HISTORICAL DEVELOPMENT OF PHONETIC VOWEL SYSTEMS — THE LAST 400 YEARS

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ABSTRACT

This paper reviews the historical development of phonetic vowel systems from 1617 to 2005. In times where the vowel system of the International Phonetic Alphabet (IPA) is the de facto standard in phonetic sciences it is important to learn more about predecessors and alternative considerations of how vowel systems could be organized. This concerns matters of transcriptions, ideas on parameters of vowel production as well as the acoustics of vowel sounds and the relation between acoustics and perceived vowel quality. The concepts of such renowned historical personalities as Robinson, Wallis, Reyher, Hellwag, von Kempelen, Forchhammer, and Jones will be reviewed and critically discussed.

Keywords: IPA, vowel system, vowel diagram, Jones

1. INTRODUCTION

For many centuries now it has been a primary goal for language researchers to understand and illustrate the vowel system and represent them in charts. Early approaches were either introspectively articuluatory or perceptually musically motivated leading to either more or less stylized sagittal sections of the tongue position in the vocal tract, or an alignment of vowels in accordance with the so called "vowel tones", comparable to the first and/or second formants (F1 or F2). Russell, who had examined approximately 3000 X-ray photographs of more than 400 speakers by 1928, and had thereby conducted the largest articulatory research in his time, even went so far as to say that physicists and sound physiologists were using artificially constructed sagittal sections of the vocal tract when actually intending the presentation of true, acoustic data [25]. Russell's results demonstrate that articulatory relations are far more complicated in reality, than suggested by stylized sagittal sections. Ladefoged [17], also pointed out that some perceptual impressions of vowel quality are easier to correlate with acoustic than articulatory measurements. This is evident from Kohler [16] and Pompino-Marschall [22] who place the front rounded vowels of German in the primary vowel quadrilateral, although the tongue position is shifted further back and slightly lower than it is for the corresponding unrounded vowels. This shift follows rather an arrangement of vowels in a formant chart with F1 and F2 and by that more the acoustic than the established, articulatory or perceptual characteristics. The background of those discrepancies, that undoubtedly persevere to this day, becomes understandable when considering those insights that caused language researchers in the past to develop, change, refine, or reject systems of vowel arrangements.

Figure 1: Vowel scheme by Robinson [24], added with the current IPA-symbols. The lips are on the right.

2. ROBINSON 1617

While Ladefoged [17] rated Robinson's work from 1617 as not influential on succeeding authors, he considered it still important as it contains the first serious attempts to graphically capture and stylize the tongue position during vowel production. Fig.1 represents his scheme: C marks the root of the tongue, the arc A-B marks the palate. Robinson distinguished ten vowels, that can be divided into five long and five short vowels, and assigned them symbols rather uncommon today. The corresponding IPA-symbols are assigned to the long vowels following Ladefoged. Quite evidently, Robinson took an introspective pseudo-articulatory approach since the stylized tongue configurations do not reflect articulatory reality. According to present knowledge, equidistant places of articulation cannot be observed for vowels and at the latest during the introspective production of an [a] it becomes evident that the size of the passage between palate and tongue cannot be the same for all vowels and is, in fact, much larger for [a] than it is, e.g. for [i]. This means that not all vowels can be described adequately by the dimensions of tongue position, ranging from *back* to *front.*

3. WALLIS 1653

Wallis, who taught two deaf-mutes in 1660 and 1661, published the first edition of his English grammar in 1653 which contains a record of physiological phonetics and its practical applications. In his two-dimensional vowel scheme, he differentiates between labial, palatal, and guttural places of articulation, while each can be produced with three different degrees of opening resulting in a total of nine vowels. While with palatal and guttural vowels the degree of opening also reflects on the tongue position, differences in vowel quality of labial vowels are represented mainly by differing lip positions. Wallis considers those nine vowels as fully sufficient for a number of languages. However, already [ø] and [œ] cannot be fitted into this scheme anymore. Wallis' work has had a lasting effect on descriptions of English phonetics.

4. REYHER 1679

In his book *Mathesis Mosaica*, published in 1679 [23], Rehyer, a professor of mathematics at the University of Kiel, includes some aspects of language on the side, in particular its textualisation and pronunciation. His work contains a particular way of assigning vowels resembling today's order of vowels and is therefore shown in Fig.2. He arranges the five numbered vowels /a/, /e/, /i/, /o/, and /u/ along a semicircle, assigning the sixth position on the far right to the schwa vowel, which is the central vowel /ə/ often elided in German. Most likely due to this common

elision he provides no symbol for it. In comparison with today's vowel trapezium, the sixth position cannot be accounted for anymore. Also, the vowels /o/ and /u/ are interchanged. Other than that, clear similarities can be seen concerning the front-back-dimension (left-right) and the up-down-dimension.

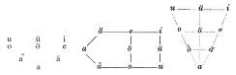
Figure 2: Semicircular vowel scheme by Reyher [23].

Reyher determined the vowel tones in 1679 first. He wrote that vowels do not just differ in the shape of mouth and tongue, but also tone height, which is to be clearly audible in whispering [23]. Thus, Viëtor [29] is wrong in claiming that Reyher determined the vowel tones by means of tuning forks which weren't invented until 1711. Evidently, the first accounts of vowel tones can be found 102 years before Hellwag [7] and by that a long time before the first German vowel system. Incidentally remarkable about Reyher's work is the finding that diphthongs are characterized by a change in vowel quality described by means of a starting and a finishing tone. He also calls the vowels /e/ and /i/ as "acute, sharp", terms that don't reoccur until the *Distinctive Features Theory* by Jakobson et al. [9].

5. HELLWAG 1781

Hellwag, who cited Reyher extensively, was the first to choose the shape of a triangle for an arrangement of vowels in his dissertation [7] and by that introduced the classical vowel triangle. The [a] is arranged at the bottom tip in order to show the relation between vowel lengths and at the same time stylize the corresponding articulatory tongue configurations (Fig.3 *left*). By that he carried out two important developmental steps at once that lead him to the very vowel triangle that can be regarded as the predecessor to today's vowel trapezium or the Cardinal vowel system since it differs neither in the number of steps in height nor in the vertical orientation.

Figure 3: *Left:* First vowel triangle by Hellwag [7]. *Middle:* First vowel scheme by Hellwag 1780 [30]. *Right:* Vowel triangle with equidistant tongue height positions by Hellwag 1783 [30].



Viëtor [29] did point out that the illustration from 1781 shows rather a pentagon if not a heptagon instead of a true triangle. But Hellwag had already chosen a fairly advanced arrangement of vowels (Fig.3 *middle*) and finally, in 1783, created a scheme of an exact triangle with equidistant levels of tongue height (Fig.3 *right*). In the first edition (1884) of his book *Elemente der Phonetik* p.18, Viëtor regards Hellwag as the prime mover behind the triangle shape of the vowel scheme, which he literally turns upside down by mistake, as he later admits [29], positioning the [ɑ] at the top. After some extensive research he corrects the graphic illustration in his second edition [29]. Sievers repeated the same mistake in the first three editions of his book *Phonetik* (1876) [26] and finally corrected the mistake in 1893 in his fourth edition [27], with reference to Viëtor's second edition. Sievers always critisized the triangular shape because he felt that it hardly took account of articulatory aspects [26].

Hellwag not only established the vowel triangle in 1781, but also, he went far beyond the assumption of fixed, intended positions in the vowel scheme: "Between these rows and steps countless others could be added that are used by people of different languages and dialects: perhaps, by this, all vowels and diphthongs any man has ever uttered could be specified mathematically by levels" [7] (p.26).

6. VON KEMPELEN 1791

In 1791 von Kempelen published his own vowel scheme [14], based on a five-step parametrization of mouth and vocal tract opening (Fig.4) because he very well realized the existence of "two sluices, holes or gates, which the tone of the voice has to pass", namely that of the tongue and that of the lips [14]. However, he fails to discuss the front rounded vowels and instead just offers the information in the shape of a sorted table that [u] and [y] have the same mouth opening, [u] the greatest "tongue channel" opening, while [y] has the second smallest tongue channel opening after [i]. Also, [o] and [ø] have the same mouth opening but very different tongue channel openings [14]. He does not realize that, aside from the degree of opening, the tongue posit-ion is also relevant, i.e. whether the tongue is further in the front or the back. Therefore, his suggested order of vowels, sorted according to the degree of vocal tract opening, was even in his days highly questionable.

Figure 4: Degree of mouth and vocal tract opening following von Kempelen [14].

As great as von Kempelens merit in the synthesis of spoken language may be, his vowel scheme must be regarded as a regression, in particular in the light of Hellwag's works. In the end, his speaking machine shows that von Kempelen did not realize his vowel scheme mechanically but left the creation of different vowel qualities up to more or less skillful cavity de- formations between a rubber funnel and a hand and by that to intuitive dexterity.

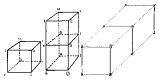
7. FORCHHAMMER 1913

As early as 1914, Jörgen Forchhammer chose the vowel cube introduced by his brother Georg in his search of a systematic vowel arrangement for a world's alphabet, reasoning that the three-dimensional nature of vowels calls for a three-dimensional coordinate system [6]. The simplest form was, in his view, the vowel cube (Fig.5 *left*). The vertical lines are meant to represent the vertical tongue movements, the horizontal lines represent the movements of the corners of the mouth (spread-rounded), and the lines running diagonally from front to back represent the tongue movements to the front and back. Forchhammer used the Russian symbol [bI] for the unrounded, closed back vowel, i.e. today's [ɯ]. In addition to the eight corner vowels a ninth one was added: "Right in the middle of the cube's inside is a point with an equal distance to every corner. The sound corresponding to this point must be considered fully articulatorily neutral […]. For the sounds grouped around this point, one could introduce the letter ə" [6] (p.299).

In his opinion, however, 9 vowels cannot constitute a world's alphabet, unlike 13, the number which includes the differentiation of three tongue height positions (Fig.5 *middle*) and reintroduces the vowel [ə]. Incidentally, Forchhammer brings out in a foot-note that the appearance of his vowel symbols have no meanings and were chosen merely due to restricted typesetting.

Jespersen had access to an early illustration of the vowel cube by Forchhammer (Fig.5 *right*) in 1913 already, which resembled a variant for German since there are no vowels assigned to the covered axis. Doubled lines represent lip movements, simple lines tongue movements from front to back and dotted lines variations in the degree of openness. Jespersen used Forchhammer's original symbols, but assigned phonetic symbols to some: å = [ɔ], ö = [œ] und æ = [ɛ].

Figure 5: *Left:* Vowel cube after Forchhammer 1914. *Middle:* Vowel block after Forchhammer 1914 with 3 levels of tongue height. *Right:* Forschhammer's the early vowel block after Jespersen 1913.

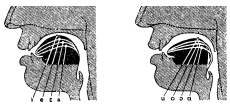


8. JONES 1917

Jones published his primary Cardinal vowel trapezium first in 1917 [11] at the same time as a disk recording containing his pronunciations of long and short variations of the eight Cardinal vowels, which he had numbered from 1 to 8 [12]. From his many years of experience in pronunciation lessons he realized that students could learn consonants best "by directing attention to tactile and muscular sensations", but not vowels because, in his opinion, "the finer adjustments of the tongue have to be done by means of sensory control from the ear" [13] (p.26).

So accordingly, the primary Cardinal vowel quadrilateral is mainly auditorily defined and only the 1st Cardinal vowel [i] and the 5th [ɑ] are defined articulatorily: The 1st is articulated in the very front and top and with spread lips. In the 5th, "the back of the tongue is lowered as far as possible and retracted as far as possible" and the "lips are not rounded" [13] p.31. The three other front vowels are inserted in perceptually equidistant steps. The three other back vowels are "chosen so as to continue this series of equidistant vowels" [13] p.32.

Figure 6: These sagittal sections, based on X-ray photographs by Jones [13] show which point of the tongue the vowel quadrilateral is derived from [13].



For Jones' Cardinal vowel articulations this led to the tongue configurations shown in Fig.6. As a simple diagram for practical lessons he derived the now established trapezoidal shape because it accounts for the greater distances between the front vowels [13]. The primary Cardinal vowel quadrilateral that Jones introduced has several advantages to all earlier approaches of vowel classifications:

(1) Since the Cardinal vowels 1 to 5 ([i] to [ɑ]) are unrounded while 6 to 8 ([ɔ] to [u]) are rounded, they cover the vowels of most languages of the world, albeit famous exceptions.

(2) The Cardinal vowel system appears to be intuitively closely related to articulation. The two-dimensional order of vowels according to tongue height and tongue position is immediately understandable and helpful, but it is only quasi-articulatory because the actual shape of the vocal tract is not described and cannot be described by symbolic means alone. Jespersen endeavored to describe not the sounds but the underlying articulation with symbols as exact as possible. He involuntarily demonstrated this to be the wrong approach and admitted that "in judging the articulation of vowels, one has to largely rely on personal assessments, which grow increasingly vague as one moves towards the back of the vocal tract and the more the tongue is distanced from the palate" [10] (p.164).

(3) The system probably works precisely because it appears to intuitively describe the articulatory, perceptual, and acoustic positions and distances appropriately. Articulatory measurements later continue to show, however, that the system is, at least in this domain, inadequate, albeit that claim was never raised.

(4) Acoustic measurements of the first and second formant of primary Cardinal vowels arrange these vowels almost independent of the chosen frequency representations (on a linear, logarithmic, or Bark scale) in a formant chart, in which F1 increases along the ordinate from top to bottom and F2 along the abscissa from right to left, strongly resembling the shape chosen by Jones (see e.g. Fig.7). (5) The spatial distances between two vowels in the primary Cardinal vowel quadrilateral closely comply with the perceptual distance; perceptually similar vowels are closely adjacent to one another in the vowel diagram.

Jones' vowel trapezium finally offers an acceptable compromise for German and English phoneticians alike as it appears to embody a perfect symbiosis of the German triangle and the English quadrilateral. Jones' system becomes more convincing, when one reviews the historical development of vowel charts, because the fundamental difference to all former systems lies in turning away from the attempt to superimpose articulatory and acoustic relations. Instead, he works only quasi-articulatorily and mostly perceptually, which is an approach none before him adopted but which was evidently quite successful since its main features have stood the test to this day.

9. DELATTRE, LIBERMAN, COOPER & GERSTMAN 1952

Experiments conducted with synthetic two-formant vowels by Delattre, et al. [5] lead to the first true acoustic-perceptual-based vowel chart (Fig.7). And even though it was not their intention to develop a new vowel system, this illustration influenced following research on vowels in that, ever since, front rounded vowels are listed in the primary vowel quadrilateral while at the same time indicating a tongue position slightly further back than that of the corresponding unrounded vowels. Fig.7 must, however, be regarded quite critically because the four authors served as test subjects in judging what two-formant-stimuli were the best representatives of natural vowels.

Figure 7: Prototypical formant frequencies for the synthesis of two formant vowels with a fundamental frequency of 120 Hz [5].

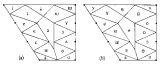
10. KINGDON 1964

Kingdon [15] did not play as big a role in the development of vowel diagrams as all previously mentioned authors, but he was the first to call for more vowel symbols after the successful introduction of Jones' system, namely at least 32, and was right along the lines with the systems of Bell [2] and Sweet [28], which have long since become obsolete. Jones had deliberately not assigned a symbol to the front rounded open vowel [ɶ] in 1962 because he felt there was simply no need for one [13]. Now Kingdon argues that the vowel quadrilateral has not been filled with vowel symbols equally in all positions [15].

The desire to introduce vowel symbols with little or no linguistic relevance, solely for the sake of symmetry

appeared to have been abandoned in favor of clear concepts just after Brücke [3]. But Kingdon distributed vowel symbols evenly in the entire vowel space and made a further mistake by not representing primary and secondary vowels in two diagrams, but spread and rounded vowels (Fig.8). Perhaps this was the rebirth of the idea to declare symmetry as the most important criterion for the design; a concept that was last fancied by Brücke [3].

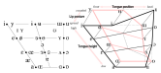
Figure 8: Kingdon's suggestion [15] for an enhancement of Jones' Cardinal vowel quadrilaterals, in order to assign a symbol to each small deviations of the vowel quality. (a) shows spread vowels, (b) rounded vowels.



11. INTERNATIONAL PHONETIC ASSOCIATION (IPA)

Between 1988 and 1993, the IPA made several modifications on the vowel scheme that had, up to then, mainly complied to Jones' Cardinal vowel system. It was especially two drastic changes that lead to today's IPA vowel diagram represented in Fig.9 *left*.

Figure 9: *Left:* The currently valid vowel symbols and their arrangement (IPA). *Right:* Three-dimensional illustration of the IPA's current vowel trapezium. The primary vowel quadrilateral with the Cardinal vowels [i] to [u] is marked with bold black lines, the secondary vowel quadrilateral with [y] to [ɯ] is brightly highlighted.



The first major change was designed in a joint paper by Ladefoged & Roach [18] and initiated by a questionnaire by Nolan [19] sent to 38 phoneticians of whom 24 responded in time. While the question whether the trapezoidal form should be abandoned was denied by 23:1, the question of combining the two diagrams into one, according to one of the four suggested alternative ideas, of which only one separated primary and secondary vowels while the other three separated the vowels after the rounded-unrounded criterion, led to only three pleas in favor of the old system. 20 participants chose one of the three alternative ideas, and so with only 10 votes the concept of combining the primary and secondary Cardinal vowel quadrilateral in one won and by that the articulatory feature "lip posture" was included as the third dimension of vowel quality. This suggestion finally became the new convention in 1989 [8].The second change was the insertion of four additional central vowels, mainly dominated by lip posture but without any purpose other than symmetrically filling up the big, empty space. This addition was suggested by Catford in 1990, who assures that by horizontal movement of the tongue, central reference positions can be learned easily, a technique recommended by Sweet [28] and required of his students by Catford [4]. His reference to Sweet [28], whose 72-vowel-system failed precisely due to its exceeding complexity is at the very least curious.

12. CONCLUSION

The currently valid vowel diagram has become very similar to the vowel cube by Forchhammer (see Fig.9 and Fig.5). The Cardinal vowel quadrilaterals can, however, only be found in a rather distorted manner as Fig.9 *right* shows. According to this three-dimensional illustration it becomes evident immediately that the classical Cardinal vowel system by Jones is incompatible with the new rounded-unrounded-dimension because big spaces result along this tightly dotted line where lip posture is undefined or maybe "neutral" since primary and secondary Cardinal vowel quadrilateral must intersect there.

In consideration of the intuitive simplicity of Jones' system, the two changes (unrounded-rounded-dimension, four additional central vowels) can only be considered as regresses to the out-dated past that has exposed the articulatorily-based definition as well an unnecessarily high number of reference vowels as impractical a long time ago. The dominance of the three articulatory dimensions tongue height, tongue position, and especially lip posture of the current IPA vowel diagram conceals the intuitive element of Jones' articulatory-perceptual definition of the primary Cardinal vowel quadrilateral, in which the 1st to 5th Cardinal vowels are defined as unrounded with decreasing lip spreading and the 6th to 8th as rounded with increasing lip rounding. Since Jones had oriented lip posture on the phonetically sensible and not the physiologically possible, his system benefited from the covariation of lip posture with vowel height and backness often observed in many languages of the world. This elegant simplicity is lost entirely.

Considering all steps of development of vowel systems presented in this paper, the recommendation is to continue using the Cardinal vowel system of Jones as a reference. In phonetic lessons it is his Cardinal vowels that are taught almost exclusively, and phoneticians all over the world are well familiar with the system introduced by Jones. Further remarkable historical vowel system developments and additional information can be found in Pfitzinger [20, 21] but had to be omitted here for space reasons.

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