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Why Do Close Harmonies and Dissonances Sound Rougher at Low Pitches than High Pitches?

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Roughness perception of two tones received simultaneously by the ear is related to *critical band*, a range of frequencies in which there is competition for the same region of the cochlea in the inner ear. If two tones are wide enough apart in frequency, each will stimulate a separate region of the basilar membrane in the cochlea. The two tones will be perceived as two separate pitches because they excite separate hair cells. To the contrary, if two tones are close enough together in frequency that they fall within the critical band, the tones will interact with each other. They will stimulate some of the same regions of the basilar membrane and thereby the same hair cells. Individual pitches and individual loudness will be difficult to perceive, and the tone combination will have an inherent roughness as a result of this uncertainty. Moore gives a formula for the equivalent rectangular bandwidth (*ERB*) of the critical band

$$ERB = 24.7\ (4.37\,f/1000 + 1)\ \text{Hz}$$

where f is the center frequency.[1]

Consider the note C_3 sung by one singer and the note D_3 sung by a second singer, or played by an accompanying instrument. This is considered close

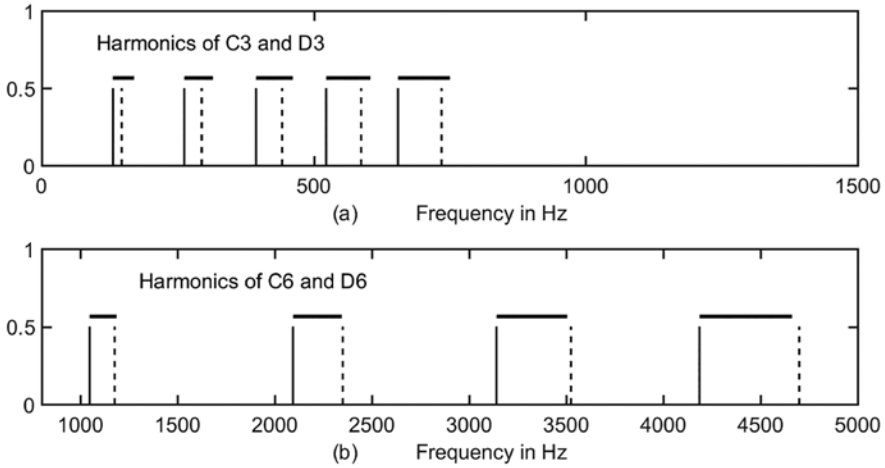

Figure 1. Harmonic frequencies of two notes separated by one whole tone: (a) for the notes C_3 (solid) and D_3 (dashed), and (b) for the notes C_6 (solid) and D_6 (dashed). The horizontal lines indicate the critical bandwidths.

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harmony by some and dissonance by others. Here we quantify whether or not there should be a perception of roughness. The fundamental frequencies are 131 Hz and 147 Hz, respectively. Figure 1 (a) shows the series of the first five harmonic tones produced , solid vertical lines for C_3 and dashed vertical lines for D_3. Horizontal bars over the top indicate the critical bandwidth. Note that all pairs of harmonics lie within the critical band, suggesting that roughness will be perceived in all harmonic pairs.

Now consider the pair of tones C_6 and D_6 shown in Figure 1 (b). Only the two fundamental frequencies are (barely) within the critical band. The second, third, and fourth harmonic pairs are separated enough to be just outside the critical band. This suggests that less overall roughness will be perceived.

The conclusion that can be drawn from this simple comparison is that, in ensemble singing or instrument playing, close harmony or dissonance is perceived to contain more roughness and more pitch uncertainty at low pitches than at high pitches. A tendency might be to assign this to errors in production, but it is entirely a perceptual phenomenon.

NOTE

1. B. C. J. Moore, *Cochlear Hearing Loss* (London: Whurr Publishers Ltd., 1998).