Ingo Titze, Associate Editor

How Are Harmonics Produced at the Voice Source?

Ingo R. Titze

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IT IS WELL KNOWN THAT a spectrum of harmonic frequencies is associated with every vowel and that this spectrum also defines the overall timbre of the voice. The strength of each harmonic can be measured by conducting routine spectrography on the acoustic signal radiated from the mouth and picked up by a microphone. But this mouth output spectrum contains the filtering characteristic of the vocal tract and therefore does not necessarily give a clear picture of what the origin of the harmonic is at the source (the glottis). Furthermore, it does not tell us how we can control the production of the harmonics.

Source harmonics are produced in two primary ways: (1) by collision of the vocal folds, and (2) by acoustic energy from the vocal tract being fed back to the glottis and altering the glottal flow. In both cases, it is a distortion of an otherwise simpler glottal airflow that has only one harmonic, the fundamental. Consider Figure 1. On the left side we see a panel of three glottal flow waveforms (three cycles of vibration for each), and on the right side we see corresponding spectra of harmonics. The top waveform has a little flat portion on the bottom, suggesting a very brief period of collision of the vocal folds. The glottis is open 80% of the time and closed only 20% of the time. The little flat portion is a distortion of an otherwise rounded bottom that the simplest (smoothest) possible waveform would have; but it is this distortion that produces a second harmonic (see second vertical line on the spectrum to the right). In the middle of the graph, the collision of the vocal folds consumes half of the period of vibration, creating a longer flat portion. This is a greater distortion of a simple rounded waveform, producing now a third harmonic. (In actuality, an infinite number of harmonics is always produced, but the higher ones are more than 30 dB below the first one, the fundamental in this case, and are therefore not shown.)

In the bottom row of Figure 1, there is an 80% glottal closure, with glottal flow occurring only over 20% of the cycle. This is a severe distortion of a rounded waveform, producing the greatest number of harmonics (seven are visible on the spectrum). Scientists have concluded from analyses of glottal waveforms that a richer timbre (or a brassier sound quality) results from greater vocal fold collision. But speech pathologists point out that it may be at the expense of greater vocal fold damage.

An alternate strategy for producing harmonics is to allow lots of energy to be fed back to the glottis from the vocal tract, thereby altering the glottal flow. Figure 2 shows a glottal waveform where an original smooth (rounded) glottal wave has been distorted by a wave that has travelled backward form the vocal tract.

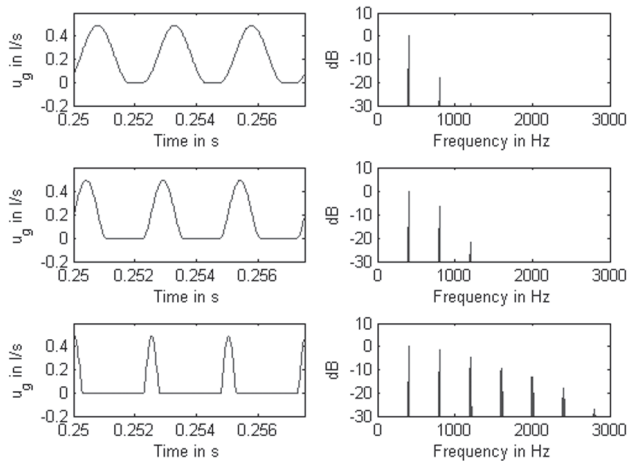

Figure 1. Glottal flow waveforms (left) and corresponding harmonic spectra (right) for three levels of vocal fold collision. The glottal flow is given the symbol u_g and is in liters/sec. Harmonic amplitudes are labeled in dB.

The spectrum shows four harmonics with energy in the 0 to –30 dB range. This production involves no collision of the vocal folds at all, and hence may be safer from an injury point of view. But it does require a narrowing of the vocal tract (typically just above the vocal folds in the epilarynx tube) to heighten the feedback energy.

Figure 3 shows an extreme case where both strategies are used simultaneously, lots of vocal fold collision and lots of narrowing the vocal tract near the glottis. Even though the pulse is small, we see a rich spectrum of harmonics because the glottal waveform is maximally distorted (in comparison to a smooth back and forth wave). Note the high frequency ripple on the short burst of airflow. This ripple is a vocal ring and corresponds to harmonic energy around 3000 Hz in the spectrogram.

In summary, harmonics in the glottal airflow waveform are produced by adducting the vocal folds sufficiently so that they can collide. This changes the waveform from a simple (smooth) oscillatory shape that has only one frequency. Alternately, or in conjunction with collision, the vocal tract can be engaged to feed back an acoustic wave to the glottal flow. The interaction between the original airflow wave and the reverse flow from the vocal tract then produces harmonic frequencies. Typically both mechanisms are used simultaneously.

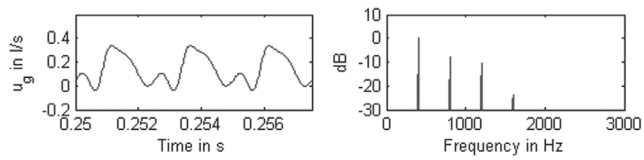

Figure 2. A glottal waveform (left) distorted by a feedback wave from the vocal tract. The corresponding harmonic spectrum is on the right.

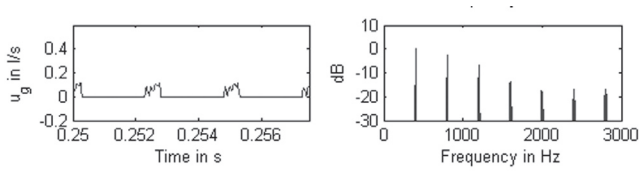

Figure 3. A glottal waveform resulting from a severe collision between the vocal folds in combination with a feedback wave from the vocal tract (left). The corresponding harmonic spectrum is on the right.

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 500 articles in scientific and educational journals, coedited two books titled *Vocal Fold Physiology*, and has authored two books called *Principles of Voice Production*, and *The Myoelastic Aerodynamic Theory of Phonotion*. 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.

Out of the slimy mud of words, out of the sleet and hail of verbal imprecisions . . . There spring the perfect order of speech, and the beauty of incantation.

T. S. Eliot (1888–1965)
Choruses from *The Rock* (1934)