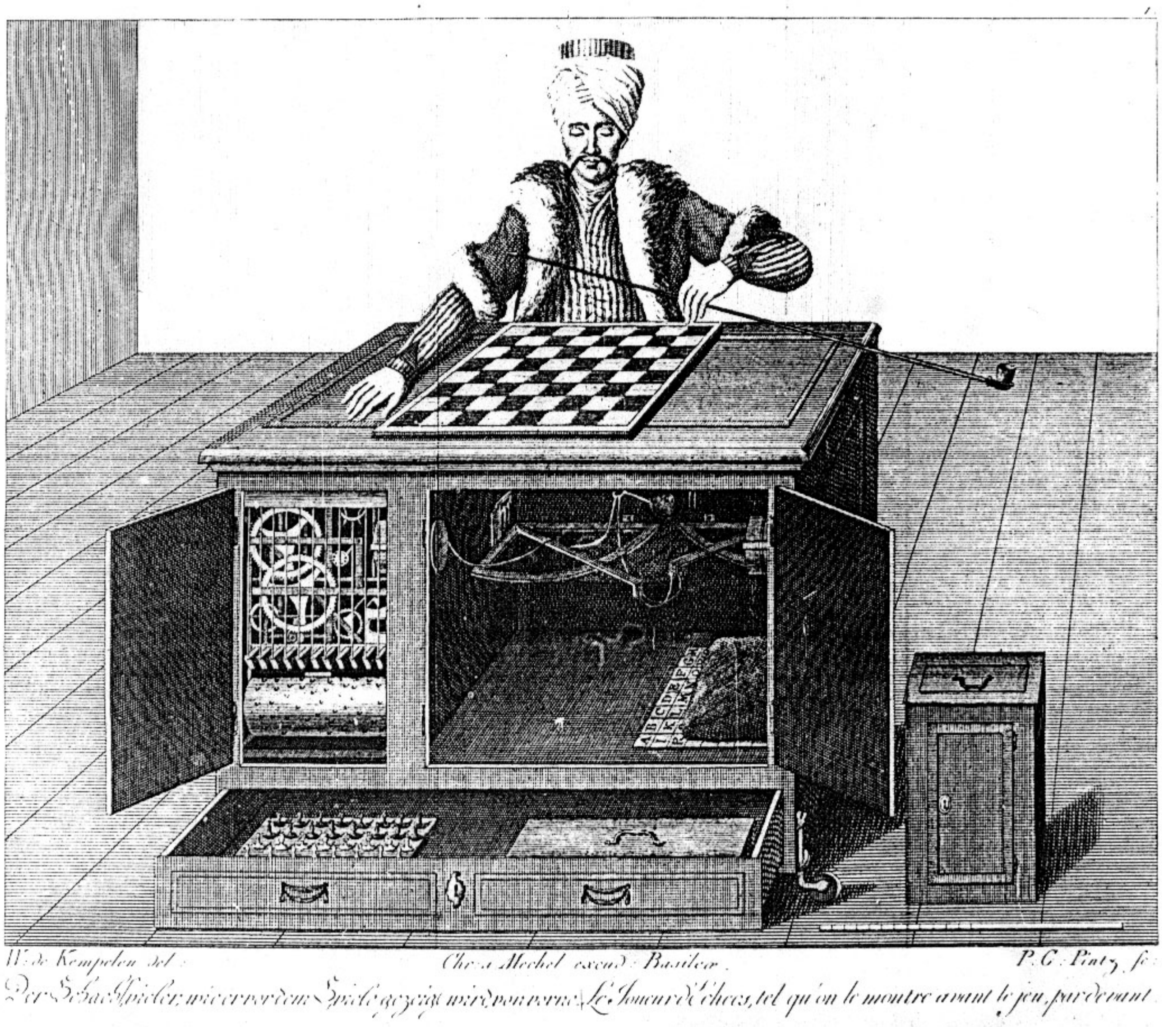


Figure 2: The chess playing 'Turk' as shown from front before the game after the engravings accompanying the "Letters …" of Windisch (1783b)

In focus here is his interest in the mechanism of human speech to which Kempelen dedicated a whole book, "The Mechanism of Human Speech Including the Description of His Speaking Machine" published on demand[1] in a German-French parallel edition of together 195 copies[2] in 1791 (cf. Figure 3). Brücke (1856: 6) – German 'Lautphysiologe' (speech physiologist) and one of the founders of modern phonetics – clearly recommends this book of Kempelen

[1] Cf. the bookseller's 1789 announcement of the publication of the "Mechanism ..." in Figure 3.

[2] At least according to the list of subscribers in the German edition. The German edition is set in black letters, the French edition in Roman type letters.

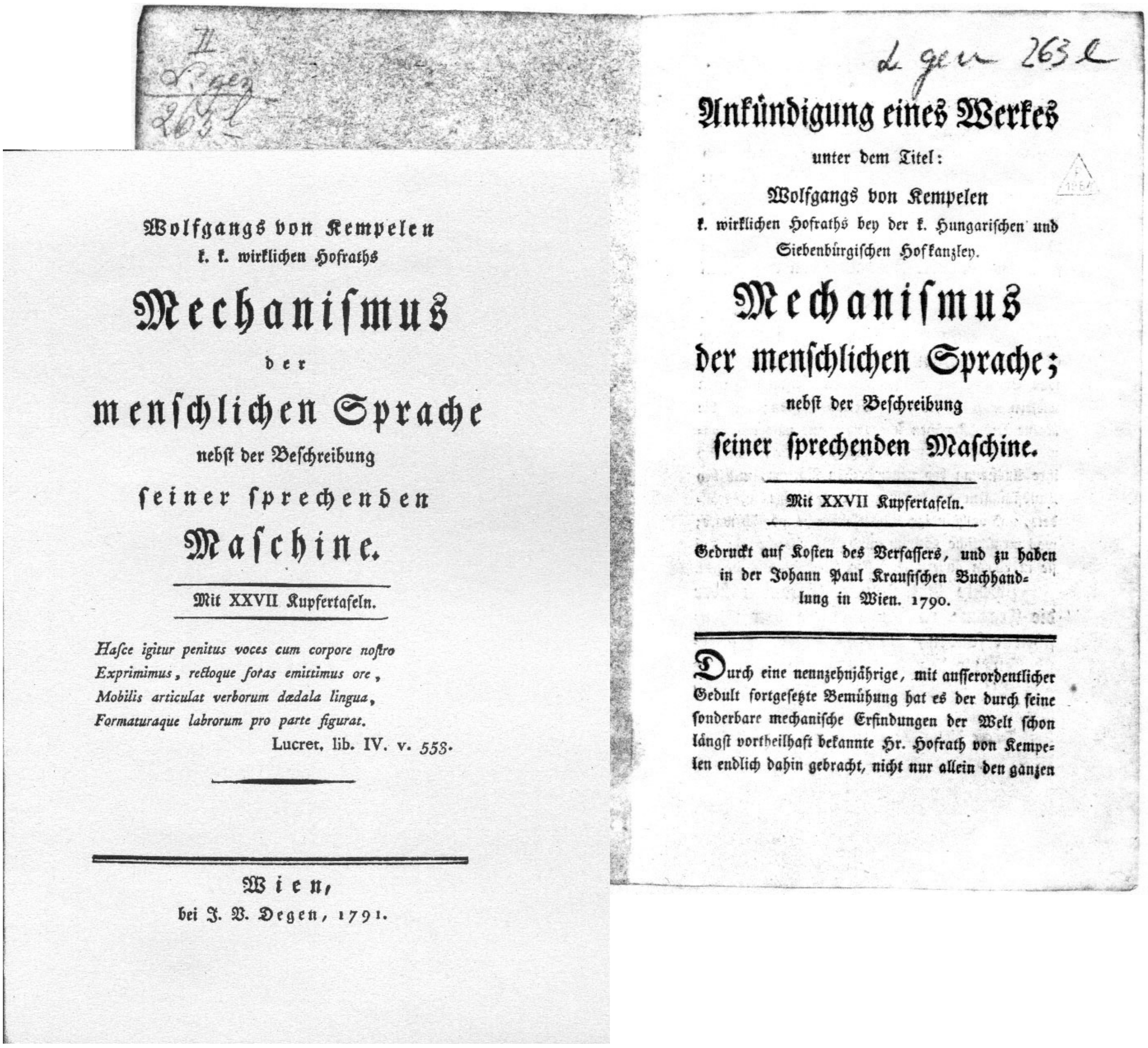
“to all linguists interested in the purely mechanical part of the theory of speech sounds.”

2. The construction of the speaking machine

In his “Mechanism …” Kempelen himself tells us about the long time he needed to construct his speaking machine: “I can‘t tell exactly what forced me to imitate human speech. But I remember that already during my work on the chess player [cf. Figure 2] in 1769 I was eager to find musical instruments resembling the human voice.” (Kempelen 1791: 389f.; my translation). His starting point thus was that human speech can be nothing but vibrating air since it is obvious that we breathe for speaking and while exhaling the air is set in motion by the voice membrane.

In his book he then continues to describe how by chance he got hold of the mouthpiece of a shepherd’s bagpipe (cf. Figure 4) that sounded to him like a singing child. This kind of mouthpiece as a first step was used by him as a sound generator in an unfinished ‘vox humana’ organ he bought. For this kind of machine he went on to construct different variable resonators that could be controlled by pressing the keys of a keyboard (cf. Figure 5). He notes some difficulties with the vowel /i/, but since he had then already reached the conclusion that although it would be possible to construct a ‘vox humana’ for single speech sounds it wouldn’t be possible to concatenate these sounds into syllables he was no longer interested in learning more about the Kratzenstein tubes (cf. Figure 6).
The leading ideas behind his approach at a speaking machine at this times can be summarized as following:

- Since speech sounds are only discernable in relation to one another you have to use a *single glottis* and a *single mouth*.
- The mouth and tongue are in *continuous* motion producing obstacles for the *sounding (!)* air.
- And since it is almost mathematically proven that
  speech = voice passing through openings
  it follows that
  for a speaking machine you need nothing else but
  - a lung
  - a glottis
  - and a mouth.


Wolfgangs von Kempelen
k. k. wirklichen Hofraths
Mechanismus
der
menschlichen Sprache
nebst der Beschreibung
seiner sprechenden
Maschine.
Mit XXVII Kupfertafeln.

Hasce igitur penitus voces cum corpore nostro
Exprimimus, rectoque foras emittimus ore,
Mobilis articulat verborum dædala lingua,
Formaturaque labrorum pro parte figurat.
Lucret. lib. IV. v. 553.

Wien,
bei J. V. Degen, 1791.

Ankündigung eines Werkes
unter dem Titel:
Wolfgangs von Kempelen
k. wirklichen Hofraths bey der k. Hungarischen und
Siebenbürgischen Hofkanzley.
Mechanismus
der menschlichen Sprache;
nebst der Beschreibung
seiner sprechenden Maschine.
Mit XXVII Kupfertafeln.
Gedruckt auf Kosten des Verfassers, und zu haben in der Johann Paul Kraussischen Buchhandlung in Wien. 1790.

Durch eine neunzehnjährige, mit ausserordentlicher Gedult fortgesetzte Bemühung hat es der durch seine sonderbare mechanische Erfindungen der Welt schon längst vortheilhaft bekannte Hr. Hofrath von Kempelen endlich dahin gebracht, nicht nur allein den ganzen

Figure 3: Title page (left) and bookseller's announcement (1789) of Kempelen's "Mechanism …" (1791a)

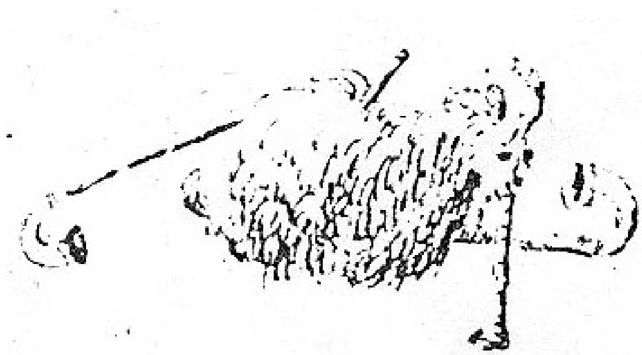


Figure 4: Kempelen's drawing of a Hungarian bagpipe (epigraph to an occasional poem dedicated to Magdalena von Wiesenthal in his family book "Gedichte. von W. v. K." [Lyrics. of W. v. K.]; 1757 ff.; National Hungarian Library)

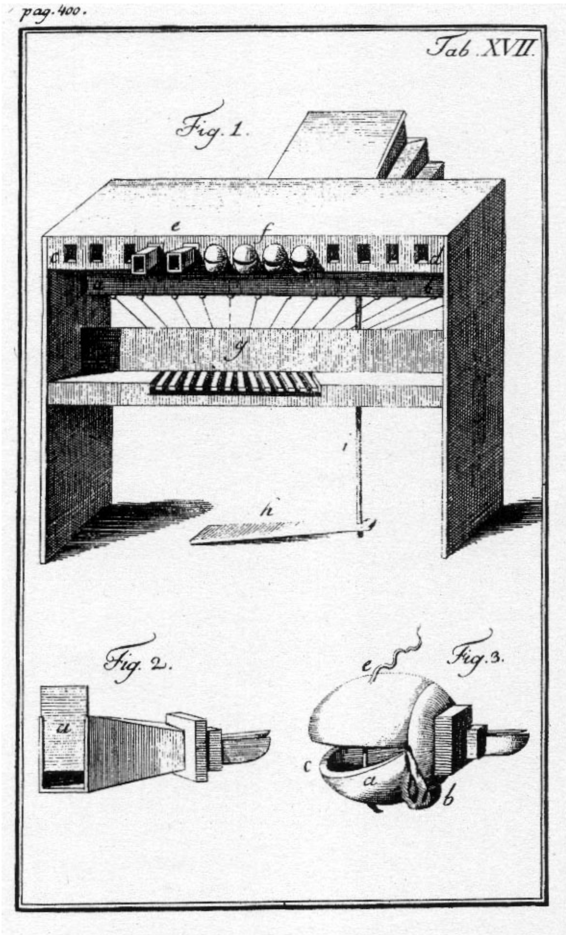


Figure 5: Kempelen's 'vox humana' trial

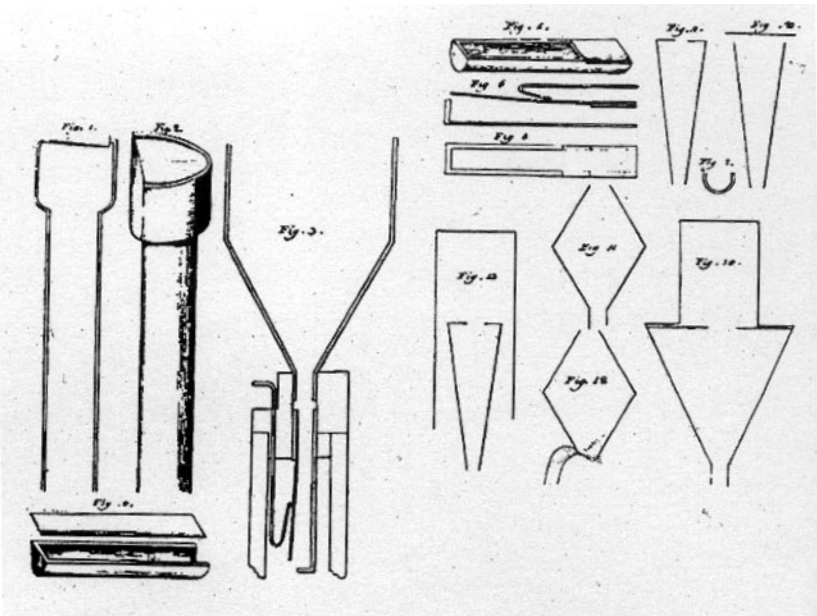


Figure 6: Kratzenstein's vowel tubes (after Panconcelli-Calzia, 1940)

In 1778, according to Bois-Reymond (1862: 129), Kempelen (partially) successfully finished the construction of his speaking machine. Clearly documented in the newspaper literature of that time, 1782 till 1784 Wolfgang von Kempelen was granted a sabbatical by Joseph II during which he undertook a European journey exhibiting both of his ‘automata’. He went through Switzerland, stayed in Paris, went on to London and visiting the German fairs at Frankfurt, Dresden and Leipzig on his way back to Hungary, always accompanied by the letters of his friend Karl Gottlieb von Windisch (1783a, b, c, 1784).
The first picture of the machine – more complicated than the one of the “Mechanism ...” (cf. Figure 8) – is given by Hindenburg (1784; cf. Figure 7).

3. Kempelen: Observer vs. engineer

Taking a closer look to his “Mechanism ...” one can see Kempelen’s twofold interest in language and speech production as a natural process on the one hand and the engineering task of building a speaking machine whose output sounds like human speech on the other hand.

In describing the phonatory functions of the larynx e.g. he developed a far more realistic membranous glottis model (cf. Figure 10) in contrast to the bagpipe mouthpiece that he used as sound generator in his speaking machine (cf. Figure 8, above left). Comparing the intermediate machine of Figure 7 – and the one at the “Deutsches Museum”, Munich (cf. Figure 9) – with the one of the “Mechanism ...” one can also see that Kempelen discards additions that he could not handle correctly: One of these pieces is the small wire at the mouthpiece’s tongue that eventually should control pitch variation.
Kempelen also makes suggestions how to construct a mechanical tongue (cf. Figure 11) instead of only changing the resonance characteristics by (partly) closing the rubber mouth or putting the fingers of his left hand inside. But he leaves it at this since he has problems with the audible burst for plosives then.

4. Kempelen and the theory of acoustic articulation

Kempelen didn’t construct his speaking machine on the base of acoustic theories but went the engineering way of analysis-by-synthesis – or trial and error. He was mainly interested in the audible result that should be reached by a simple mechanism as close as possible to our articulatory apparatus on the one hand and playable like a musical instrument on the other.

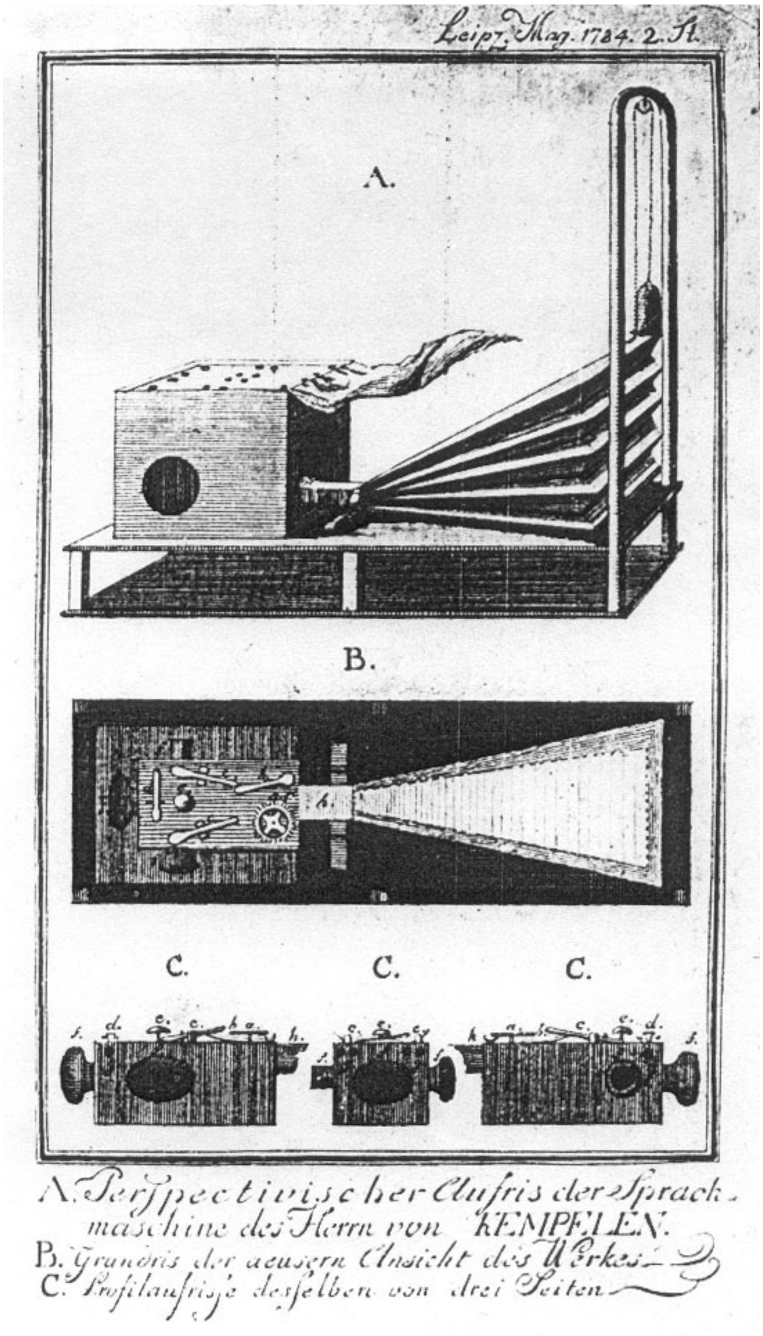


Figure 7: The first picture of the speaking machine (Hindenburg, 1784)

Kratzenstein, inspired by Euler on the other hand, tried to find his way into the nature of vowels through geometric-acoustic considerations based on reflections within elliptical cones (cf. Figure 12) although these were wrong and the tubes he finally used didn't resemble these constructions very much (cf. Figure 6).

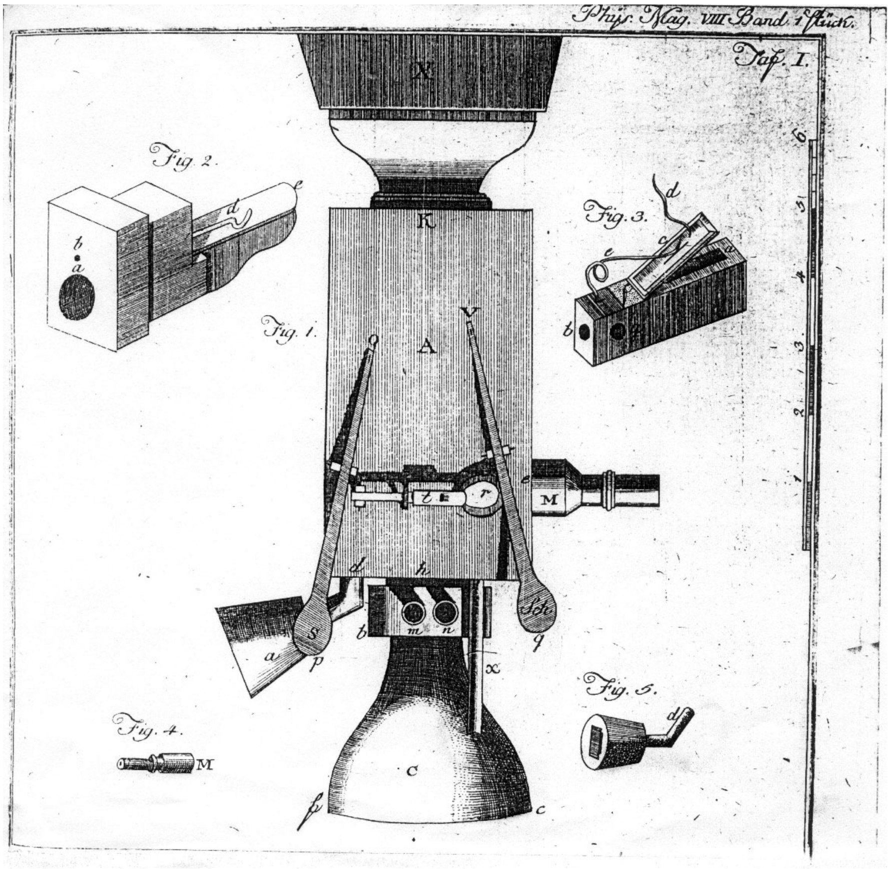


Figure 8: The machine of the "Mechanism ..." (anonymous review of 1792)

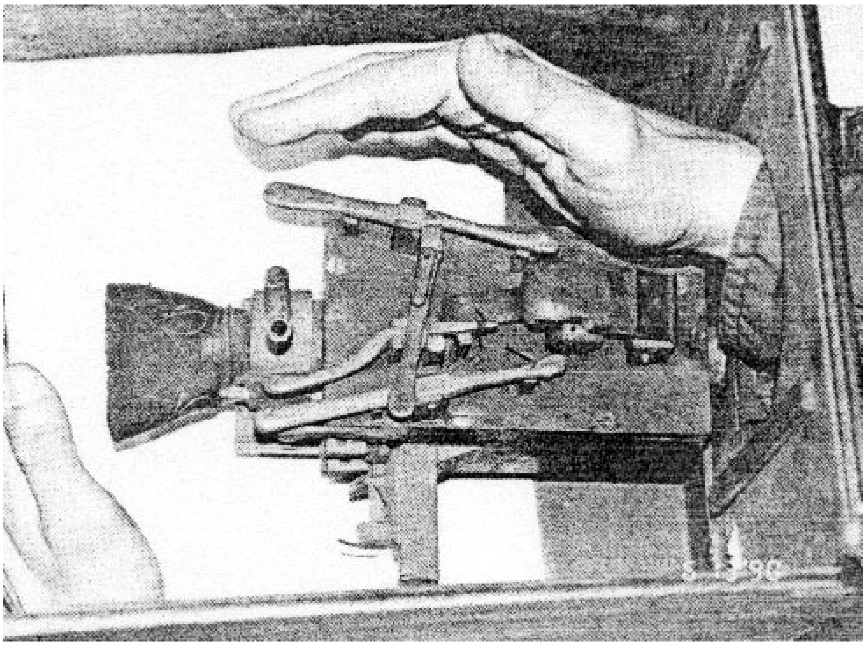
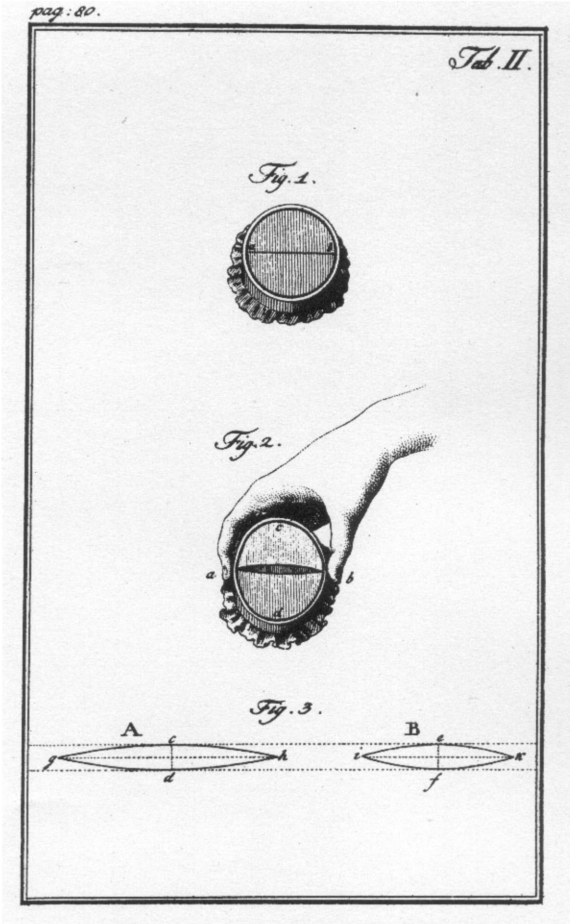


Figure 9: Kempelen's speaking machine at the "Deutsches Museum", Munich

Figure 10: Kempelen's membranous glottis model



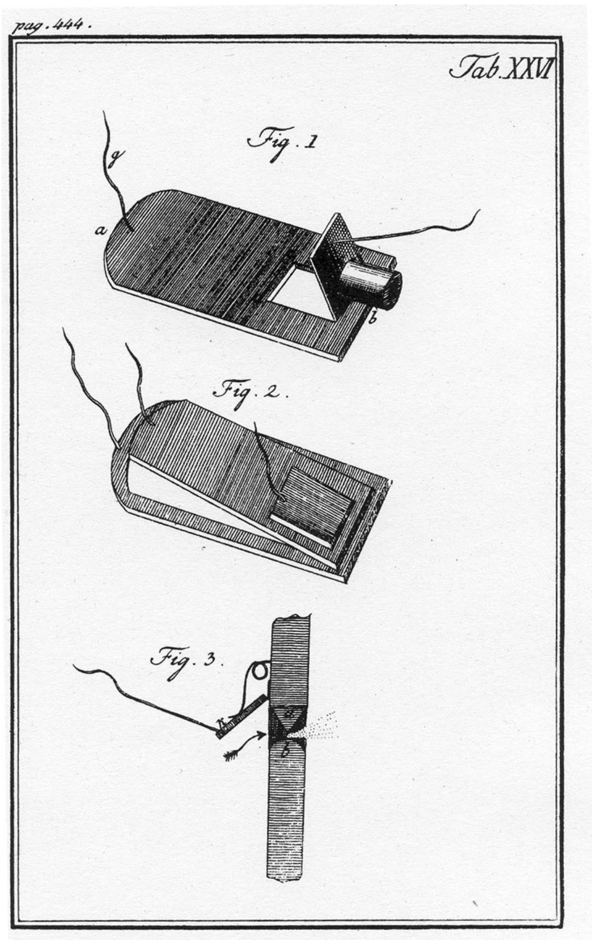


Figure 11: Kempelen's possible solution for a mechanical tongue for lingual stop production

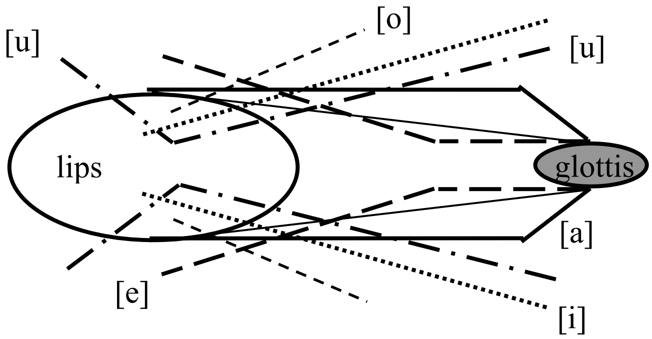


Figure 12: Kratzenstein's geometric-acoustic considerations based on reflections within elliptical cones (after Gessinger 1994)

Kempelen only once in his "Mechanism ..." gets deeper into vowel acoustics (cf. Figure 13).
He classifies the vowels according to the width of the lip channel giving a ranking of A > E > I > O > U and the width of the so called tongue channel that can be interpreted as horizontal tongue position. Kempelen goes on to remark that although he tried to produce the different vowels at the same pitch the vowel with a smaller tongue channel seemed to be higher in pitch. Although Kempelen isn't very explicit here, the observation clearly resembles the perceptual analysis of the second formant in whispered vowels described a century before by Reyher (1679; as cited in Kohler, 2000; cf. Figure 14) and the vowel tunes of von Helmholtz (1862; cf. Figure 15)

In 1830 it was Willis, starting from the ideas of Kratzenstein and von Kempelen, who first gained reasonable insight in the resonating properties of neutral tubes that would be able to give the illusion of different vowels (cf. Figure 16). In 1838 Wheatstone who also rebuilt Kempelen's machine added the theory of multiple resonance. During the 19th and part of the 20th century there existed allegedly contradictory theories on the nature of vowel sounds: On the one hand there was the harmonic theory stating that vowel frequencies have to be simple multiples of the fundamental frequency (Wheatstone, Helmholtz; Stumpf, Fant) and cavity tone theories (Willis, Hermann; Chiba & Kajiyama, Ungeheuer) that denied this. Today we know that harmonic analysis and resonance analysis are not real contradictions to one another but are merely two sides of the same coin. But a thorough theory of acoustic articulation (without simplifications) is still missing.
Kempelen's "Mechanism ..." is therefore a milestone in the history of phonetics, incorporating many insightful observations on articulatory mechanisms, whereas the speaking machine clearly a milestone in audio engineering.

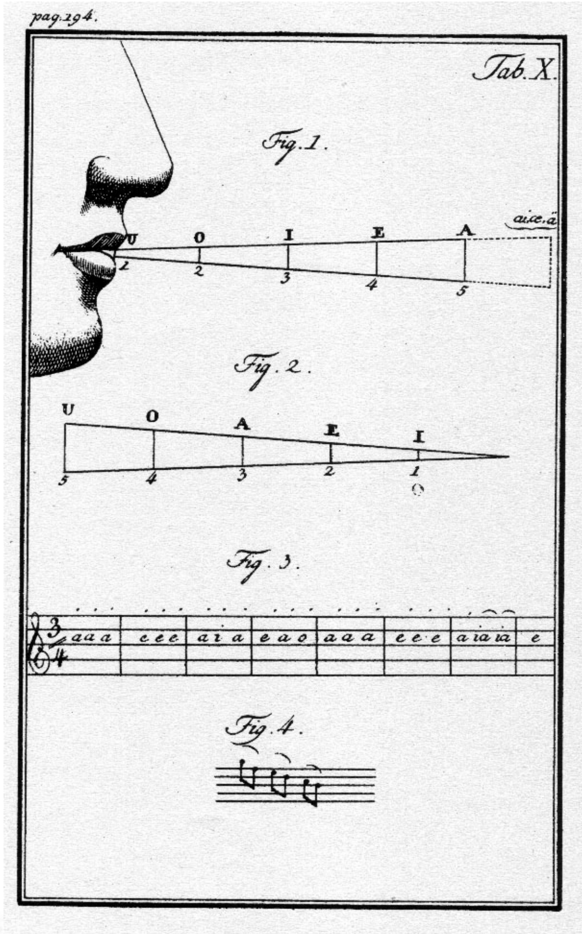


Figure 13: Kempelen's vowel categorisation according to the width of the tongue channel and the lip channel

Figure 14: Whispered vowel tunes of Reyer (1679; after Kohler 2000)

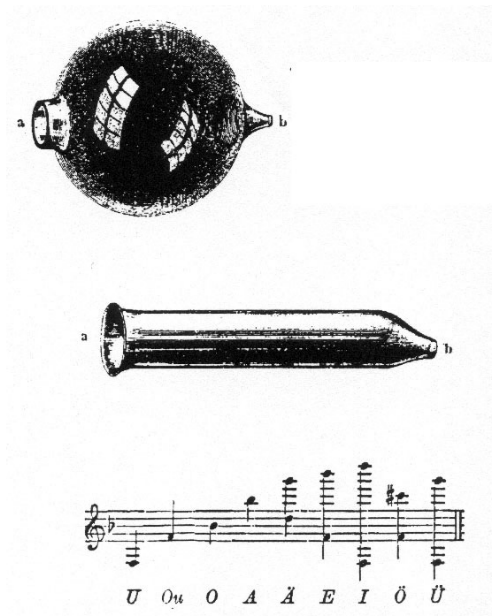


Figure 15: Vowel resonances after Helmholtz (1862)

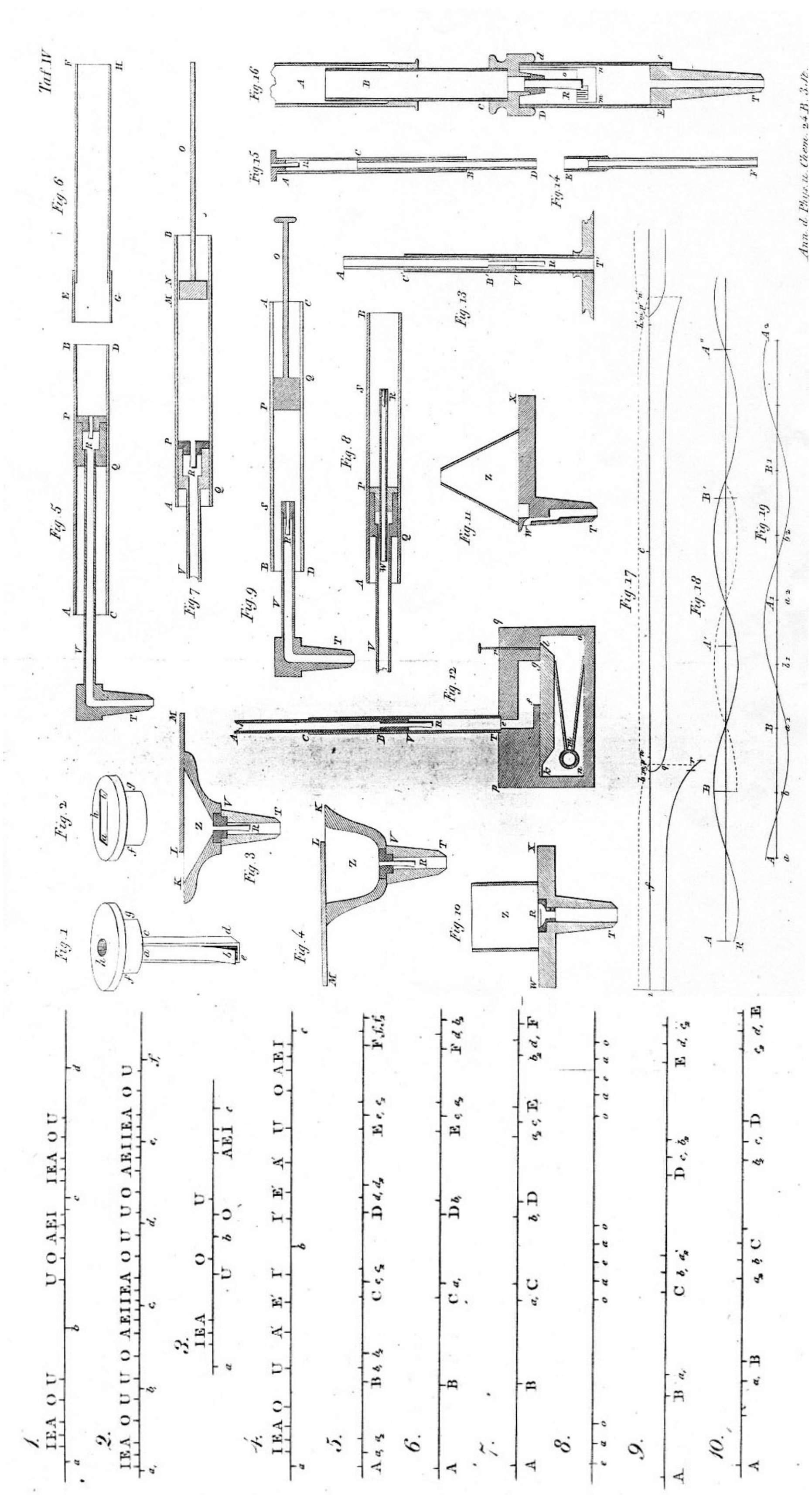


Figure 16: The experimental set-up of Willis (1832)

Acknowlegements

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