dox—one cue, an increase in the amplitude of the first harmonic, is interpreted either as signaling nasality or breathiness depending on values of other cues present in the signal).

Voice quality variation associated with changes in glottal opening is illustrated in physiological terms in the A row of Fig. 1, which shows a schematic view of the glottis from above. The positions of the arytenoid cartilages (triangles) and vocal processes are illustrated for laryngealized, modal, and breathy phonation. The characteristics of a modal voice are illustrated in column 2 of Fig. 1. The vocal folds are nearly approximated, leading to a typical volume velocity waveform, panel (2B), with an open quotient of about 50% to 60% of the period and a waveshape during the open phase that is slightly skewed (closure is more rapid than opening). The spectrum of the normal voicing source, panel (2C), has an average falloff of about − 12 dB per octave of frequency increase.

In preparation for laryngealized phonation (column 1 of Fig. 1), the arytenoids are positioned so as to close off the glottis, and perhaps even apply some medial compression to the vocal processes. When lung pressure is applied to the system, the vocal folds vibrate, producing a glottal volume velocity waveform as shown in panel (1B) of the figure. The glottal pulse is relatively narrow; i.e., the duration of the open portion of a fundamental period is relatively short. In addition, the fundamental frequency is substantially lowered during laryngealization, and there may be period-to-period irregularities in both the duration of the period and the amplitude of the glottal volume velocity pulse (Timke *et al.*, 1959). Possible perceptual cues to laryngealization (associated with changes to the source spectrum) are a reduction in the relative amplitude of the fundamental component in the source spectrum, panel (1C), and a lowered fundamental frequency contour.

The glottal configuration during a breathy vowel is shown in panel (3A) of Fig. 1. The arytenoid cartilages are well separated at the back, but the vocal processes are sufficiently approximated so that the vocal folds vibrate when a lung pressure is applied to the system. Since the glottis is never completely closed at the back over the vibratory period, there is considerable dc airflow (panel 3B). This increased airflow results in the generation of turbulent aspiration noise, which is combined with the periodic voicing component to form a source spectrum consisting of both harmonics and random noise [panel (3C)]. Being relatively weak in amplitude, the aspiration noise might not be audible were it not for the fact that the vibratory behavior of the vocal folds is modified in a breathy vowel (Fant, 1980, 1982a). Ordinarily, as illustrated in the middle column, the vocal folds close simultaneously along their length, leading to an abrupt cessation of airflow and relatively strong excitation of higher harmonics at the instant of closure. In a breathy vowel, however, the folds close first at the front, and then closure propagates posteriorly, leading to a volume velocity waveform with a rounded corner at closure [panel (3B)]. The implications of this behavior for the harmonic components of the source spectrum are twofold—the waveform is more nearly sinusoidal and thus has a very strong

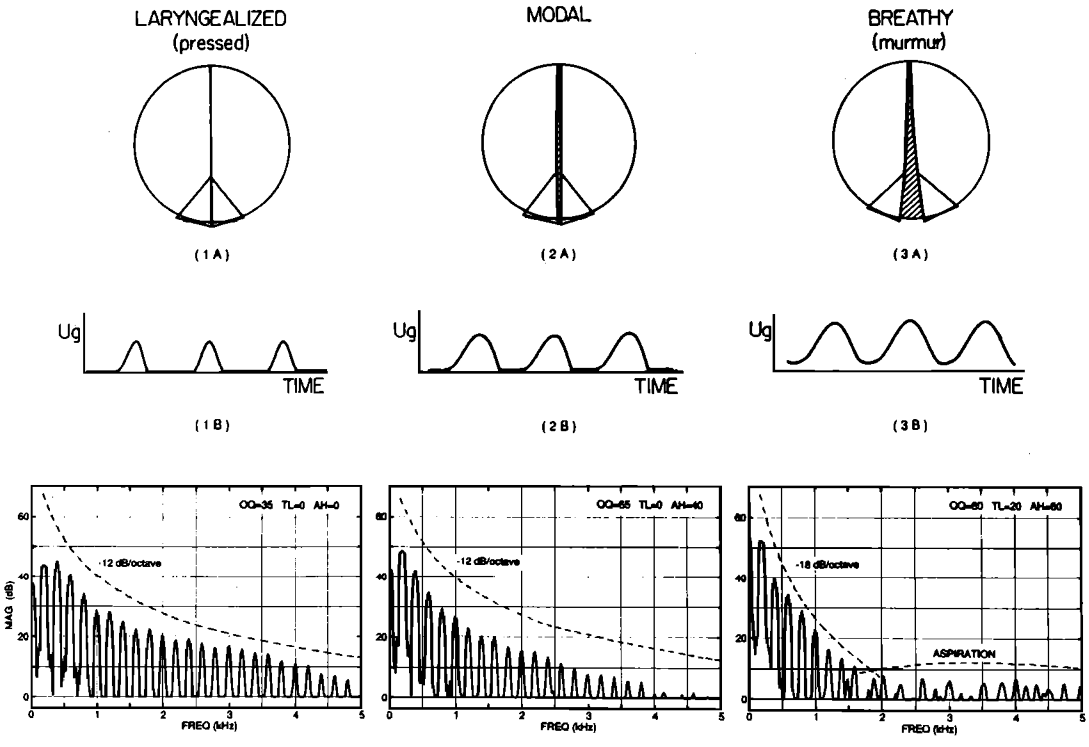

FIG. 1. Glottal configurations (row A) for (1) laryngealized, (2) modal, and (3) breathy vowels. An increased opening at the arytenoids results in glottal volume velocity waveforms (row B) with a progressively longer duration open period, an increased dc flow, and a less abrupt closure event. The source spectra (row C) have a more intense fundamental component from left to right, and the breathy configuration results in a spectrum with weaker high-frequency harmonics being replaced by aspiration noise. Figure adapted from Stevens (1977).

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