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Report

Individual Differences Reveal the Basis of Consonance

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Summary

Some combinations of musical notes are consonant (pleasant), whereas others are dissonant (unpleasant), a distinction central to music. Explanations of consonance in terms of acoustics, auditory neuroscience, and enculturation have been debated for centuries [1–12]. We utilized individual differences to distinguish the candidate theories. We measured preferences for musical chords as well as nonmusical sounds that isolated particular acoustic factors—specifically, the beating and the harmonic relationships between frequency components, two factors that have long been thought to potentially underlie consonance [2, 3, 10, 13–20]. Listeners preferred stimuli without beats and with harmonic spectra, but across more than 250 subjects, only the preference for harmonic spectra was consistently correlated with preferences for consonant over dissonant chords. Harmonicity preferences were also correlated with the number of years subjects had spent playing a musical instrument, suggesting that exposure to music amplifies preferences for harmonic frequencies because of their musical importance. Harmonic spectra are prominent features of natural sounds, and our results indicate that they also underlie the perception of consonance.

Results

Figure 1A shows the pleasantness ratings given by a group of subjects to different combinations of notes. Some combinations were consistently rated higher than others, irrespective of the instrument playing the notes. This is the phenomenon of consonance, the origins of which have remained controversial throughout history [1–12].

Ancient thinkers viewed consonance as determined by ratios (Figure 1B), but in modern times it has been linked to acoustic properties thought to be important to the auditory system [10]. The dominant contemporary theory posits that dissonance is due to beating between frequency components [2, 13–15]. Beating occurs whenever two sinusoids of differing frequency are combined (Figure 1C, top left). Over time, the components drift in and out of phase, and the combined waveform waxes and wanes in amplitude. This modulation produces a sound quality, known as roughness, that listeners typically describe as unpleasant [21, 22] and that has been thought to be prevalent in dissonant, but not consonant, musical chords [13–15].

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Figure 1C (bottom two rows) shows spectra and waveforms for two musical intervals (chords with two notes). The minor second, a dissonant interval, contains many pairs of frequency components that are close but not identical in frequency and that produce beating, visible as amplitude fluctuations in the waveform. The (consonant) fifth presents a different picture, containing frequencies that are widely spaced or exactly coincident and that thus produce little beating.

However, the intervals differ in another respect. The fifth contains frequencies that are approximately harmonically related—they are all multiples of a common fundamental frequency (F0) (Figure 1C, top right). Not every component of the harmonic series is present, but each frequency corresponds to a harmonic. In this respect the fifth bears some resemblance to an individual musical note, whose frequencies are generally a series of harmonics, the F0 of which corresponds to the pitch of the note. The resemblance does not hold for the minor second, whose frequencies are inharmonic. This contrast exemplifies an alternative view—that consonant chords derive their pleasantness not from the absence of beating, but rather from their similarity to single notes with harmonic spectra [3, 17–20].

It has also seemed plausible that consonance might not be rooted in acoustics at all and is instead the arbitrary product of enculturation [23]—listeners might simply learn to like specific chords that are prevalent in the music of their culture. This notion is fueled in part by the use of the equal-tempered scale in modern music, in which consonant intervals only approximate integer ratios (Figure 1B) and are thus somewhat less harmonic, and less devoid of beating, than they would be otherwise. Of course, enculturation and acoustic-based explanations are not mutually exclusive. If a particular acoustic property were to underlie the distinction between consonance and dissonance, listeners could potentially learn an aesthetic association with that property by hearing it repeatedly in music.

In our efforts to address these issues, we took advantage of the fact that some listeners showed stronger consonance preferences than others. We investigated whether intersubject variability in consonance preferences could be explained by variation in preferences for particular acoustic factors. We measured acoustic preferences by asking subjects to rate the pleasantness of nonmusical stimuli designed to independently vary in beating and harmonic content. To isolate the aesthetic contribution of a particular factor, we formed preference measures by subtracting the ratings of stimuli possessing that factor from those that did not. If beating or harmonic spectra underlie consonance, the associated acoustic preference measures should be correlated with our consonance measures. To ensure robustness and replicability, we separately examined these correlations for chords made from different instrument sounds and separately tested two large cohorts of subjects (n = 142, 123).

Consonance Preferences

We measured consonance preferences with chord rating tests (Figure 1A). Two summary measures of this preference were computed for each instrument sound (timbre), one for

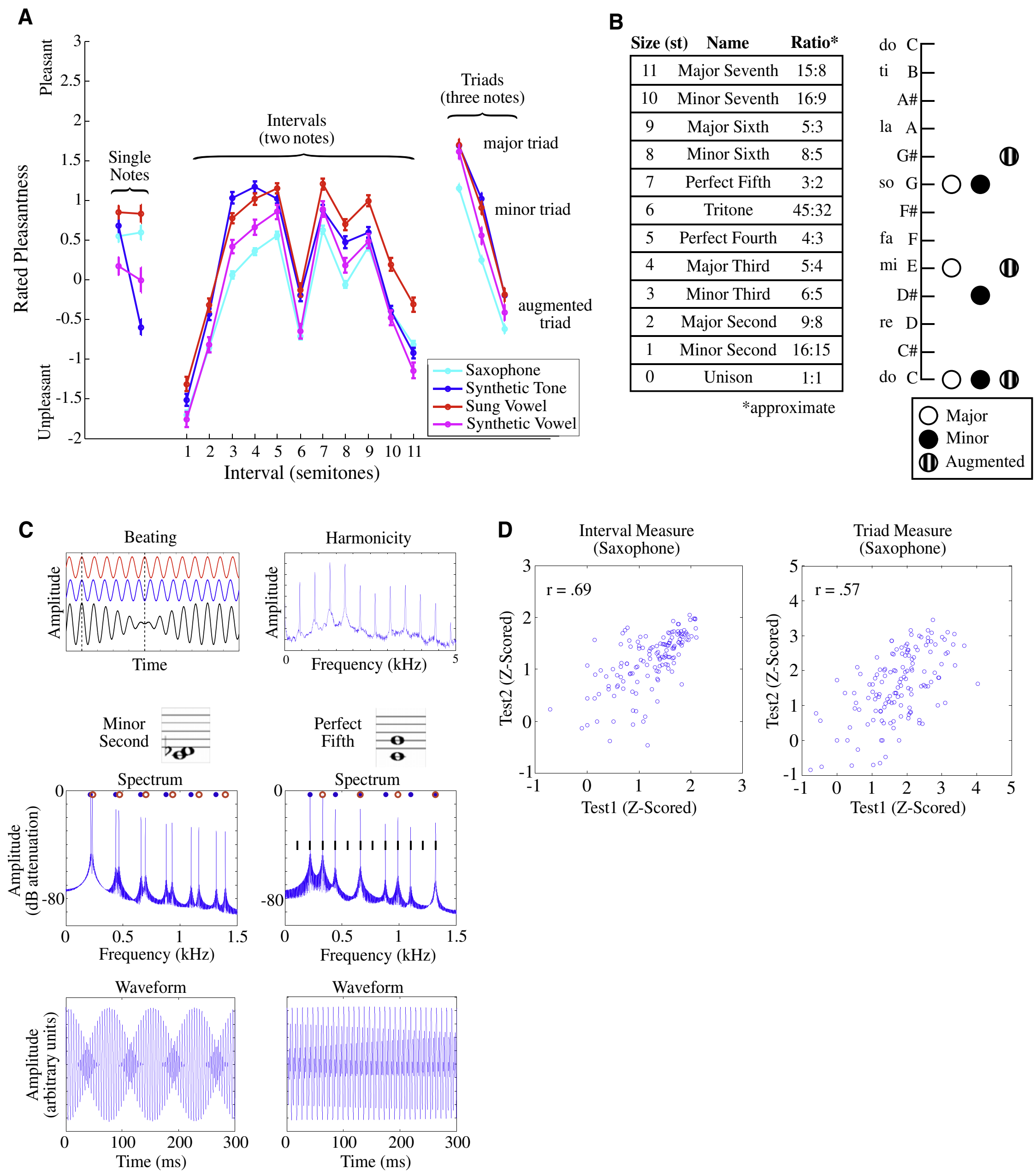

Figure 1. Consonance Preferences and Their Possible Acoustic Basis

(A) Mean pleasantness ratings of individual notes and chords, for cohort 1. The two single-note conditions differed in pitch (lower pitch on left). Error bars denote standard errors (SEs).

(B) Chords used in experiments, with diatonic scale as reference. Ratios in stimuli approximated those listed, because the equal-tempered scale was used.

(C) Beating and harmonicity in consonant and dissonant intervals. Top left: two sinusoids of different frequencies are plotted in red and blue; their superposition (in black) contains amplitude modulation known as "beating." Top right: amplitude spectrum for the note A440 played on an oboe. The frequencies in the note are all integer multiples of the fundamental frequency of 440 Hz and as a result are regularly spaced along the frequency axis. Bottom rows: spectra and waveforms for the minor second and perfect fifth, generated by combining two synthetic complex tones with different fundamental frequencies. Red and blue circles denote the frequencies belonging to each note. The frequencies of the fifth are approximately harmonically related (black lines denote harmonic series). Amplitude modulation (from beating) is evident in the waveform of the minor second, but not the fifth.

(D) Scatter plots of consonance preference measures computed from z-scored ratings of cohort 1 (saxophone notes) on two successive tests. The interval consonance measure was formed by subtracting the mean rating of the five lowest-rated intervals from that of the five highest-rated intervals. The triad consonance measure was formed by subtracting the ratings for the augmented triad from that of the major triad. Each circle denotes the scores of a single subject. Here and elsewhere, r is the Spearman correlation coefficient.

two-note chords (intervals), and one for three-note chords (triads). Each measure was formed from the difference between the ratings of consonant and dissonant chords. Large values of these measures indicate strong preferences, and individual subjects produced consistently different values, indicated by correlations in their scores from two successive