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Resurrection from the Coffin

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The first edition of Berton Coffin's book on the sounds of singing appeared over thirty years ago, followed by a second edition about ten years later.[1] Coffin's work was deeply rooted in the linear source-filter theory of vowels, which in his day was the workhorse of speech science. His primary colleague in voice science was Pierre Delattre, a phonetician-acoustician who made major contributions to vowel theory as it was evolving in Europe, Japan, and the United States in the second half of the twentieth century.

The pedagogic element in Coffin's work was the "favorable vowel chart," later published in color as the "chromatic vowel chart for voice building and tone placing." Based on the then accepted linear source-filter theory of vowels, the chart shows which vowels most likely resonate the fundamental frequency and harmonics of any note in the vocal range. The chart is comprehensive and complete, but somewhat antiquated now because the most interesting pitch-vowel interaction phenomena are based on a nonlinear source-filter theory. Thus, the old chart is in the coffin, but the Coffin idea needs to be resurrected. This little essay is the beginning of such a resurrection, with, one hopes, many additional installments to come.

The main difference between the current nonlinear source-filter interaction theory and the older linear theory is that formants need to be avoided, not sought out, in the choice of a vowel. It is still true that formants (the resonances of the vocal tract) can boost the energy of any harmonic of the source, but this selective "boosting" often creates irregularity in the vibration pattern of the vocal folds. Unlike in a woodwind or brass instrument, where the horn is long and steady in its geometry, the vocal tract in humans is relatively short and constantly changing due to articulation of phonemes. This does not permit an orderly line-up of source harmonics with vocal tract formants. Hence, it is better to keep the harmonics away from the formants. Furthermore, nonlinear source-filter theory predicts a preference in placing harmonics on the left side of a formant (below the formant frequency) as opposed to the right side (above the formant frequency). Fortunately, there is more than one formant, so vowels can be chosen such that a "leap over the formant" can be made by a harmonic so that it lands on the upslope of an adjacent formant. Thus, chasing "favorable vowels," as Coffin called them, on an ascending pitch scale is like walking up a tall mountain that has multiple peaks and valleys along the way. You stay on the upslopes and try to leap over the valleys as quickly and effectively as possible. The difficulty is that if "you" are the harmonic, all your family members (the other harmonics) have to do the

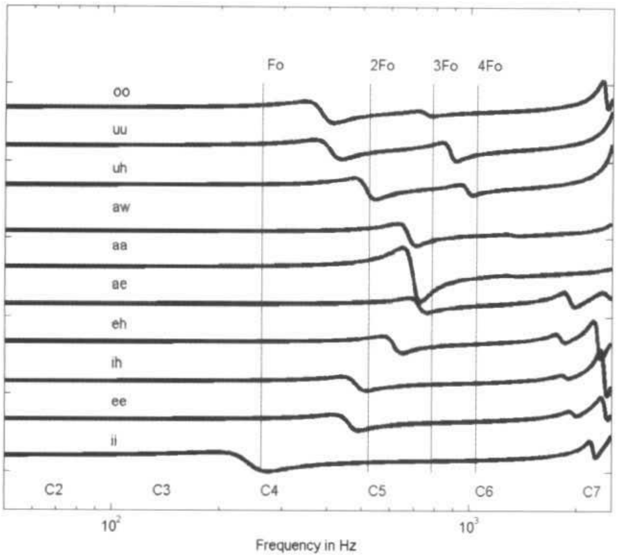

Figure 1. New Coffin chart.

same thing in lock-step. You walk in a row, separated by a constant distance, but the peaks and valleys are not equally apart.

Figure 1 shows the process. Ten vowels are represented as nearly horizontal lines. The double letter vowel labels have the following phonetic interpretation: uu = /u /, oo = /o/, uh = /U/, aw = /ɔ/, aa = /ɑ/, ae = /æ/, eh = /ɛ/, ih =/ I/, ee = /e/, and ii = /i/. The numbers on the vertical axis are an arbitrary scale for vowel separation. The peaks and valleys in the curves represent the changes in vocal tract *inertance*. Vocal tract inertance has been shown to enhance vocal fold vibration.[2] The greater the inertance, the more enhancement there will be for a harmonic of the source. As seen in the figure, inertance changes rapidly only near the formants. For the ii = /i/ vowel, for example, the first formant is near C_4; for the ih = / I / vowel, the first formant is near C_5; for the ae = / æ / vowel, the first formant is between C_5 and C_6 (note the pitch labels C_2, C_3, C_4, C_5, and C_6 on horizontal axes). For any selected pitch, there will be a series of harmonics created at the source. The first four harmonics are shown as vertical lines in Figure 1 for a pitch C_4. Note the location of these harmonics in the peak and valley terrain of the vowels. Stable and acoustically strong productions result when each of these harmonics (F_0, $2F_0$, $3F_0$, and $4F_0$, as labeled on top) resides in high inertance territory, which is to the left of a formant. Whenever a dominant harmonic lands in the formant region, where inertance rises and falls quickly, vocal fold vibration can be destabilized, or the sound output changes suddenly from strong to weak (or vice versa). For the C_4 pitch chosen in our illustration, F_0 is in trouble with the vowel ii = /i/, $2F_0$ is in trouble with the vowel ih = /I/, and $3F_0$ is in trouble with the vowels aa = /ɑ/ and ae = /æ/. As the pitch changes, of course, different vowels present problems for the harmonics. Thus, the singer modifies the

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vowels to maintain consistency of harmonic energy throughout the pitch range.

How is this different from what Coffin taught? In principle, there is no difference. There are good vowels and bad vowels for a given pitch. In practice, however, the new theory is less restrictive because harmonics and formants do not need to be fine-tuned to each other. It is only important to "lift" a harmonic over an inertance valley by modifying the vowel. The new theory also makes a strong connection between vowel modification and voice registers (sometimes called lifts), a topic that will be addressed in later essays. The current message is simply that Coffin is not in the coffin, but resurrected via a new vowel chart. The final (immortal) version of this chart is yet to be revealed.

NOTES

1. Berton Coffin, *Coffin's Sounds of Singing: Principles and Applications of Vocal Techniques with Chromatic Vowel Chart*, 2nd Edition (Metuchen, NJ: The Scarecrow Press, 1987).
2. Ingo R. Titze. "The Physics of Small-Amplitude Oscillation of the Vocal Folds," *Journal of the Acoustical Society of America* 83, no. 4 (1988): 1536–1552.

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