Vocal Tract Resonance In Singing

Johan Sundberg

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Johan Sundberg at Strasbourg

Introduction: Why Bother?

Why should a successful singing teacher bother about the functioning of the voice? From the teacher's experience, voice function has become a well-known area, and a reliable terminology has resulted that can accurately describe the relevant phenomena. By gift and intuition the teacher can successfully teach students how to use the voice so that they will become good singers. So, what contributions does scientific research have to offer this teacher? My view is that science does not have very much to offer in these cases.

However, my experience has also been that several singing teachers develop a great curiosity. They tend to ask themselves WHY IS THIS SO? when they note that THIS is advantageous for most students while THAT is detrimental. Perhaps they have noted that THIS is a never-failing instruction while THAT is an almost always-failing instruction, and yet these instructions mean the same thing. Curiosity might also pull them away in other directions. For instance, one might want to know what the physical ties and relationships are between various vocal phenomena, such as loudness, jaw opening, pitch, vowel quality, vibrato, covering, and what not. Persons suffering from (or enjoying?) such a curiosity cannot resist keeping track of what is new in voice research.

Not only professional curiosity might generate an interest in voice research on the part of the singing teacher, but also, the need for a common terminology may lead to the same result. Vocal pedagogy is loaded with personal terminology which remains unclear to most people, except, hopefully, the user him/herself. The term "support" is an excellent example. Each teacher, of course, would know what he/she means with that term, but one cannot take for granted that it means the same thing when used by others. This is an uneconomic state of the matter, limiting the possibilities of exchanging experiences between colleagues. And, still worse, colleagues might even develop hostility simply because they mean different things with the same terms. The medicine against this disease is objective knowledge, that, ideally, scientific research should offer.

Another advantage with a common terminology is that people from other fields of voice, such as speech therapy, laryngology, and logopedics, more easily can understand what singing means in their terminology. This usually is not the case now: few voice scientists can understand exactly what singing teachers try to tell them, and then the teacher's knowledge about voice largely remains his/her personal secret because of terminology problems. This counteracts development and understanding in all the areas involved.

Respected readership, I realize that what made you read this article was a strong desire to know what science has to tell about the functioning of the singing voice. Still, I felt like making the above statements; hopefully they could be of use when you speak with colleagues who are less curious than you are.

As I see it, scientific work should answer two main questions: HOW? and WHY? In other words, it should *describe* and *explain* reality. In the case of voice research the voice sounds are described by means of acoustic analysis. The explanation is a theory for the generation of sound in the voice organ.

In this presentation I will first talk about voice function in general, and then concentrate on the significance of resonance to Western opera and Lieder singing.

Generation of Vocal Sound

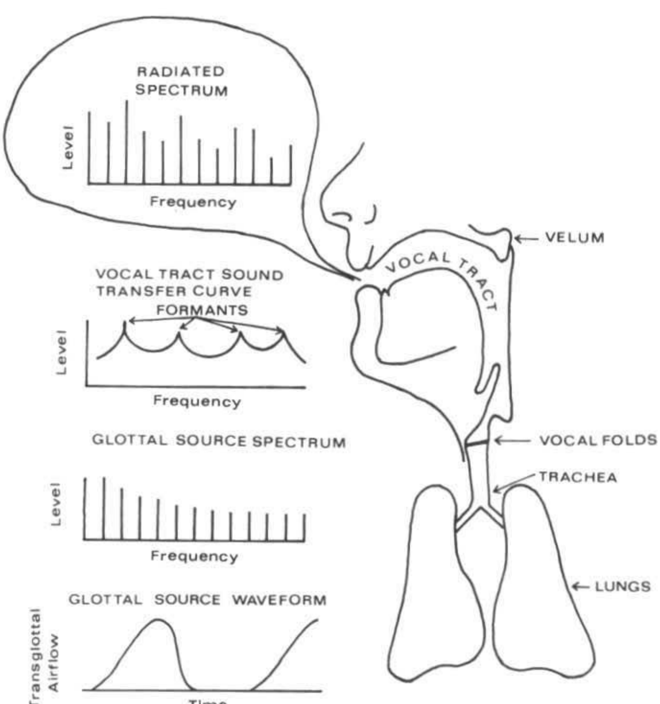

Figure 1. Schematical illustration of the voice organ.

The human voice organ consists of three parts, as is schematically illustrated in Fig. 1. One is the breathing apparatus, which acts as a compressor: it compresses the air contained in the lungs. The second is the pair of vocal folds, which acts as a proper sound generator: it chops the air stream from the lungs into a sequence of air pulses which is actually a sound. It sounds as a buzz tone and contains a complete set of harmonic partials. The third part is the cavity system constituted by the pharynx and mouth cavities, or the *vocal tract;* it acts as a resonator, or a filter, which shapes the sound generated by the vocal folds. In producing nasal sounds, we lower the velum, and so supplement the vocal tract resonator by the nasal cavity, called the *nasal tract*. Of the three parts, the breathing apparatus, the vocal folds, and the vocal tract, it is only the latter two which directly contribute to forming the voice timbre. In other words, the acoustic characteristics of the voice are determined by two factors, (1) the voice source, i.e., the functioning of the vocal folds, and (2) the vocal tract. In this article I will focus on the role of the vocal tract resonator.

The voice source passes through the vocal tract resonator, which thereby shapes it acoustically. The nature of this shaping depends on the vocal tract configuration. For the act of changing the shape of the vocal tract I will use the term *articulation,* as is done in phonetics and other voice sciences. Also, the structures that we use in order to arrange the shape the vocal tract in different ways will be called *articulators*. For example, the tongue is an articulator.

The vocal tract is a *resonator.* What is a resonator then? Actually, almost anything is a resonator: every system that can be compressed and that weighs something. The air column in the vocal tract is one out of many examples.

Sound within a resonator decays slowly. If one hits a resonator, it will resound for a little while rather than disappear immediately. This phenomenon of resounding is called *resonance*. In the vocal tract, the decay is rapid, but still it is possible to hear how a sound in the vocal tract decays. If one flicks one's neck above the larynx with a finger with closed glottis and open mouth, one can hear a quickly decaying tone; it sounds as when one hits an empty bottle or tin, which, incidentally, are other examples of resonators.

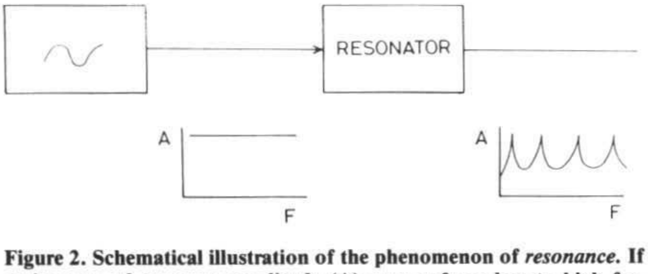

Figure 2. Schematical illustration of the phenomenon of *resonance*. If a sinewave of constant amplitude (A) sweeps from low to high frequency (F), the frequency-dependent sound transfer ability of the resonator imposes great variations in the amplitude. The amplitude culminates at the resonance frequencies.

Another aspect of resonance is that a resonator applies very different conditions for sounds that try to pass through it. The frequency of the candidate sound makes all the difference. This is illustrated schematically in Fig. 2. Sounds having certain frequencies pass through the resonator very easily, so that they are radiated with a high amplitude from the resonator. These preferred frequencies fit the resonator optimally, so to speak, and they are called *resonance frequencies*. It is tones with these resonance frequencies that resound in a struck resonator. In the case of the vocal tract resonator, however, the resonances are called *formants* and the resonance frequencies *formant frequencies*. Tones with frequencies in between these formant frequencies are attenuated more or less when they are transmitted through the resonator. They are not preserved when the resonator is struck.

These formants are of paramount importance to the voice sounds. They totally determine vowel quality and they give major contributions to the personal voice timbre. In the vocal tract there are four or five formants of interest. The two lowest formants determine most of the vowel color, while the third, fourth, and fifth are of greater significance to personal voice timbre.

We are very skilled in tuning our formant frequencies. We do this by changing the shape of the vocal tract, i.e., by moving our articulators. In this way, the vocal tract may assume a great variety of shapes. The mandible is one articulator which may be raised or lowered. The tongue is another one that may constrict the vocal tract at almost any position from the hard palate to the deep pharynx. The lip opening is a third articulator that may be widened or narrowed. The larynx can be raised or lowered. Evidently, the latter two variations also affect vocal tract length. Finally, the side walls of the pharynx can be moved.

The vocal tract length affects all formant frequencies. Adult males have a tube length of about 17 to 20 cm. Assuming a cylindrical vocal tract shape of length l = 17.5 cm, the formant frequencies occur at the odd multiples of 500 Hz: 500, 1500, 2500...Hz. Because of sex differences in vocal tract length, a similar articulatory configuration gives formant frequencies that are about 40% higher in children than in adult males. As adult females have shorter vocal tracts than adult males, their formant frequencies are on the average 15% higher than those of adult males.

The most common way for tuning formant frequencies is by adjusting the vocal tract shape. A reduction of the lip opening and a lengthening of the vocal tract by a lowering of the larynx or by protruding the lips lowers all formant frequencies. Similarly, constricting the vocal tract in the glottal region leads to an increase of the formant frequencies.

Some articulators are particularly efficient in tuning certain formant frequencies. The mandible, which expands the vocal tract in the lip region and constricts it in the laryngeal region, raises the frequency of the first formant. In vowels produced by male adults the first formant varies between 200 and 800 Hz, approximately.

The second formant is particularly sensitive to the tongue shape. The second formant frequency in male adults varies within a range of about 500 to 2500 Hz.

The third formant is sensitive especially to the position of the tip of the tongue or, when the tongue is retracted, to the size of the cavity between the lower incisors and the tongue. In vowels produced by male adults the third formant varies between 1600 and 3500 Hz, approximately.

The relationships between the vocal tract shape and the fourth and fifth formants are more complicated and difficult to control by particular articulatory means.

However, they seem to be very dependent on vocal tract length and also on the configuration in the deep pharynx. In vowels produced by adult males the fourth formant frequency is generally in the vicinity of 2500 to 4000 Hz, and the fifth, 3000 to 4500 Hz.

It is evident that the formant frequencies must have a great effect on the spectrum, as the vocal tract resonator filters the voice source (see Fig. 1). The spectrum envelope of the voice source slopes off at a constant rate, approximately 12 dB per octave, if measured in airflow units, as mentioned. The spectrum of a radiated vowel, however, is characterized by peaks and valleys, because the partials lying closest to a formant frequency get stronger than adjacent partials in the spectrum. In this way the vocal tract resonances *form* the vowel spectrum, hence the term formants. Recalling that formants are vocal tract resonances we realize that it is by means of vocal tract resonance that we form vowels.

Various vowels correspond to different articulatory configurations attained by varying the positions of the articulators as illustrated in Fig. 3. In the vowel /i:/ (as in heed), the tongue bulges so that it constricts the buccal part of the vocal tract. As a consequence of this, the first formant is low while the second formant is high. In the vowel /u:/ (as in the word who'd), the first and second formant frequencies are both low, and in the vowel /a:/ (as in the Italian word caro), the first formant is high and the second takes an intermediate position.

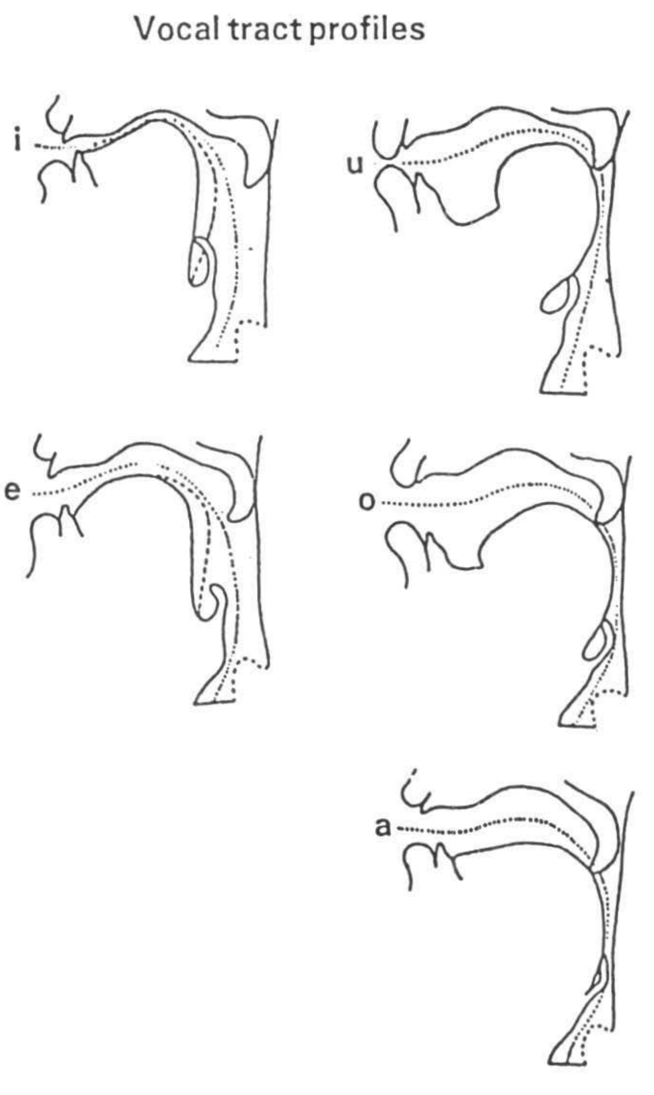

Figure 3. Tracings of X-ray profiles of the vocal tract showing articulatory configurations for some vowels. (After G. Fant, *Acoustic Theory of Speech Production,* 1960.)

Fig. 4 shows typical formant frequencies for various spoken vowels as produced by male adults. The "islands" in the figure imply that the vowel marked will result, provided the frequencies of the first and second formants remain within that island. For example, if the first and second formants are between 350 and 500, and 600 and 800 Hz, respectively, the vowel will be an /o:/. Note that the vowels are scattered along a triangular contour, the three corners of which are the vowels /i:/, /a:/, and /u:/. The vowel /oe:/ (as in *heard*) is located in the center of the triangle.

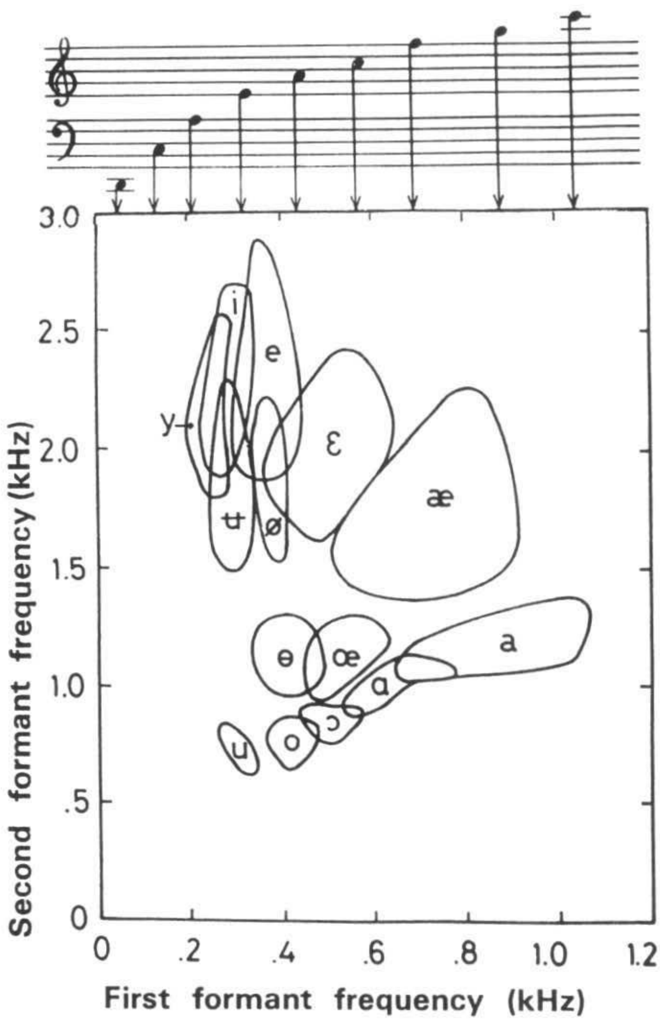

Figure 4. Typical mean values for the two lowest formant frequencies for various spoken vowels as produced by male adults. The first formant frequency is given in musical notation at the top.

Thus, the formant frequencies determine the vowel quality. Still, different individuals tune their formant frequencies a bit differently for the same vowel. For instance, it would be completely impossible for small children to bring their formant frequencies down to the values typically used by adult males, children's vocal tracts simply not being sufficiently long. This is the reason why the vowels are represented by islands rather than dots in the figure. The exact position of the two lowest formant frequencies for a given vowel depends on the individual morphology of the speaker's vocal tract, among other things, and also on the habits of pronunciation.

Formant Frequencies in Singing "Singer's Formant"

With regard to the loudest possible tones, it is remarkable that there is no clear difference between a trained singer and a nonsinger. This can be seen in Fig. 5, which shows average maximum and minimum sound levels as functions of pitch frequency for professional male singers and nonsingers. Thus, the singers do not sing more loudly than nonsingers. Why, then, can we hear a singer so clearly even when he is accompanied by a loud orchestra?

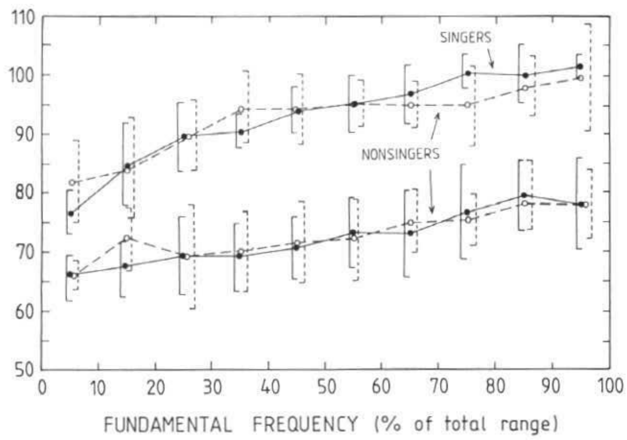

Figure 5. Average maximum and minimum sound pressure level at 0.3 m distance in anechoic room as produced by 10 professional singers and 10 nonsingers. The bars represent +/- one standard deviation. From Gramming & al. (1987).

The answer can be found in the spectral characteristics, which differ considerably between male singers and nonsingers. Moreover, vowels spoken and sung by male singers typically differ with regard to the spectrum characteristics. Fig. 6 illustrates the most apparent difference, called the *singer's formant*. This is a prominent spectrum envelope peak appearing in the vicinity of 3 kHz in all vowel spectra sung by male singers and also by altos. It belongs to the typical features of a sung vowel.

The level of this peak varies depending on the voice classification. It is lower for a bass and highest for a tenor. Sopranos, on the other hand, have a much lower spectrum level of this peak then the other categories. It appears that in the case of the soprano this peak is nothing but a perfectly normal third and fourth formant.

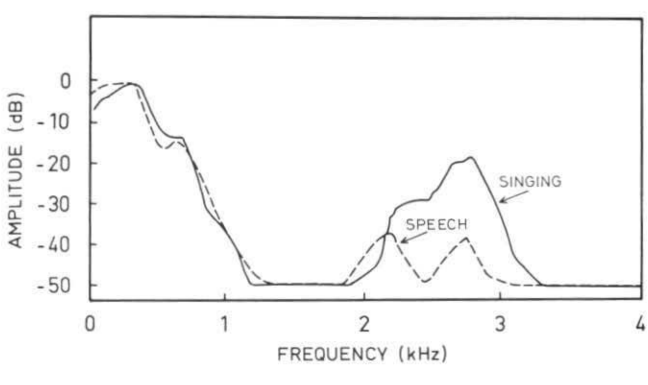

Figure 6. Illustration of the *singer's formant*, a prominent peak in the spectrum envelope appearing in the vicinity of 3 kHz in all vowel spectra sung by male singers and also by altos.

Regardless of voice category, the level of the singer's formant also varies with loudness of phonation, as illustrated in Fig. 7: an SPL increase of 10 dB is accompanied by an increase of 12 to 15 dB in the singer's formant. This effect derives from the voice source, the sound generated by the vocal fold vibrations.

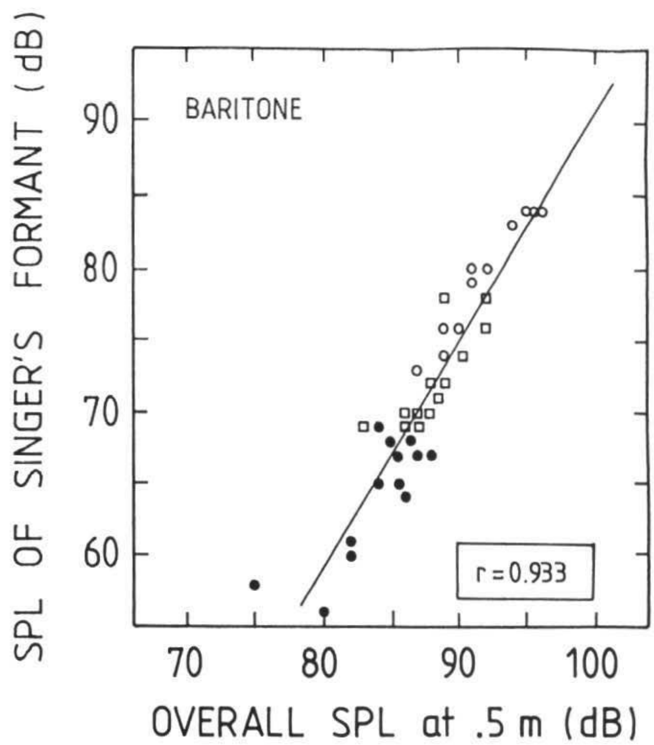

Figure 7. Level of the singer's formant as function of loudness of phonation. (From Cleveland & Sundberg, 1983.)

As regards the center frequency, the peak varies, depending on voice category. In bass singers, it centers around 2.2 kHz; in baritones, around 2.7; in tenors, around 3.2; and in altos, around 2.8 kHz. These frequency differences seem to contribute significantly to the timbral differences between these voice categories.

The presence of the singer's formant in the spectrum of a vowel sound has a marked advantage in that it helps the singer's voice to be heard through a loud orchestral accompaniment. In the spectrum of the sound from a symphony orchestra the partials near 500 Hz tend to be loudest, and above this frequency region, the levels of the spectrum components decrease with rising frequency. This is illustrated by the long-term-average spectrum of orchestral music shown in Fig. 8, where the slope above 500 Hz is about 9 dB/octave. Incidentally, normal speech appears to yield similar long-term-average spectrum characteristics. The perceptual point with a singer's formant is, then, to raise the spectrum envelope in a frequency range where the sound of the accompaniment offers only a moderate acoustic competition, so to speak.

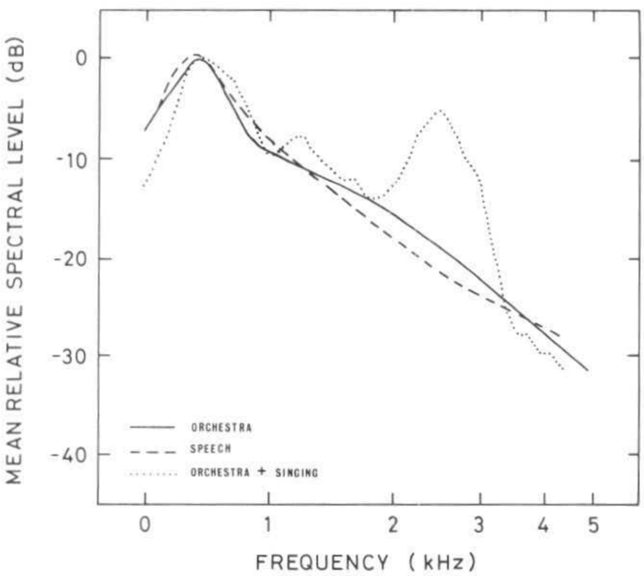

Figure 8. Long-term-average spectrum of orchestral music with and without a solo singer's voice.

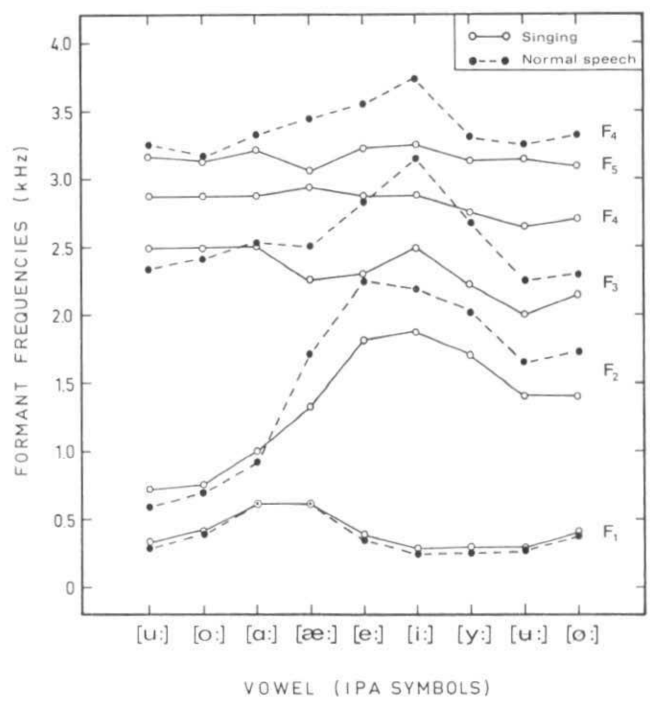

Figure 9. Average formant frequencies for vowels spoken normally and sung by professional singers.

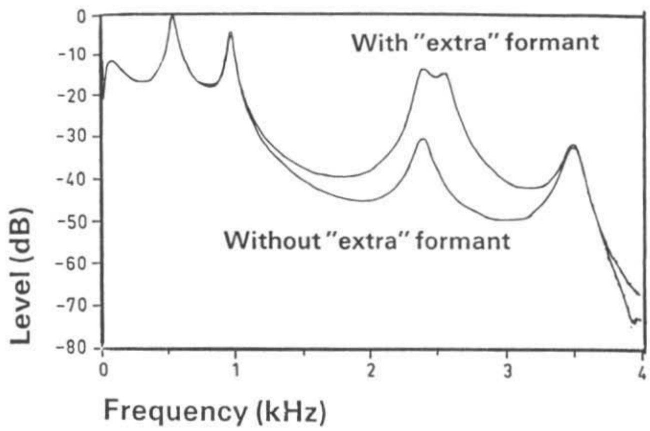

Figure 10. Clustering of formants when pharynx is wide as compared with entrance to the larynx tube.

How do singers generate this spectrum peak in all voiced sounds? The answer is "By resonance!" If it is assumed that the third, fourth, and fifth formants are close in frequency, thus forming a formant cluster, the "singer's formant" peak can be explained as an articulatory phenomenon that can be produced with a normal voice source. In Fig. 9, formant frequency measurements compatible with this assumption for vowels sung by professional singers are compared with those typical for normal speech. As can be seen, the fifth formant in the sung vowels is lower than the fourth formant in the spoken vowels. Thus, five formants appear in the same frequency range as four formants in spoken vowels. In the vicinity of the singer's formant, the density of formants is high in the sung vowels.

The acoustic consequence of clustering formants is that the spectrum partials in the frequency range of the cluster are enhanced in the radiated spectrum, as is illustrated in Fig. 10. In other words, the singer's formant is compatible with the normal concept of voice production, provided a clustering of the higher formants is possible.

Experiments with acoustic models of the vocal tract showed that such a clustering of formants can be attained if the pharynx is wide as compared with the entrance to the larynx tube. It seems that in many singers this effect is obtained by a lowering of the larynx. In this case, the larynx tube acts as a separate resonator with a resonance in the vicinity of 2.8 kHz (Sundberg, 1974).

There may be other, as yet unknown, though, ways of generating a singer's formant, too. A Chinese researcher, S. Wang, found that in Chinese singing and in the type of singing developed for medieval music, a singer's formant was produced without a lowering of the larynx. He hypothesized that the peak was produced by an acoustic interaction between the voice source and the vocal tract resonator. The testing of this hypothesis has been left to future research.

The particular arrangements of the vocal tract that generate vowels with a singer's formant have certain consequences for the vowel quality, too. This is also illustrated in Fig. 9. We can see that the second and third formant of /i/ are low, in fact almost as low as in the German vowel /y/. This is in accordance with the common observation that vowels are "colored" in singing. This coloring can be seen as a price which the singer pays in order to buy his singer's formant.

Summarizing, we see that resonance is of a decisive relevance to singing, as it creates major characteristics of the singing voice in the cases of male voices and altos. It should be observed, however, that all this resonance takes place in the vocal tract. It has not been possible to demonstrate any acoustic significance at all from the vibration sensations in the skull and face that one feels during singing. It seems that they are important to the control of articulation and phonation. In any event, they do not contribute directly to the filtering of the sound to any significant extent.

Super Pitch Singing

We just saw that there are typical formant (or resonance) frequency differences between speech and singing in male and in alto singing. However, the formant frequency differences between spoken and sung vowels are much greater in the super pitch part of the female singers. The reason for this seems to be the exceedingly high fundamental frequencies that occur in female singing. While a bass singer is not required to go higher than 330 Hz fundamental frequency, the maximum for a high soprano may amount to no less than 1500 Hz (pitch F_6).

Let us now recall Fig. 4, which showed the formant frequencies for various vowels. The scale for the first formant frequency was given in the usual frequency unit Hz, but also, at the top of the graph, in musical pitch symbols. From this we can see that the super pitches in female singing are very high indeed as compared with the normal frequency values of the first formant in most vowels. The first formant of /i:/ and /u:/ is about 250 Hz, and the highest value for the first formant in a vowel occurs at 900 Hz for the vowel /a:/.

It is difficult to determine formant frequencies accurately when the fundamental frequency is high. The spectrum partials of voiced sounds are equidistantly spaced along the frequency axis, as shown in Fig. 11, since they form a harmonic series. This implies that the partials are densely spaced along the frequency axis only when fundamental frequency is low. In this case the formants can easily be identified as spectrum envelope peaks. In the opposite case, such peaks are often impossible to discern, particularly if there is no partial near the formant frequency. (It is certainly for this reason that male voices have been much more often analyzed than female voices. Still, certain attempts have been made to determine the formant frequencies in female singers, also.)

Using various experimental techniques, I have attempted to estimate the formant frequencies in female singing. One method was to use external excitation of the vocal tract by means of a vibrator while the professional soprano silently articulated a vowel. Another method was to take an X-ray picture of the vocal tract in profile while the singer sang different vowels at different pitches. For obvious reasons the number of subjects in these studies had to be kept low, only one or two. Still the results were encouraging in that they agreed surprisingly well. This supports the assumption that they are typical.

Some formant frequency values for a soprano singer are shown in Fig. 12. These results can be idealized in

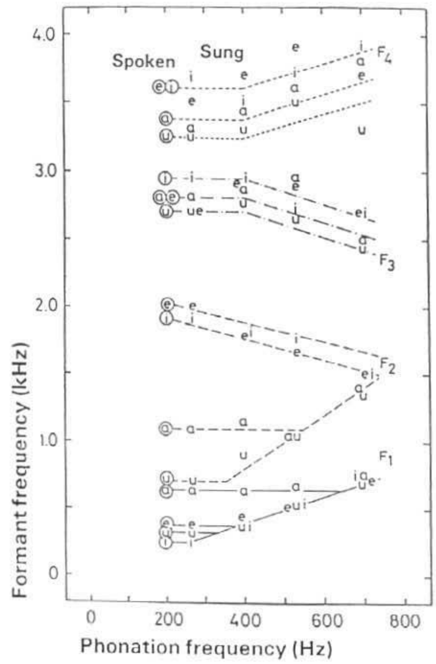

Figure 12. The vowel symbols show formant frequency estimates of the first, second, third, and fourth formant frequencies for various vowels as sung by a professional soprano singer. The circled vowel symbols represent the corresponding data measured when the vowels were pronounced by the same subject in a speech mode. The lines represent an idealization of how the formant frequencies changed with fundamental frequency.

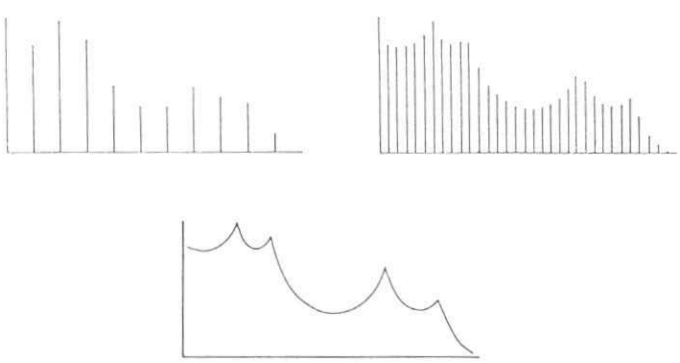

Figure 11. Illustration of the differing difficulty of determining formant frequencies in spectra with a high (left) and a low (right) fundamental frequency. Both spectra were generated using the same formant frequencies represented by the idealized spectrum envelope below.

terms of lines, also shown in the figure, relating the first, second, third, and fourth formant frequencies to the fundamental frequency, and to the formant frequencies in speech. The main principle seems to be as follows. As long as fundamental frequency is lower than the normal value of the vowel's first formant frequency, this formant frequency is used. At higher pitches, the first formant is raised with increasing fundamental frequency. In this way the situation is avoided that the fundamental goes higher than the first formant. With rising fundamental frequency, the second formant of front vowels is lowered, while that of back vowels is raised to a frequency just above the second spectrum partial; the third formant is lowered and the fourth is raised.

What articulatory means do the singers use in order to achieve these great pitch-dependent rearrangments of the formant frequencies? An articulatory tool that female singers seem to recruit frequently for the purpose of tuning the first formant is the jaw opening. Formal measurements on female singers' jaw opening have shown that under controlled experimental conditions, it is systematically increased with rising fundamental frequency. This rule is illustrated in Fig. 13. It shows the

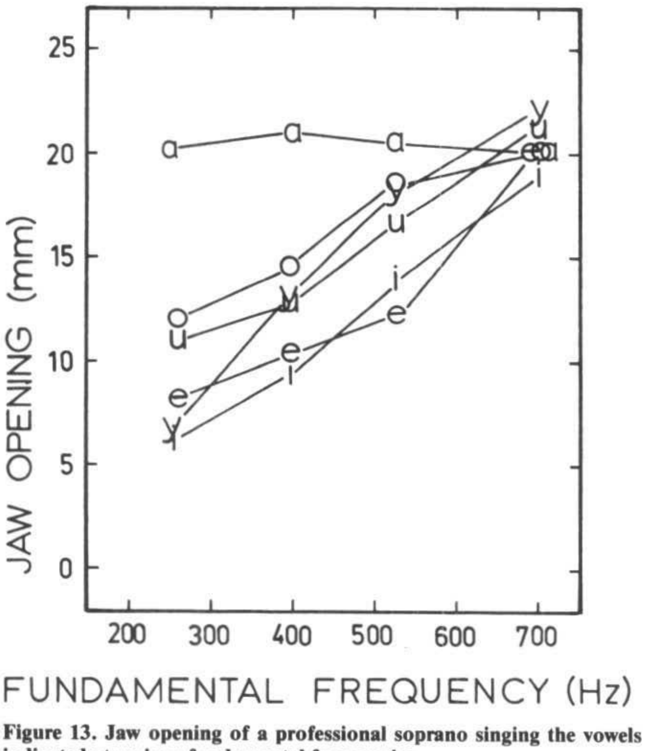

Figure 13. Jaw opening of a professional soprano singing the vowels indicated at various fundamental frequencies.

jaw opening of a professional soprano as a function of fundamental frequency. Within the pitch range covered by this figure, all vowels are produced with a jaw opening that increases with fundamental frequency. Even at the lowest fundamental frequency the jaw openings are wider than those used for the spoken versions. This system applies to all vowels except /a:/, which is sung with a similar jaw opening throughout this range. However, the first formant frequency of this vowel is higher than the highest fundamental frequency used in this experiment.

The jaw opening is an excellent tool for the purpose of raising the first formant frequency, as mentioned. There are also other articulators that can be recruited for the same purpose. One is the lip opening: by contracting the mouth corners, the vocal tract is shortened, so the frequencies of all formants will increase. The vocal tract can also be shortened by raising the larynx. At least some professional female singers take advantage of this tool for raising the first formant frequency. Fig. 14 gives

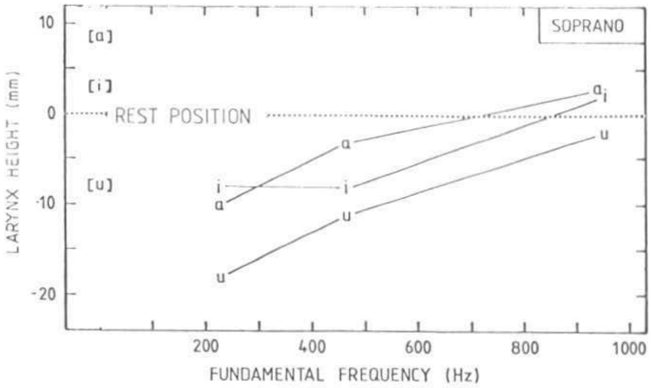

Figure 14. Vertical larynx position as determined from X-ray profiles of the vocal tract of a professional soprano singing the indicated vowels at various fundamental frequencies.

an example. It is interesting that most singing teachers regard such a pitch-dependent adaptation of larynx height as a mistake from a singing technique point of view. Perhaps, these teachers do not mean larynx elevation in general, but rather an elevation that is associated with an audible shift in the mode of phonation and vowel quality; in normal speech, a raised larynx is generally associated with a pressed type of phonation, such as in screaming.

All the pitch-dependent formant frequency changes illustrated in Fig. 12 are not consequences merely of changes in jaw opening and larynx height. As shown in Fig. 15 there are also considerable changes in tongue shape. It appears that tongue shape changes rather abruptly with pitch. In the subject examined, the vowels

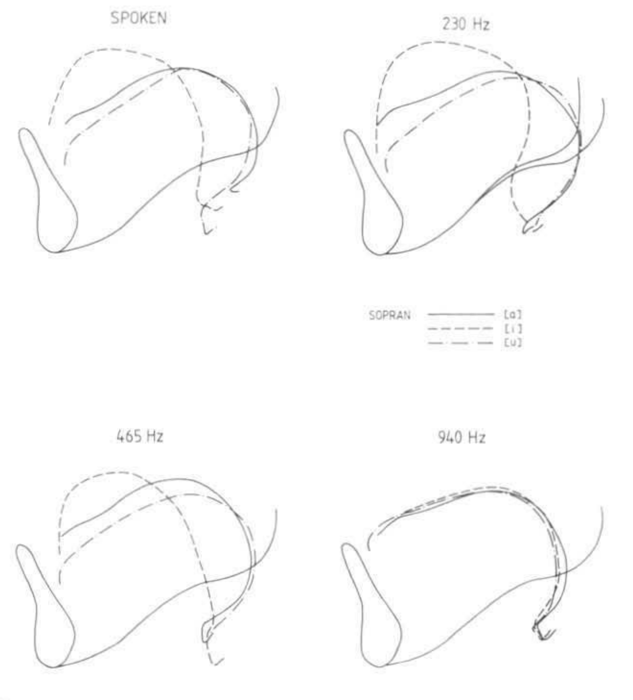

Figure 15. Midsagittal tongue contours as determined from X-ray profiles of the vocal tract of a professional soprano singing the indicated vowels at various fundamental frequencies shown.

/a:/, /i:/, and /u:/ were all produced with very similar tongue shapes only at the fundamental frequency of 960 Hz (pitch $B^{\flat}_5$). It is possible that the tongue shape differentiation is influenced by preceding and following consonants at these pitches. Still, with these wide jaw openings, a small difference in tongue shape is not likely to affect the formant frequencies to any appreciable extent.

Even though this principle of tuning formant frequencies depending on the fundamental frequency has been found to be applied by soprano singers only, it could be used even by other singers; all singers, except possibly basses, can encounter a situation where the first formant is lower in frequency than the fundamental prescribed by the composer. As the first formant frequency varies between vowels, the case depends on the vowel. In the highest range of a baritone, the vowels /i, y:, u:/ would need pitch dependent first formant frequencies. In the top part of an alto's range all vowels except /a:/ and /ae:/ need modification of the first formant frequency. It is likely that the other formant frequencies are modified in similar ways as in the case of the sopranos.

The profit of these arrangements of the formant frequencies is great. They imply that the sound level of the vowels increases enormously in some cases. Fig. 16 shows the gain in sound level attained by means of the pitch-dependent choice of formant frequencies that was shown in the previous figure. The gain is seen to amount to no less than 30 dB in some cases. This is a truly huge increase in sound level that the singer gains by sheer resonance.

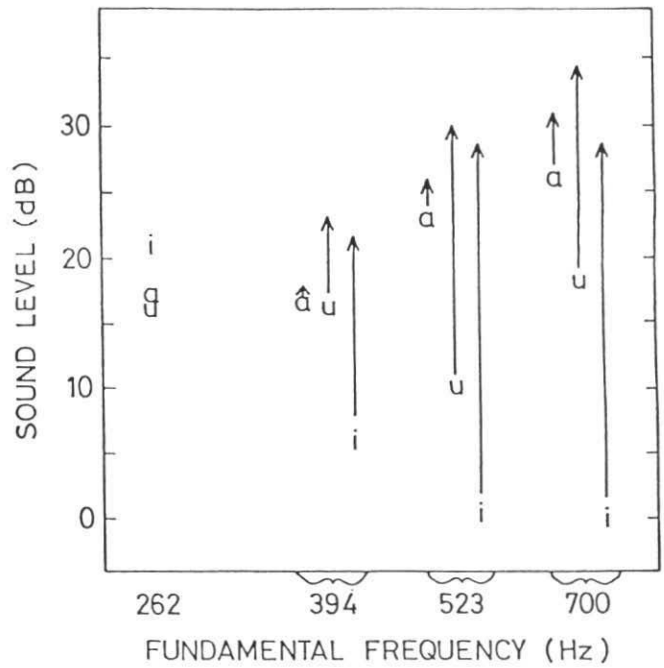

Figure 16. Gain in sound level at different fundamental frequencies resulting from the pitch dependent choice of formant frequencies that were represented by the lines in Figure 11.

Choral Singing

An often discussed question is to what extent choral singing requires the same vocal technique as solo singing. Choir directors tend to maintain that there are no important differences, while many singing teachers see huge differences.

As the singer's formant apparently serves the purpose of helping the individual singer's voice to be heard through a loud orchestral accompaniment, it can be hypothesized that the singer's formant is not indicated in choral singing. This hypothesis was supported by experiments in which male singers, experienced in both choral and solistic performance, were asked to sing in a choral and in a solistic framework (Rossing & al., 1986). For solo singing they heard over earphones the piano accompaniment of a solo song that they were to sing. Similarly, for choir singing they heard the sound of a choir that they were asked to join. As shown in fig. 17a, the subjects had a singer's formant that was more prominent in solo than in choir singing, while the lowest spectrum partials, below the first formant, were weaker in solo singing. The higher level of the singer's formant in solistic singing was associated with a denser clustering of the third, fourth, and fifth formant frequencies. As these subjects, unlike an average choral singer, were also excellent solo singers, it can be assumed that the differences between soloistic and choral singing are mostly greater than was revealed by this experiment.

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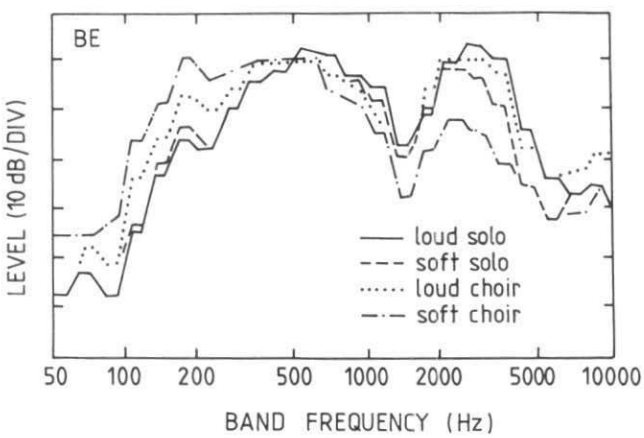
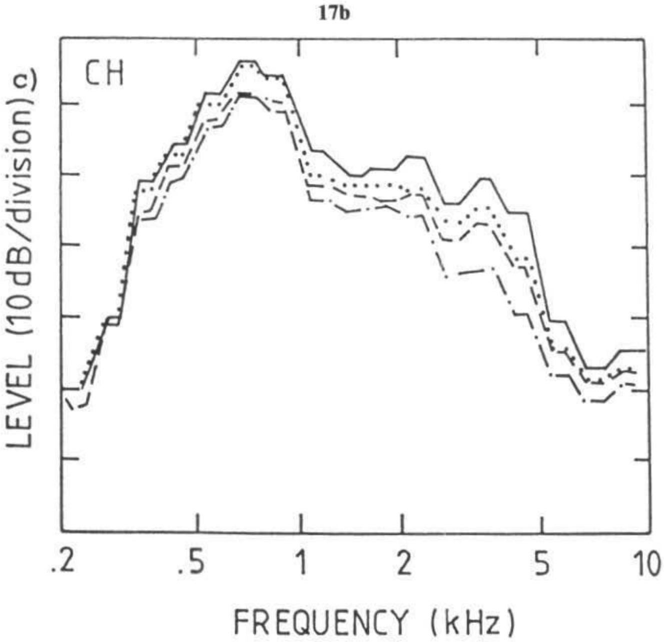


17b



17c

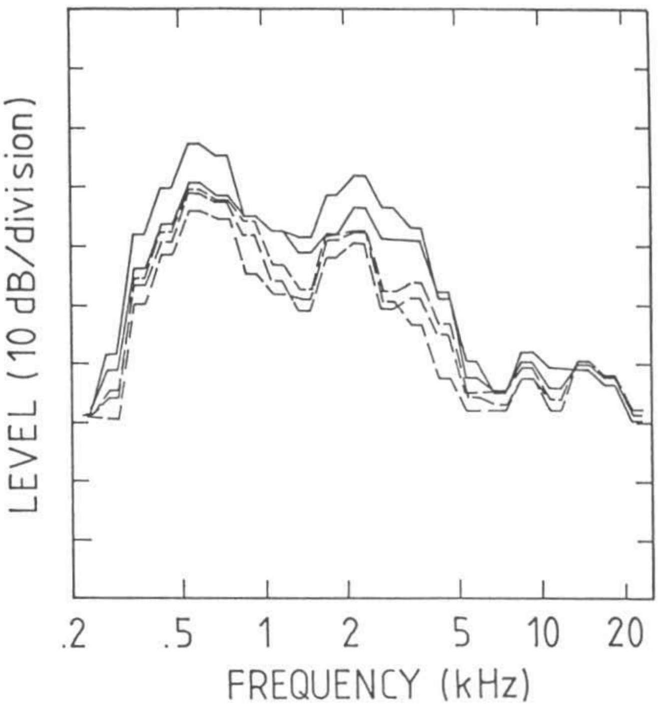


Figure 17. Long-term-average spectra of male (17a) and female (17b) singers singing as soloists and as members of a choir. In 17a and 17b solid, dashed, dotted and chain-dashed pertain to loud and soft solo, and loud and soft choral singing, respectively. In 17c the solid curves represent the spectra of two opera sopranos of international fame and the dashed curves pertain to sopranos who sang professionally both as soloists and as choir singers.

The corresponding experiment was also performed with soprano subjects (Rossing & al., 1985). Disregarding the fact that it seems inadequate to speak of a singer's formant in soprano singing, the result was similar, as can be seen in Fig. 17b; the mean spectrum level at 2-3 kHz was clearly higher when the singers sang in a solo mode. This suggests that even female solo singers profit from high levels of the higher spectrum partials. This assumption was further supported by the fact that two opera sopranos of world fame were found to sing with a clearly higher level of the partials in the 2-4 kHz band than the singers who worked both as choral and solo singers. These measurements seem to indicate that solo and choral singing differ slightly with respect to the vocal technique.

Overtone Singing

In some music cultures, a very special type of singing is practiced where the voice pitch remains constant, as in a drone, while the musical interest is caught by the sounding of high overtones. The vocal technique underlying this phenomenon has been studied (Smith & al., 1967). Fig. 18 shows an example of a vowel spectrum produced in this type of singing. The pitch perceived in these cases corresponded to the sixth and seventh partial, or a tone two octaves plus a fifth or a seventh above the fundamental. In view of the spectrum, this is not an unexpected finding. These partials are quite outstanding in the spectrum.

The vocal technique behind such spectra seems based on formant tuning. The singers tune the second and third formants so that both are quite close to the partial to be enhanced. The other formants are carefully tuned so as to avoid enhancing any of the other partials. As a

(continued on page 31)

liberate themselves from their creations are no longer singer actors but insane. Fortunately, few singers exist on the far side.

Even though the technique of characterization may be difficult to implement, its benefits for student growth and development far outweigh the challenge and frustration it may create. Singing teachers willing to employ the integrated technique that comes from the melding of physical function and emotional context will be equipping their singers to deal more competently with the real world demands of the art of singing.

Vocal Tract Resonance In Singing *(continued from page 19)*

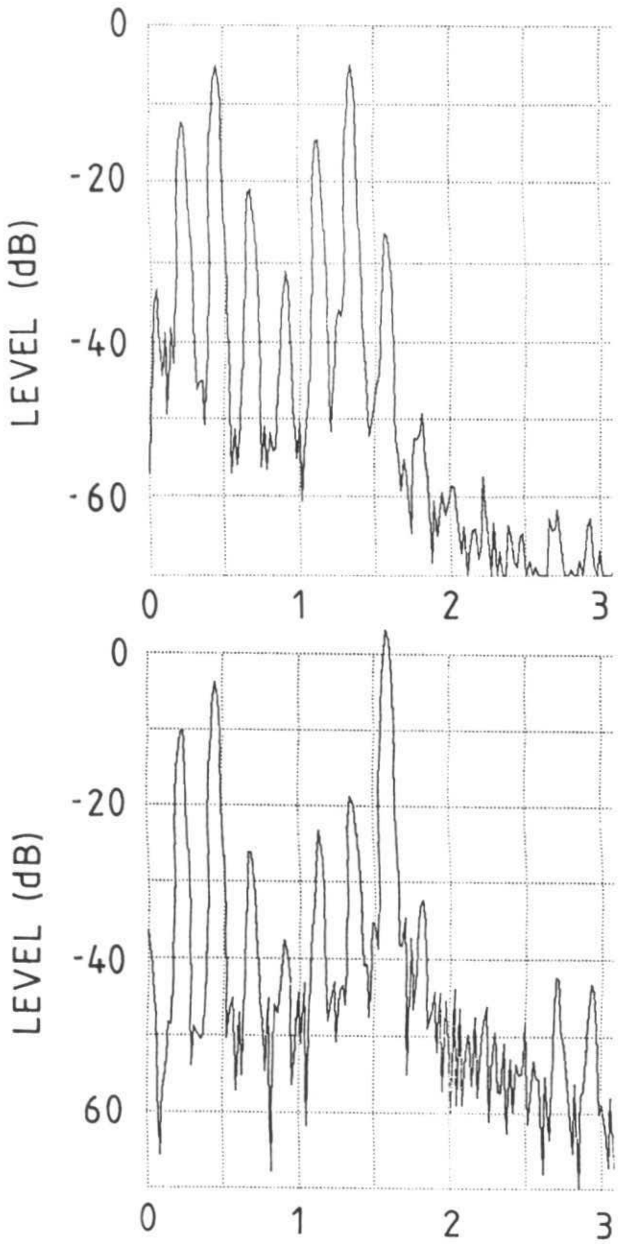


Figure 18. Vowel spectrum produced in two cases of overtone singing performed by one of the members in The Harmonic Choir. In the upper graph the sixth harmonic partial was perceived as an extra tone in the spectrum, two octaves plus a fifth above the fundamental. In the lower graph the seventh harmonic partial was perceived as an extra tone, two octaves plus a seventh above the fundamental.

result, one single partial becomes much stronger than the others, so that its pitch stands out of the timbral percept. The articulatory tools used seem to be tongue shape and lip opening in the first place. The tongue tip is often raised while the tongue body is pulled anteriorly or posteriorly. In addition, the voice source characteristics seem to be adjusted so that the fundamental is suppressed, presumably by shifting the type of phonation toward pressed phonation.

A more modest form of overtone singing is rather simple to practice and learn. The point is to keep the fundamental constant at a rather high frequency, say, 300 Hz, and then to vary articulation while changing the tongue shape and lip opening rhythmically in several steps between the /u:/ and the /i:/ positions. If the rhythmical pattern is repeated, the ear will soon catch individual overtones. Then, it is rather easy to moderate articulation so as to enhance the effect.

Head and Co-resonance

Above we have encountered several examples of the enormous significance of resonance in singing. Thereby, the only type of resonance dealt with has been the formants, the resonances of the vocal tract. No mention has been made of face or skull resonances. There is no doubt, however, that the voice sets up forceful vibrations in the structures limiting the voice organ, such as the chest wall, the throat, the face, and the skull. However, these vibrations are much too feeble to compete with the sound radiation from the open mouth. In other words, such vibrations do not contribute acoustically to the formation of vowel sounds. This is not to say that they cannot be used as a sign of a properly used voice organ.

Conclusions

The vocal tract resonances, called formants, are of paramount significance to voice and vowel quality. The two lowest formants decide what the vowel quality is going to be. The higher formants determine much of the personal voice characteristics, including voice classification. In male singers the third, fourth, and fifth formants constitute the singer's formant, which helps the singer's voice to get heard through a loud accompaniment. In female high-pitched singing the two first formants are tuned so that they optimally match the pitch frequency, thereby increasing the loudness of the voice considerably. It is also possible to play small articulatory games with formants and have them "show" individual partials to the listener.

However, the great relevance of voice tract resonance to singing should not conceal the fact that there are other factors of great importance, too. Thus, the voice source, reflecting the chopped air stream through the vibrating glottis, is as decisive to voice quality as are the formants. The resulting great variability, of course, complicates the work of both singers and singing teachers; there are a great number of control parameters that the singer needs to bring under proper control. On the other hand, the reward is generous; the abundant timbral variability that may result certainly offers the singer one of the potentially best musical instruments.

Johan Sundberg *is Professor of Music Acoustics, Department of Speech Communication and Music Acoustics, Royal Institute of Technology, Stockholm, Sweden.*