The F_0–F_1 Crossover Exercise

Ingo R. Titze

It has become a long term goal of this writer to understand and appreciate proven exercises and vocalises used by singing teachers. One such exercise is the downward glide in pitch on a vowel [u] or [o], beginning on about D_5 (around 600 Hz) and ending one to two octaves lower. This exercise dictates a crossover between the fundamental frequency F_0 and the first formant frequency F_1 of the vocal tract. Because F_1 is low for a vowel with nearly closed lips (around 300 Hz), and because the second formant F_2 is also low (around 800–100 Hz), there is ample opportunity for F_0 and its harmonics ($2F_0$ and $3F_0$, in particular) to be momentarily located on either side of a formant. This produces a variety of constructive and destructive interferences between the source of sound and the vocal tract (the filter).

Journal of Singing, January/February 2006
Volume 62, No. 3, pp. 295–297

Figure 1 shows a spectrogram of an [u] vowel, simulated by computer, with noise excitation at the glottis. The two dark bands represent formants F_1 and F_2, located at 370 Hz and 800 Hz, respectively. The top of the vertical axis is 2000 Hz. The horizontal axis is time; from 0 to 8 s. Everything remains steady over the 8 s, in the form of a hiss that has a bit of an [u] quality.

Now consider a case where the source of sound is a downward gliding pitch, with F_0 and all its harmonics changing linearly from 600 Hz to 100 Hz. This is shown in Figure 2. The formants are in exactly the same place as in Figure 1, but they are less easily seen because acoustic energy is available only at the harmonics and not at all frequencies, as with the noise excitation. In this F_0 glide, the computer simulation is designed so that the vocal tract is not allowed to change the harmonics at the source, but only as they are transmitted to the mouth. We call this a linear (noninteractive) source-filter model. Note the slightly darker regions (shown by arrows) where the $2F_0$, $3F_0$, $4F_0$ and higher harmonics are boosted in energy as they pass through the second formant at 800 Hz. F_0 (the lowest line) passes through the first formant, but the transition is so gradual that the whole line is darkened.

What we have discussed so far is not remarkable and would be expected by most speech and voice scientists. The linear source-filter theory of vowel production is deeply embedded in all our minds. If it always held true in human phonation, the gliding F_0 exercise would have little pedagogic value other than controlling a smooth glissando. A different story emerges, however, when the acoustic pressures in the vocal tract are allowed to interact (and interface) with vocal fold movement. This is known as the

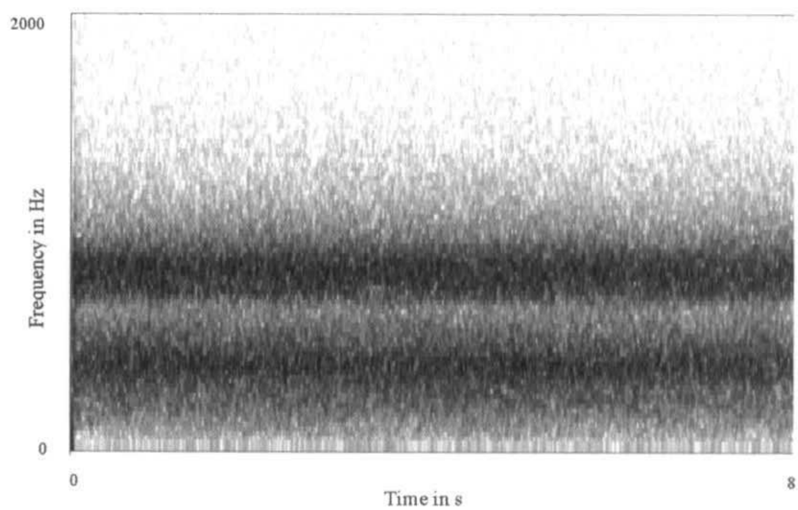

Figure 1. Spectrogram of simulated [u] vowel with noise excitation at the glottis.

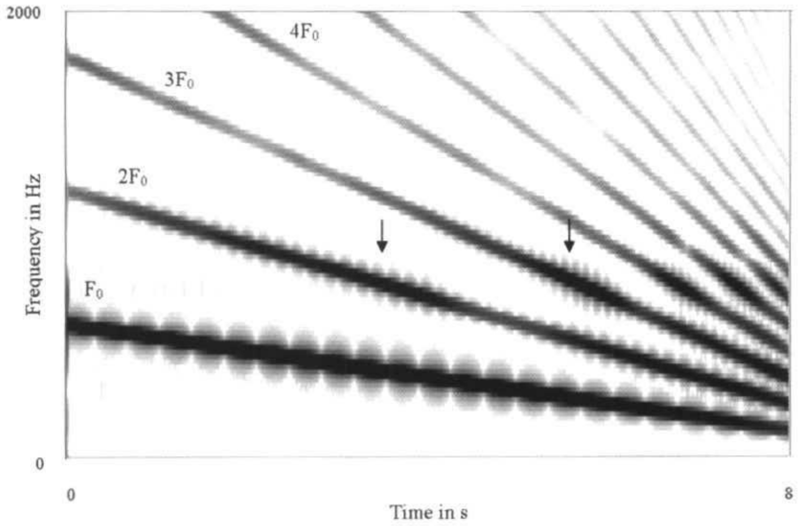

Figure 2. F_0 glide from 600 Hz to 100 Hz for a linear source-filter model.

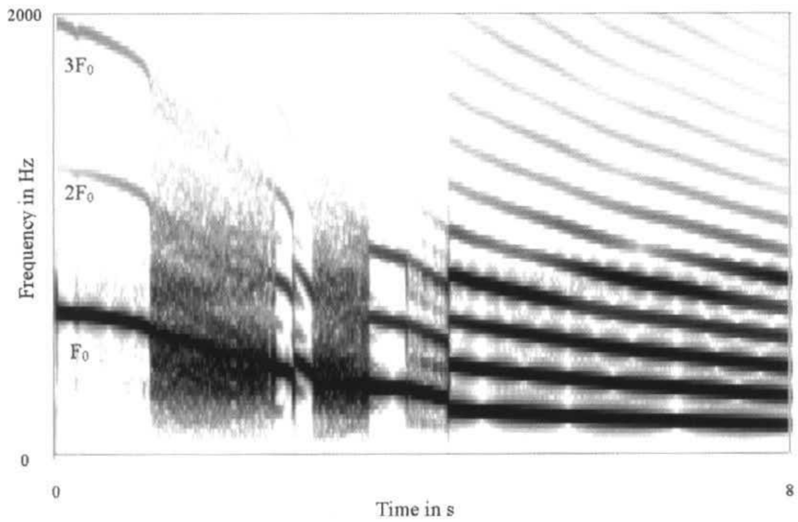

Figure 3. F_0 glide from about 600 Hz to about 100 Hz for a nonlinear source-filter model showing multiple bifurcations.

nonlinear source-filter theory. Figure 3 shows the pitch glide under these interactive conditions. The beginning and the end of the glide are similar to what we saw in Figure 2, but in the middle there are abrupt changes known as bifurcations (sudden qualitative changes in the vibrational behavior of the source-filter system). The first bifurcation (addition of noise between the harmonics) occurs when F_0 approaches the first formant from above. Here, when $F_0 > F_1$, the vibration of the vocal folds becomes unsteady, which creates the noise. Another bifurcation occurs when $F_0 = F_1$. Here F_0 and $2F_0$ suddenly jump to a higher value. Noise due to unsteady vibration re-occurs shortly thereafter, ending with a short segment of pure descending harmonics. After another brief episode of noise and yet another F_0 jump (downward this time), a final steady pattern emerges. In this second half of the glide, where F_0 is in the speaking range, the linear source-filter theory seems to hold.

What does this mean to us pedagogically? Some singers have tuned their source-filter system to be highly interactive. A primary mechanism for this is narrowing the epilarynx tube just above the vocal folds, which I have discussed often in previous *Journal of Singing* contributions. Strong interaction can increase the sound output and provide a greater variety of voice qualities. But the price that is paid for strong interaction is an occasional instability at pitches where harmonics interfere with formants. The F_0-F_1 crossover exercise makes us aware of these instabilities and allows our muscles to adjust appropriately. The more we learn to live in this unstable region, not labeling it a pathology or faulty technique, the better off we are. In fact, we can learn to *control* instability and noise in the voice, using it to an artistic advantage rather than being embarrassed by it. But it does take practice to reach any level of consistency.

Ingo R. Titze is Distinguished Professor of Speech Science and Voice at the University of Iowa and Executive Director of the National Center for Voice and Speech at the Denver Center for the Performing Arts. His formal education is in physics and electrical engineering, but he has devoted much of his studies to vocal music and speech. Dr. Titze has published more than 250 articles in scientific and educational journals, coedited two books titled Vocal Fold Physiology, *and has authored a book called* Principles of Voice Production. *He has lectured throughout the world and has appeared on such educational television series as* Innovation, Quantum, *and* Beyond 2000. *He is a recipient of the William and Harriott Gould Award for laryngeal physiology, the Jacob Javits Neuroscience*

Investigation Award, the Claude Pepper Award, the Quintana Award, and the American Laryngological Association Award. He is a Fellow of the Acoustical Society of America and the American Speech-Language-Hearing Association. Dr. Titze has served on a number of national advisory boards and scientific review groups, including the Scientific Advisory Board of the Voice Foundation and the Division of Research Grants of the National Institutes of Health. In addition to his scientific endeavors, Dr. Titze continues to be active as a singer. He is married to Kathy Titze and has four children. Mail should be addressed to Ingo R. Titze, National Center for Voice and Speech, 330 WJSHC, Iowa City, IA 52242. Telephone (319) 335-6600.