ABOVE THE NEW METHODS OF ACOUSTIC DIAGNOSIS OF VOCAL TONE

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Abstract: The modern concept of singing education is based on the book Resonance in Singing by Donald Gray Miller. The research is realized using the VoceVista Professional software, which analyzes the individual components of each tone and determines its fundamental frequency and further higher harmonics (H1, H2, etc.) It also shows the presence of other formants contributing to the quality of the tone. The individual components are quantified by their frequency (Hz) and intensity (dB). The result of the tone displayed in this manner is an objective description of the tone and a visualization of tone components that can help both singing teachers (for voice diagnostics) and students when studying singing.

Keywords: fundamental frequency, formant, resonance

Modern singing education, more than any other field of music, opens the question of the nature of the relationship between the macroworld and the microworld of musical performance – i.e. to what extent there is a connection between the quality of a tone and the interpretational concept of what is being sung. In practical education, the described connection is often viewed equally from the educational-psychological (manner of teaching), physiological (voice care) and interpretational-conceptual perspectives, as well as from the perspective of the singing technique. These perspectives may be combined, complement each other or even be incompatible with each other[1].

However, the modern concept of singing education that is coming from the countries of northern Europe, Benelux and from the university in the US Princeton suggests an interdisciplinary cooperation of physio-acousticians, singing teachers and music theoreticians[2]. It is inspiring also for other fields of practical arts of music. Hence conventional singing education may use sufficient feedback from the diagnostics of natural sciences thanks to the developed method of studying resonance in singing on the basis of physio-acoustic connections[3]. There is a tool but it still waits for wider application.

The basic concept of voice studying is presented in the book Resonance in Singing by Donald Gray Miller[4]. The research is realized using the VoceVista Proffessional software (VVP), which is an actual tool for voice analysis. The method can be briefly characterized by the following points:

1. The sung tone (recorded for the purposes of the analysis or reproduced from a CD or another medium) is, in real time, parcelled out by the VVP software into the fundamental frequency[5] (F0) and further higher harmonics (H1, H2 etc.)[6]. These are quantified by their frequency (Hz) and their intensity (dB). A detailed composition of the sounding tone is expressed in a so-called power spectrum (VVP, Power Spectrum, see Fig. 1 on the bottom left). As well as any other recording, there is also the standard waveform envelope in the VVP dialogue box (Waveform Envelope, Fig. 1 on the top left).
2. The condition of the glottal activity is mapped by an electroglottograph, which enables to create a model of a specific glottal vibration in a glottal cycle (these data may also be a part of the dialogue box, as in Fig. 1)[7].
3. The research also maps the acoustic possibilities of sung vowels[8].
4. For the quality of singing, the existence of the so-called formants and their profiling is important, i.e. the general presence of such physio-acoustic phenomena arising from the cooperation of the glottal signal with articulators[9]. Formants cause resonances in singers. These are independent from the fundamental frequency but are, among other things, affected by the vowels pronounced. A typical trait of human voice is (as opposed to musical instruments) that most of its F0 is relatively weak and the volume of the sound comes from higher harmonics. Strong harmonics, i.e. formants owe their intensity to the resonances of the vocal tract. The first five strongest formants (which are marked according to their frequency from the lowest to the highest F1 – F5) have the biggest impact of singing production. Their frequencies are variable and are conditioned by the position of the lips, the tongue, opening of the jaw and by the position of the other articulators[10]. Quoting a significant Czech acoustician, Václav Syrový, we may add: "By changing the form of the vocal tract, it is possible to adjust the position of a formant towards one of the harmonic components of the glottal tone. That is how a conspicuous resonance of the relevant component occurs at the frequency of the formant, resulting in a general amplification and improvement of the voice"[11].
5. The research is evaluated in relation to the conclusions of a voice teacher's professional listenings[12].

Results based on the physio-acoustic analyses of classically trained voices of the opera type fundamentally differ from

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[1] As a most charming example of such a paradox, let us mention the recent visit of a group of singing and voice teachers to the Voice Centre in Prague, where, for scientific purposes, each of them underwent an individual examination of their vocal cords by the prominent phoniatrician Dr. Vydrová. The doctor identified the vocal cords of one of our colleagues as soprano – to everybody's surprise because she was in fact a singer of a lower voice range. The following discussion revealed that the discrepancy between the phoniatric diagnostics and the singing reality is common. However, one important finding follows from this and that is the fact that the influences on the vocal realization of a composition interact with a number of factors and it is not easy to accent one of them at the expense of others.

[2] For example Czech music theory brings into the voice science something unprecedented in the form of Zich's concept of the systematics of interpretational means, as well as Janeček's melodics.
From the perspective of music theory, for instance the following questions are asked:
a) What is the structure of a melody and what is the form of the melody line?
b) In terms of the link to the accompaniment surrounding the melody, we assess whether it is an independent melody or a bound one
c) In terms of style assumptions, we express the features or traits of a style
d) In terms of the link to the text, the connection with text is also important, as well as the musicalization in terms of metrics, as well as the contents

[3] The history of research is mapped by SUNDBERG, J. Research on the singing voice in retrospect. *TMH-QPSR*. 2003, 45, 1, p. 11-22. Also available at WWW: <http://www.speech.kth.se/qpsr>. In the Czech lands, it was Špelda and Burghauser who has participated in the research of history, or Švec at the present time – see the sources.

[4] MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7.

[5] i.e. the higher harmonic whose pitch equals the pitch of the sounding tone

[6] The abbreviations are borrowed from the above-mentioned book. The term "higher harmonic" is a synonym for the older term "aliquot tone". From what has been said, it may be deduced that H1=F0, that H2 has twice the frequency of F0, etc. The article does not include the new terminology of tones used in the book (e.g. A4 from the book corresponds to our a1). However, when reading the book, the reader is highly recommended to get acquainted with this somewhat confusing system and acquire it quickly.

[7] Despite the clear influence of the individual specifics of the glottal cycle on the singing performance, we will not deal with this issue here. It is because it introduces the phoniatric dimension into the discussion, which we do not consider in our area of mapping. For further information see MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7. Chapters No. 2 (pp. 7-12) and No. 5 (pp.34 – 44)

[8] See MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7. Chapter No. 4 (pp. 21 – 33)

[9] The moveable parts of the vocal tract (the tongue, the jaw, the velum, etc.) condition the (adjustable) formant frequencies and the air stream affects their dynamics – these parts are all called articulators. All the terms are borrowed from the dictionary of terms of the above-mentioned book – p. 110.

[10] See MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7. Chapter No. 3 (pp. 13 – 21).

11 SYROVÝ, Václav. Hudební akustika. 2nd supplemented edition. Prague : HAMU, 2008. 448 p. ISBN 978-80-7331-127-8. p. 211

12 Donald Gray Miller notes on this topic: "Like pedagogical expertise itself, this knowledge is acquired slowly through experience; the objective nature of the signals, however, limits the degree to which a given teacher is free to interpret them." MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7. Chapter 5, Practical Science, p. 35.

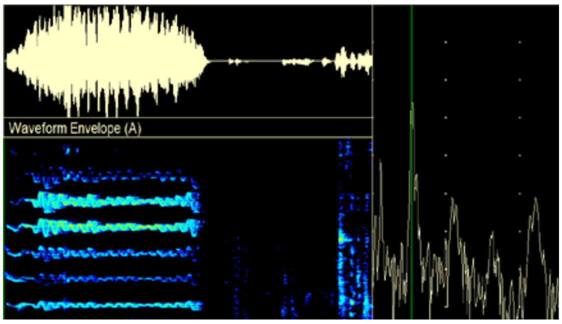
untrained voices (see below). Although significant scientists of the field state that all the factors participating in the creation of an opera voice have not been identified, the following comparison shows:

1. the singing formant[13] appearing in the case of a singing voice, as well as a significant profiling of the formants of lower frequencies. In comparison with their frequency environment, the mentioned formants manifest themselves in their higher intensity (dB).
2. the influence of vibrato in a trained voice that creates variations in the fundamental frequency and its harmonics in such a way that the higher the number of the given harmonic, the higher the variance (e.g. if F0 in a vibrato demonstrates the variance of 15 Hz, for H10 it shows the variance of 10x15 = 150 Hz, etc.)
3. the impossibility to fully rely on mere abstract mathematical calculations of frequencies and intensities of the individual harmonics. The specific harmonizing of the formants by the singer (either intuitively or by controlled efforts), vibrato and other elementary interactions within the sounding tone cause differences from the calculations and are often conspicuous[14].

To illustrate what has been said, let us perform a short analysis of a tone sung by a specific trained voice – a soprano singing c2 (see Fig. 1). Let us concentrate only on the items of the power spectrum at the right side of the dialog box. These are able to document the conclusions made above.

Fig. 1

Field No. 1 2 3 4 5



The cursor of the power spectrum (Spectrum) shows the fundamental frequency of the sung c2 tone in the syllable [yo][15]. Table 1 demonstrates the arrangement of formants for the individual harmonics. These are determined by the parameters of frequency and intensity. For better orientation, the fields in Fig. 1 in which they are located are also given.

Table 1

Fundamental frequency F0 = H1 (534Hz)	**-30dB 1st field**
F1 H2 = 1082Hz (as if c3)	**-52dB 2nd field**
F2 H4 = 2201Hz (as if d^{b}4)	**-53dB 3rd field**
F3 H5 = 2705Hz (as if e4)	**-56dB 3rd field**
F4 H3 = 1612Hz (as if g3-a^{b}3)	**-62dB 2nd field**
F5 H6 = 3246Hz (rather a^{b}4)	**-64dB 3rd field**

A number of higher harmonics beginning at c2 that are given in the table should correspond to the pitch where H2 = c3, H3 = g3, H4 = c4, H5 = e4, H6 = g4. Note that particularly H3, H4 and H6 show deviations. They are possible because (see above) for instance vibrato may play a role here (e.g. the variation is four times higher for H4 than for F0), or other interactions between harmonics. To determine values closer to the "ideal" positions of harmonics that are defined mathematically, a long-term averaging of singing performance data would have to be carried out[16].

A lot may be deduced from Table 1, for instance that:

a The strongest frequency of the studied singer's sounding tone is the fundamental frequency. Based on this finding, it may be said that the characteristics of her voice comes predominantly from the glottal source. Note that the distance from the next reinforced harmonic H2 (that is simultaneously the resonance space of F1) has the intensity of 22 dB. That is the largest difference between adjacent harmonics that can be noted in the discussed table. This fact is somewhat in conflict with what is said above. It may be interpreted as that it causes a narrow soprano type, but, in terms of intonation, the clearer. (The fundamental frequency is not a formant but it is a starting impulse for all the physio-acoustic processes happening before the tone leaves the last space in the vocal tract which it goes through and which affects it both in terms of quality and quantity – the oral cavity[17]).

b From the perspective of intensity, the resonance areas of F1 – F5 form a relatively homogenous territory that is placed between 52dB and 64 dB (In Fig.1, it corresponds approximately to the space between the two dots of the vertical intensity scale). However, the range of frequencies belonging among the mentioned intensities is rather large. It involves the tones of the pitch between c3 and as4 but it needs to be realized that it is in fact the space between H2 and H6 that occupies only 5 higher harmonics[18]. However, the intensity-bound group of formants F1 – F5 – in average for one formant – is weaker than F0 by almost a half. Therefore the volume of the voice cannot be dramatically increased. (F1 and F2 are also directly formed from the glottal source and are generally the most conspicuous in the resulting sound. They also determine individual vowels[19]. Other formants affect predominantly the individual voice timbre. Their parameters are formed by the configuration of the vocal tract.)

c Despite a certain intensity slump between F0 and further studied higher harmonics[20], we may observe some manifestations of the processes that triggered the creation of the so-called singing formant in the analyzed tone. The table clearly shows that the closest distance of frequencies, when observing the area F3 – F5, can be found between H5 and

[13] The singing formant is formed by the clustering of at least two formants from the selection of "F3, F4 and F5" that are far less variable than the vowel formants F1 and F2. The singing formant is influential in the frequency area of 2.3 – 3.5 kHz and is a tool that helps the voice to be perceived. In the high tones of some voices, the resonance of the singing formant greatly contributes to the overall level of the acoustic pressure (ibidem p. 120).

[14] Computer data of the mathematical predictions discussed are obtained for example through the so-called linear predictive coding (LPC). However, its results are only plausible for the frequency range of human speech. Ibidem p. 117.

[15] According to the table of the tone frequency of tempered tuning (mentioned for instance in the above-mentioned Hudební akustika by Václav Syrový, p. 431), c2 corresponds to the frequency of 523.26 Hz. In order for the absolute pitch of the tone to be identifiable by hearing as assigned, it can differ from the table parameter by up to 10 Hz (disproportion lower than a quarter tone). Hence in this case, the norm is met.

[16] In the book Resonance in Singing, the author discusses a so-called long-term average spectrum (LTAS), which can present useful information about the frequencies and the strength of the singing formant. For further details see MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7. Chapter No. 5 (pp.34 – 44)

[17] Thanks to the Madde software (Granqvist, Royal Institute of Technology Stockholm, 2005), it is possible to simulate an acoustic synthesis of voice by creating an electro-acoustically generated voice on the basis of adding or revoking formants to an F0.

[18] It is not possible to use a keyboard to demonstrate the described reality because its system is not composed in compliance with the processes happening within the sounding voice.

[19] See also MILLER, Donald Gray. *Resonance in Singing : Voice Building through Acoustic Feedback*. 1. Princeton, USA : Inside View Press, 2008. 131 p. ISBN 978-0-9755307-5-7. Chapters No. 3 (pp. 13 – 21) and No. 5 (pp.34 – 44)

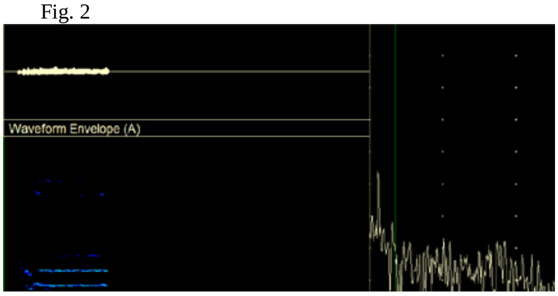
[20] The decrease in intensity between F0 and higher harmonics is not caused only by the specifics of the voice, but also by the natural physio-acoustic processes accompanying the journey of the glottal tone through the cavities of the vocal tract. The amplitude of the harmonics of the source spectrum – i.e. the sound spectrum, before it is lead to the resonances of the vocal tract, decreases with the increase of frequency by 6 – 12 dB per octave. This phenomenon is called the frequency slant.

H6 (creating resonances F3 and F5; from the perspective of intensity, it is F3 which is more significant though). And it is here where we can find the typical space for an effective influence of the singing formant on the voice penetration. The absence of the influence of F4 that is, in terms of frequency, not close either to F3 or to F5 may be also the reason for a lower voice volume of the singer, as perceived by a professional aural analysis.

d The spectrogram in the bottom left part of Fig. 1 documents the development of the tone sung depending on time. The point that is, in parallel, marked by the green cursor in the power spectrum (studied in the analysis) coincides with the left vertical framing of the image. The spectrogram documents that fine segmenting enables us to find further, though inaudible, inner life of the tone. But even it is, in a way, formed by singing training.

For a comparison, an image of a tone sung by an untrained voice, as generated by VVP, is attached (Fig. 2). The difference from the image of the performance of the trained voice is obvious[21].

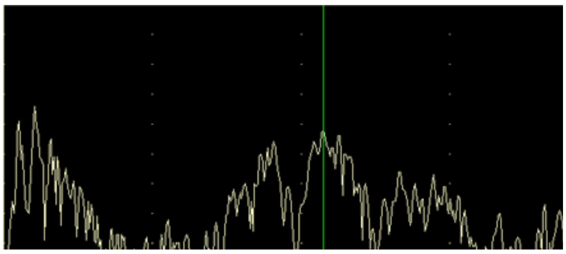
Fig. 2



The absence of formant peaks is evident, as well as the very low intensities of higher harmonics (being often above -70 dB). The measured values belong to a fresh university student, whose voice was recorded and measured during the first lesson of the subject Music Education. If her studies are successful, the better quality of her singing will demonstrate itself not only outwardly, but also in the discussed measuring.

It is always problematic to assess whether an interesting, artistically valuable singing voice has been "created" by the influence of a teacher or whether it has been the natural physiological dispositions of the singer that have played the decisive role in its development. The complexity of this assessment is demonstrated by Fig. 3, which shows the formant structure of a mezzo-soprano voice that has been developing for 15 years "only" on the basis of choir activities under the guidance of an experienced choirmaster. I would like to use the following image as an attractive, scientifically documented argument for parents to convince them that sending their children to a children's choir is perspective for the healthy development of their children. However, in order to preserve the scientific objectivity of what is stated below, I remain impartial.

Fig. 3



[21] It is not important for the comparison that the tone analyzed is different here (f1 here). It is the tone structure that matters, i.e. whether it has or does not have the resonance characteristics expressed by the presence or absence of formants. The form of such a structure is individually linked with each singer, as well as "non-singer" and accompanies in basic contours each of his or her singing and "non-singing" performance.

Fig. 3 is also accompanied by a table (see Table 2):

Table 2

Fundamental frequency F0 = H1 (347Hz)		**-51dB 1st field**
F1 H6 = 2149Hz (as if c4)		**-43dB 3rd field**
F2 H5 = 1821Hz (as if a#3)		**-46 dB 2nd field**
F3 H7 = 2660Hz (as if e4)		**-56dB 3rd field**
F4 H8 = 2889Hz (as if f#4)		**-59 dB 3rd field**
F5 H14 = 4895Hz (as if d#5)		**-60dB 5th field**

The cursor of the higher harmonics in Fig. 3 shows the most conspicuous item of the sung tone f1 (the syllable [lah]), i.e. the first formant that occupies the space of H6 (hence higher than F0[22] by 2 and half octaves). The full timbre of the voice is also supported by the fact that the first five most influential formats cooperate with the harmonics 5 – 8 (i.e. in the space of a#3 – f#4). Even H14 competes with these (approx. d#5). The mentioned harmonics are significantly distant from F0, hence create a striking voice volume. By summarizing all the mentioned above, we find out that the stated acoustic attributes resemble rather the structuring of the voice trained by an experienced singing teacher, as could be noted in Fig. 1 and Table 1.

Conclusions

The analysis of one tone presents only one perspective on singing performance. However, when evaluating the quality of a voice, such a perspective is an important one. If we agree that a tone is only an "atom" of music though, it is necessary to observe further its mutual horizontal and vertical correlations with other tones. It is important to ask the question of how the physio-acoustic attributes of a vocal tone that are demonstrated through voice quality and its timbre coexist with the interpretational concept, or to put it more generally – with the interpretational thinking of the singer. However, singing education still waits for the question to be answered.
magna ipsum, volutpat ut pulvinar sit amet, iaculis in odio.[23]

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[22] From the perspective of intensity, F0 is the third.

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