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Introduction

The human ear detects sounds within the range of 30 to 15,000 or 20,000 cycles per second, and the pitch attributes of pure tones are defined over the larger part of this range. For steady-state tones in the region of 1000 cycles per second the ear gives evidence of a sensitivity for changes of pitch as low as 0.003 for $\Delta f/f$, where f is the frequency and Δf the change of frequency.

If a complex steady-state tone impinges on the ear, the end-organ of hearing may be said to perform an harmonic analysis and, if the sensation level of the tone is above the threshold of audibility, its pitch can be determined largely by the fundamental of the harmonic series. In the absence of appreciable intensity of the fundamental, the pitch is defined by the difference tone common to three or more near-lying partials of comparable strength. In the usually accepted theory of hearing, the region of maximum excitation or the pattern of distortion along the basilar membrane determines the pitch of a note.

Present Study

This study is a report on some work in which the ear was exposed to short isolated pulses of sound in which the duration and frequency could be varied. The frequency was made to vary continuously either in an upward or a downward direction over defined musical interval-ranges.

Apparatus

The stimuli were produced by the use of phonographic reproductions of pitch glides and short pulses of steady-state tone recorded from the output of a beat-frequency oscillator. A rotary variable condenser of unique design was placed in parallel with a fixed condenser in the oscillator to produce the desired frequency modulation. Adjustment of the variable condenser made possible the variation of both extent and duration of the signal. Upward and downward frequency modulations was made possible, as well as steady-state tones, the latter in combination with or separated from the glide. For a given pulse of sound, the modulation was always in one direction only (either up or down). The intensity of the output remained essentially constant. The geometric mid-point of the frequency sweeps, regardless of their direction or extent, was held at $D_{42} = 293$ cycles per second. Durations of 0.025 sec. (7 cycles) to 0.3 sec. (88 cycles) were used for the glides. Extents of frequency modulation ranged from 0.2 tone ($\Delta f/f = 0.012$) to 5.0 tones ($\Delta f/f = 0.334$).

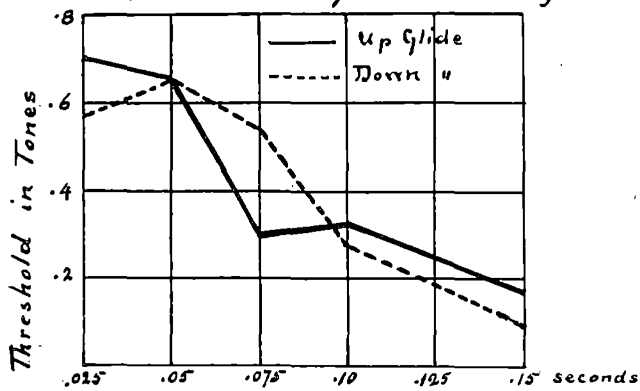
Procedure

Graduate music students and musically trained psychologists served as observers. They were instructed to judge, in the case of each stimulus, whether the pitch changed upward or downward, or remained constant. A judgment was regarded as correct if it agreed with the frequency pattern of the stimulus.

Results

Computations of threshold values for the discrimination of direction of glide were based upon the standard error of the percentage of correct responses that would have been obtained if chance alone had been operating. With three categories of response three standard errors ($\delta_p = \sqrt{pq/N}$) above the chance percentage of 33% could justifiably be taken as a basis for computing threshold values. Threshold values computed from the psychophysical data are presented in Fig. 1. It is apparent from the curves that, for bare detec-

Threshold Values for the Bare Detection of Direction of Pitch Change.



tion of pitch change, thresholds vary as a function of both amount and rate of frequency modulation, i.e., threshold values, expressed in terms of duration, decreased with increasing extent pitch variation, and expressed in terms of extent of modulation, the values decreased with increasing duration. The psychophysical data thus indicate that both the perception of extent and direction of frequency modulation is dependent upon the duration of presentation of the stimuli. Above the threshold value of approximately twenty-five milliseconds the data indicate rather consistent discrimination between the three catagories of response, i.e., up-glide, down-glide and steady-state tone.

Interpretation

It is perhaps not altogether wise to make comparisons of the conditions existing in the ear when it is exposed to a steady-state sound of considerable duration and those existing when the stimuli come in short pulses. If pitch recognition and the perception of pitch changes depend upon the excitation of a given point on the basilar membrane and the movement along the length of the membrane of the point of stimulation, these experiments may be said to measure the minimum time required to set up a condition which approaches the steady state.

In short pulses such as were used in the present study, the "transient terms" due to the onset and cessation of the stimulus are very important. Such factors are brought in also because the frequency of the sound is continually varied. A Fourier Analysis of such isolated pulses of sound is not valid from many points of view, but if it is assumed that the short pulse represents one "wave-length" or one complete cycle of a continuous steady sound, a Fourier Analysis can be carried out. It is interesting to point out that if such an analysis is made of two trains of pulses which differ only in that the frequency modulation is upward in one and downward in the other, the component frequencies and amplitudes are the same but there is a phase change of 90° in each component. If then one accepts the extrapolation from the steady-state case to that in which short pulses are analyzed by the same methods, the present study indicates that the ear can detect changes of phase in that it can detect the direction of pitch changes in pulses as short as 0.025 second. This, however, probably places an undue burden on the factor of phase.

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