Perception of musical tonality as assessed by the probe-tone method.

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Introduction

The purpose of the experimental research reported in this presentation was twofold: (1) to assess the reliability of the probe-tone technique as a method of recovering listeners' representations of the tonal hierarchy; and (2) to examine both sensory and cognitive accounts of the data by comparing the relative success of selected predictor variables.

The tonal hierarchy. Tonality is a function of the hierarchical organization of pitch relationships. Hierarchical pitch relationships exist at three interrelated levels, that of note, chord, and key, and involve increasing levels of abstraction. The concept of the tonal hierarchy describes the relationship among the single tones within a key. One single tone, the tonic, forms a reference point for all tones in the key. Each of the remaining tones is located in a hierarchical relationship with the tonic. It is hypothesized that listeners relate individual tones to these reference tones in an ongoing fashion as music is heard, a process that contributes to a sense of tonality.

The probe-tone method. The probe-tone method was first used by Krumhansl and Shepard (1979) as an effective means of quantifying listeners' responses to tonality. As generally applied (Krumhansl, 1990), subjects listen to a stimulus context, typically consisting of a short sequence of notes or chords, or a scale or melody context, and then rate a following tone, the "probe tone", for degree of completion or goodness-of-fit with the context. The probe tones consist of all possible tones from the 12-note chromatic scale. The set of ratings, one for each of the 12 probe tones, is called the probe-tone profile for the context. The profile is assumed to reflect the hierarchy of stability of tones in the context. Where key-defining contexts have been employed, the profile is thought to reflect the relationship between each probe tone and the tonal centre of the context.

Method

The data for the probe-tone tests described below were collected as part of a larger study involving an extensive series of music and cognitive tests.

Subjects. One hundred subjects participated in this study, ranging in age from 18-40 years (mean = 27, SD = 6.2), with years of formal education ranging from 7-22 years (mean = 15.6, SD = 2.7). Sixty-one subjects had little or no music training, 22 subjects had moderate amounts of music training, and 17 subjects had high amounts of music training or were professional musicians.

Apparatus. A Yamaha TX81Z synthesizer controlled by a Zenith Z-248 computer running "DX-Score" software was used to create the single-note stimuli for the Probe-tone Melody test. A Yamaha TX802 synthesizer controlled by an Atari 1040ST computer using "Notator" music processing software was used to create the "Shepard-tone" stimuli for the Probe-tone Major and Minor Cadence tests. Shepard tones and chords do not have a well-defined pitch height. Each tone contains sine-wave components distributed over a multi-octave range under a half-cosine amplitude envelope which approaches hearing threshold at the high and low ends of the range (Shepard, 1964). All music sequences were recorded on audiocassettes and reproduced through the speakers of a portable tape player at comfortable listening levels, as determined by each subject.

Probe-tone procedures. For the Probe-tone Melody test, the melody used was the "March of King Laois" (from Johnston, 1985), an obscure 16th century Celtic tune, highly tonal in nature, characterized by simple elaborations of the tonic triad. The melody was played at a tempo of MM=100 (dotted half note) and lasted 12.2 seconds, and was followed, after a one-second pause, by a probe tone of one second duration. Each of 12 probe tones in the chromatic pitch set was presented twice, in random order, for a total of twenty-four presentations of the melody and probe tone. The Yamaha TX81Z synthesizer was set to factory present A15 (Wood Piano) while recording the melody and probe tones. Subjects were required to rate, on a scale of 1 - 10, how well the probe tone fit in with the melody that came before it. A rating of "1" indicated a poor fit and a "10" indicated a good fit.

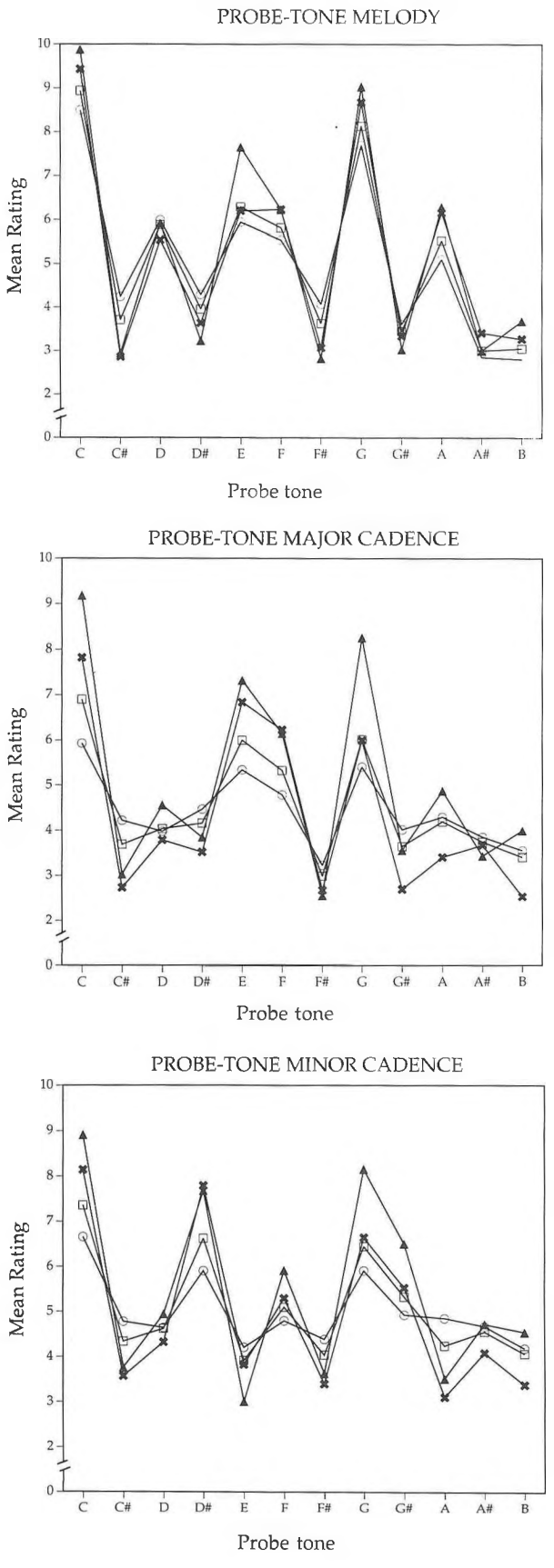
For the Probe-tone Major and Minor Cadence tests, twenty-four major (IV-V-I) and twenty-four minor (iv-V-i) perfect cadences, of three seconds duration, was each followed, after a one-second pause, by a probe tone of one second duration. The cadences were played at a tempo of MM=110 (quarter note). Each of 12 probe tones in the chromatic pitch set was presented twice, in random order, for a total of twenty-four presentations of each cadence and probe tone. Each chord was constructed as a Shepard chord and consisted of fifteen notes spaced over six octaves. The probe tones were similarly constructed as Shepard tones and consisted of sine-wave components spaced at octave intervals. The Yamaha TX802 synthesizer was set to produce sine tones for each chord tone and probe-tone note, with rise and decay times of 20 ms. each. Subjects were required to rate the probe tone, on a scale of 1-10, on how well it fit in with the preceding chord pattern. A rating of "1" indicated a poor fit and a "10" indicated a good fit.

Results and Discussion

All obtained probe-tone profiles resembled the standardized profiles reported in the literature (Krumhansl, 1990). The order of the ratings was consistent with music theoretic descriptions of the tonal hierarchy. Subjects generally rated the tonic note (C) the highest, followed by the other notes of the tonic triad (E and G for the melody and the major-cadence contexts; Eb and G for the minor-cadence context), the remaining diatonic notes, and, finally, the nondiatonic notes (see Figure 1). These results suggest that each of the probe-tone contexts reliably assessed subjects' sense of tonality, and that all subjects evidenced a sense of tonality, regardless of level of music training.

It was noted that subjects with high music training produced profiles in which ratings were more clearly differentiated than subjects with little or no music training, and correlations of the profiles with music theoretic predictions were highest for subjects with high music training. Nevertheless, there was close correspondence between the profiles for the three training groups (average $r = .93$, all $p < .001$).

We next examined psychoacoustic and musical correlates of the perceived tonal hierarchies. A number of predictor variables were derived and the amount of variance in the



profiles accounted for by each predictor variable was computed.

The first set of predictors tested the acoustical property of consonance. Six sets of consonance values were obtained from a summary table in Krumhansl (1990, p. 57). These predictors assigned values to each probe tone in terms of the degree of acoustical consonance between the probe tone and the key centre of the musical context. Values were obtained, for example, from the roughness calculations of Helmholtz (1885/1954) and also from critical bandwidth modifications of the Helmholtz values.

The second set tested the predictive power of statistical properties of tonal music. The values assigned by these predictors were the relative frequencies with which each probe tone occurred in both major and minor keys. The values are obtained from statistical distributions of samples of tonal music (see Krumhansl, 1990, p. 67).

The third set of predictors were derived from Parncutt's (1989) model of pitch salience. This model, which applies specifically to the cadence contexts, assigns a value to each probe tone in terms of its spectral and virtual pitch weight in the stimulus context. Three versions of the model were tested.

Parncutt's model of pitch salience yielded the greatest success, both for the cadence contexts, and, surprisingly, for the melody context. One version (containing a sensory trace decay) consistently accounted for over 80% of the variance in probe-tone profiles for all three contexts. Possible reasons for the goodness-of-fit of this model will be discussed.

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Figure 1. Mean probe-tone ratings for Probe-tone Melody and for Probe-tone Major and Minor Cadences for all subjects and by levels of music training. (Open squares - all subjects; open circles - low music training; x's - moderate music training; triangles - high music training.)