The dancing diaphragm

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The musical instrument we all possess and which we can all play to some extend is our own voice. But despite we may assume that man has always sung, it is only since half a century that we have a scientific understanding of its mechanism. Of course that does not mean that in the past vocal pedagogues messed things up. They learned from experiences and pass on the acquired knowledge. But this is not without risks. If no one exactly understands the mechanisms of the instrument, many ideas may arise of which the validity is difficult to proof. In a piano we can see and agree that pressing a key will force a hammer to beat a string, which generates vibration both in the string and the air. But it is not that simple in the human voice. We can hardly see the focal folds vibrate without special instruments and from neural activation we still do only known very little. Yet, science has made a lot of progress over the last fifty years in understanding voice and speech. And especially over the last twenty years we have witnessed a growing scientific interest in the singing voice. In this paper I will discuss a few results.

Voice production

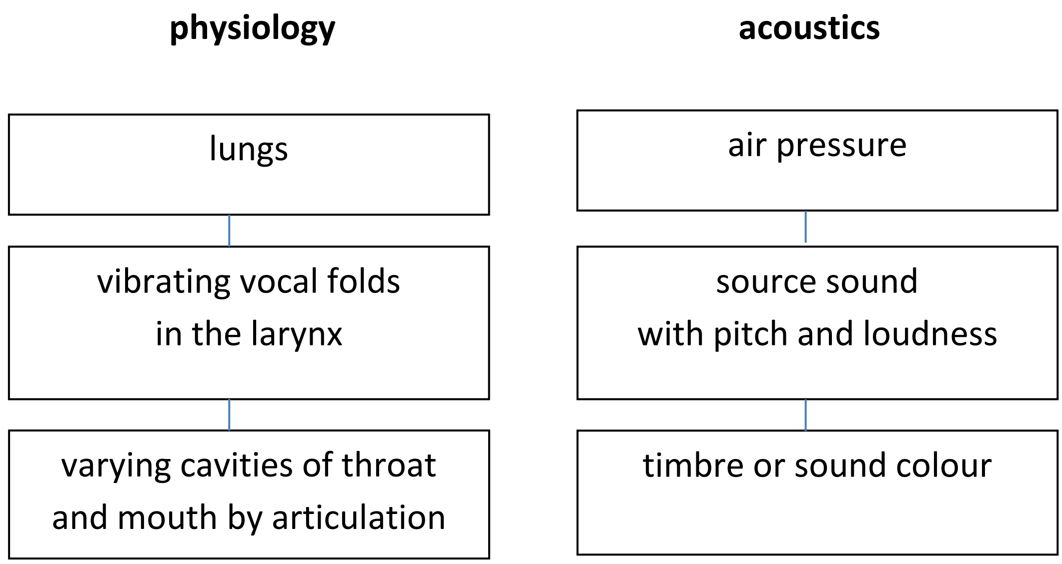

Figure 1. Basic modules in singing

Just like most musical instruments the voice has a sound source and a resonance box. The sound source are the vocal folds who are driven by the air pressure in the lungs. The resonance box is the cavity of the throat and mouth, or vocal tract, with sometimes the nasal cavity connected. That is all (figure 1). It is remarkable that nowadays singers still have difficulties with this simple scheme. They feel all kinds of vibration in the body, especially in the head and in the chest. It is then easy but erroneous to conclude that also the chest and frontal sinuses play an active role in sound production.

But let us first consider what happens in voice production. First, air pressure should be built up in the lungs. For that we close the vocal folds and then there are several options for muscles to pressurize the lungs. Abdominals, diaphragm and intercostal muscles all may play a role. But any fixation is out of the question: especially the diaphragm should be very flexible during singing, it should dance slightly up and down for every sung tone and any fixation would deteriorate the sound. This is because for every tone a special balance is needed between the air pressure in the lungs and the pressure that adducts the vocal folds. This holds in the same manner for a trumpet player for whom the lips are the sound source, and for all other wind instruments with a sound source outside the body: the diaphragm dances along with the music.

During singing, the vocal folds are closed by the muscles in the larynx and the lungs provide just enough pressure to open them. The air then flows out and this reduces the air pressure between the vocal folds slightly, just enough to close again. Then the lung pressure increases again, the vocal folds open, and the process continues. One after another little puffs of air are created and this is the source of sound. The frequency, the pitch of the sound, equals the number of times the vocal folds open and close in a second. This depends on both the adduction pressure of the vocal folds and the air pressure of the lungs. At very low pitches this is about 70 times a second, but for a soprano it can rise to as high as 1500 times a second. This is the highest mechanical frequency our body can produce!

The air puffs that leave the vocal folds bring the air in the vocal tract in vibration with a certain frequency. But besides frequency the shape of the air puff (its variation in air pressure) has an effect on the sound as well. A fast closure of the vocal folds generates a louder sound and a different sound colour. An exaggerated pressure by both the vocal folds and the air pressure, by which the folds hardly open but close very fast, leads to a pressed sound. Because there are dozens of muscles which influence the vocal folds, the latter can be manipulated in many ways, not only in frequency, vocal intensity and timbre, but also in type of vibration or vocal register. A major distinction is between two registers, in modern naming the modal and the falsetto register or in a different description the heavy and light register. The term register originates from organ building, from an (incorrect) comparison of the voice with an organ pipe.

Vocal registers

The existence of vocal registers creates a problem in singing pedagogy. The number of registers that has been distinguished in the past is enormous. For about a century the register phenomenon is related to the mode of vibration of the vocal folds and since about 20 years the number is scientifically limited to only two modes. Well known and widely used old, but still widely used terms are the chest register and the head register. These unhappy terms originate in an incorrect understanding of voice production. At loud lower pitches a singer can indeed feel vibrations in the chest bone. This is because the vocal folds not only generate vibrations in the vocal tract but downwards in the trachea and lungs as well. These vibrations propagate to the chest bone. But this vibration of the chest bone does not have in itself any influence on the production of sound. Many singers however had this idea, exemplified by the anecdotical story of the singing bones of Caruso.

The name of head register, or head voice, has a comparable origin as the chest register. The air vibrations in the vocal tract pass on to all the surrounding tissues and the bones in the head. The frontal sinuses have a certain volume and the air in it will start resonating when the corresponding frequencies are present in singing. There exist indeed very small direct canals to the frontal sinuses, but their acoustical resistance is too high to have any influence on sound production. The resonance frequency of the frontal sinuses is high and can be noticed when singing high-pitched notes, which is the origin of the name of head register. It may be understandable, but it has led to incorrect idea that sensations in the head are essential for a correct way of singing. Singing ‘in the mask’ is still a commonly used term. In the worst case this may lead to a forced way in trying to create certain internal head sensations, with a total loss of the relaxation needed for good singing.

We preferably distinguish for both male and female singers the names of heavy and light register or modal and falsetto register. Falsetto register may still be an unhappy term since it is as term highly unusual for female singing although the underlying mechanism is the same for males and females. For the sake of completeness it should be noted that especially for female singers a subdivision of the light register has been proposed as well. This distinction is usually less evident than between the heavy and light register and more difficult to describe. Finally, it is important to note that the *use* of registers depends highly on fashion and culture. In the 19th century a high c could be sung by a tenor in falsetto register, but later it was far more appreciated when this note was sung in a forced heavy register.

This brings us to another point of dispute in singing technique: the position of the larynx. In the 19th century the tenor Duprez discovered that he could realise very high pitches in the heavy register with a technique that was called ‘covered singing’, again a term borrowed from organ building. Nowadays we talk about singing with a low larynx position. The larynx with the vocal muscles is flexible located on the trachea and can move up and down several centimeters. During yawning or during singing of a glide by an untrained male singer we can easily see this from the varying position of the laryngeal prominence. It seems that trained singers vary the position of the larynx much less and can position it even lower at will. In general, a wide pharyngeal cavity is favourable for a specific resonance in singing, but such a condition can also be realised by other means than a lowered larynx. The relation between transition between registers and larynx position is still insufficiently known.

Phonetography

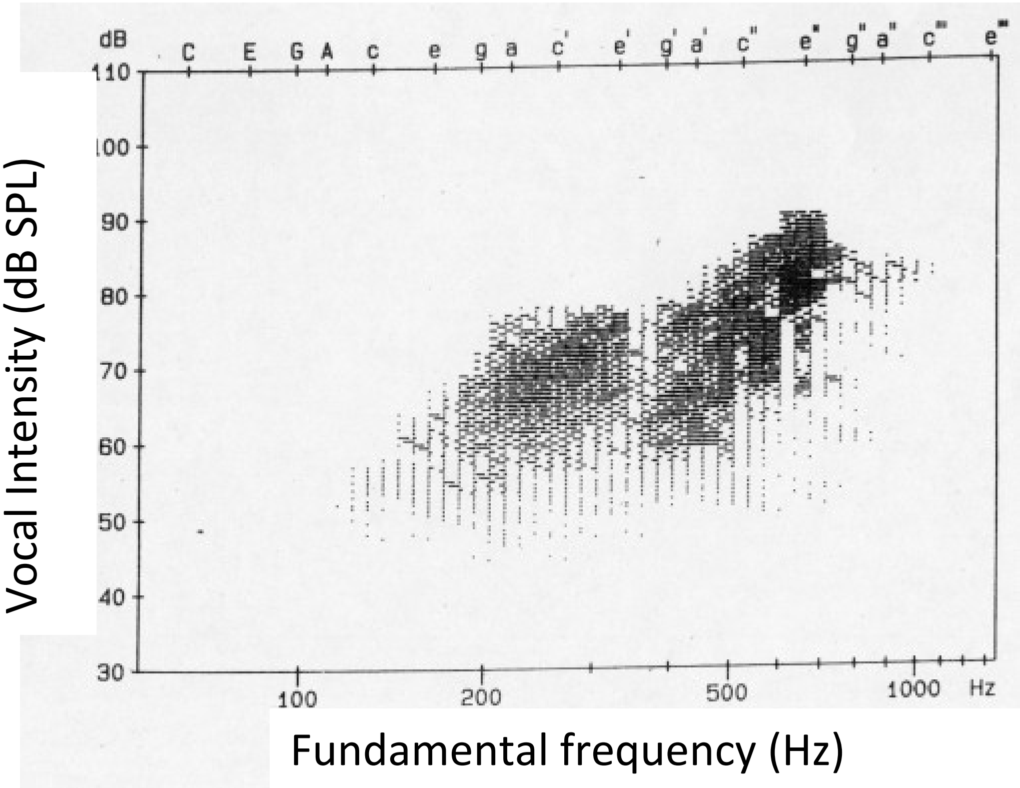

Figure 2. A phonetogram (or voice profile) of a female singer (according to Pabon). The darker the area, the more regular the voice.

Nowadays there are excellent methods to see the vibration of the vocal folds (by videostroboscopy or high speed camera) and to map the acoustic possibilities of the voice. The latter is called the technique of phonetography (or voice profiling) and brought to high standards by Pabon from the Institute of Sonology in The Hague. In phonetography, a singer is singing while the sound is analysed in real time by a computer. Pitch, vocal intensity (loudness) and other acoustical properties are measured and shown to the singer on a computer screen. This screen, see figure 2, shows the pitch on the horizontal axis and vocal intensity on the vertical axis. Of course a singer has a limited range for both pitch and vocal intensity which shows as limitations of the area where voice is possible. The shape of the vocal area informs us about the voice of the singer. A bass singer will occupy a different area than a tenor or soprano singer. In general the shape of the phonetogram is like a shallow egg: vocal intensity will rise with increasing pitch. In addition, figure 2 also shows the regularity of the vibration of the vocal folds: the darker the more regular. We see that the phonetogram is cut through half way by a lighter area where the voice is more unstable. This illustrates the transition area between the heavy and the light register. It also shows that the register transition does not take place at a fixed pitch, at louder voice the transition is made at a higher pitch. Also the bottom part of the phonetogram is much lighter: very soft singing in a stable way is very difficult.

Resonances

Up to now we only described the functioning of the vocal folds as a sound source, but the vocal tract offers many interesting possibilities to colour the sound. During the vibration of the vocal folds not only the basic tone (fundamental) is generated, of which the frequency determines the pitch, but at the same time also a series over overtones (or harmonics) which each have a frequency which is a multiple (from 2 until very high) of the frequency of the fundamental. The more firm the closure of the vocal folds the more powerful this series is in vocal intensity. This complex of overtones determines the sound colour (or timbre) of singing. By means of articulation we can influence the intensity of the overtones and therefor the timbre of the voice. In this respect the human voice is quite special and distinct from other musical instruments: we have a resonance cavity which can take an infinite number of shapes, and associated voice colours. The role of the nasal cavity is usually limited (although some pedagogues will think differently). The effect of the nasal cavity is easily verified by holding one’s nose during singing of a vowel. If the uvula closes the nasal cavity no difference will be heard.

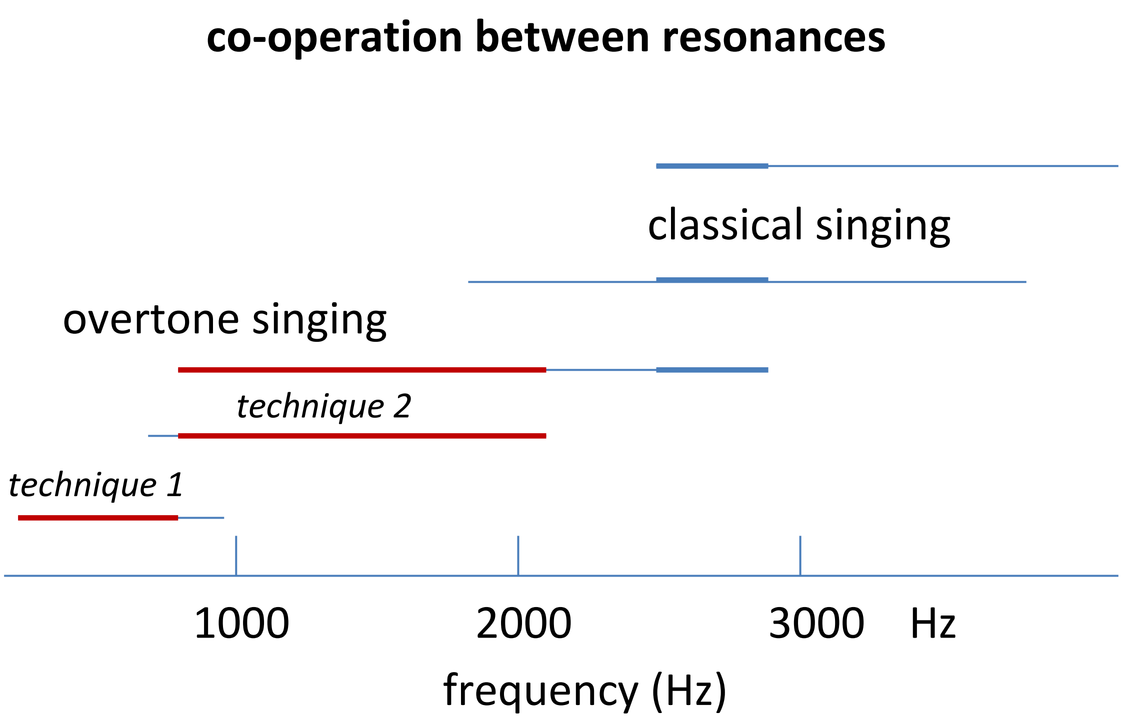

Figure 3. Frequency range of the five resonance areas in singing. Bold lines indicate the possibility of co-operation between resonances in overtone singing and in classical singing.

There is a complex relationship between articulation and its effect on singing. Roughly the vocal tract is associated to five resonances which each can strongly propagate overtones in the corresponding frequency range . The manner of articulation determines the five frequency ranges, which are different for every way of articulation. If we articulate an ‘a’ sound other overtones are dominant than when we articulate an ‘i’ sound. Figure 3 shows the frequency ranges over which the resonances are active. From bottom to top: if we open our mouth, like between ‘u’ and ‘a’ the lowest resonance frequency moves from 200 to 900 Hz. If we move our tongue from back to front, like between ‘u’ and ‘i’ than the second resonance frequency moves from 800 to 2200 Hz. The resonances at higher frequencies are related to smaller volumes in the vocal tract, especially those in the pharyngeal region.

It is of interest that there is an overlap between the frequency ranges of the five resonances. That offers the opportunity of co-operation between resonances by special articulation. Western classical singing uses a co-operation between the three resonances with the highest frequency ranges: by means of the shape and volume of the pharyngeal cavity (some claim a lower larynx position) a combined and very strong resonance is realized with a frequency between 2000 and 3000 Hz. This is what is called ‘the ring of the voice’ or the ‘singers formant’. In overtone singing as mastered by the people of Mongolia and the Central Asian republic of Tuva a co-operation of the second and third resonance is used to reinforce individual overtones (as a whistle) in the range of 800 to 2200 Hz (technique 2 in figure 3). The articulation in overtone singing is like a very slow articulation of the word ‘*worry*’ during which the tongue closure is moved very slowly from back to front in the mouth. For lower overtones they make use of the first resonance in combination with nasal phonation (technique 1 in figure 3). These lower overtones are usually much weaker. Overtone singing is realised with a very pinched voice to reinforce overtones.

This concludes our description of facets of singing. A few basic principles were discussed, of which we know that they are not that easy to grasp. Yet it is important that singers and vocal pedagogues have an understanding of them. Not as a recipe to learn how to sing, but as a basis to avoid incorrect and outdated ideas which can hinder good vocal development. Because studying singing is difficult enough in itself. The musical instrument is part of yourself, vulnerable, irreplaceable and unique. And the uncertainties can be equally complex. Science can only take away a small part of that.