Determination of difference limen at low frequencies

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IV. PSYCHOACOUSTICS

A. DETERMINATION OF DIFFERENCE LIMEN AT LOW FREQUENCIES

Summary of thesis work for "civilingenjörsexamen"

A. Askenfelt

Abstract

Difference limen for frequency was determined in the region 40-200 Hz. Three types of stimuli were used; double-bass synthesis, low-pass filtered pulse train, and pure tones. Subjects listened to pairs of tones and adjusted the frequency of the second tone until they had matched the pitches to their own satisfaction. The standard deviation of the settings was used as measure of DL.

The obtained DL's are a tenth of the often quoted data of Shower & Biddulph and Zwicker & Feldtkeller but in close agreement with the data of J. Nordmark (1968). Pure tones gave nearly twice as high values of DL's as the complex tones.

1. Introduction

It has been realized for a long time that data on pitch discrimination are of relevance not only to psychoacoustics but also to musicology (1). Since the end of the 19th century a number of investigations of difference limen (DL) for frequency has been carried out (2, 3, 4, 5, 6, 7). The results of some of the more important works are shown in Fig. IV-A-1. As seen in the figure there is a considerable degree of disagreement, which in part is probably due to differing methods of measurement. Also, it appears to a musician that some of the values reported are strikingly high. For example, the classical work of Shower & Biddulph (3) gives a DL of 3 Hz at a frequency of 60 Hz. This corresponds to 85 cents, almost a semitone (1 semitone = 100 cents). All but one of these results are derived from stimuli consisting of pure sinusoids. No attempt has earlier been made to measure DL for frequency with more "natural" sounds.

The purpose of this work is to determine DL for low frequencies using stimuli similar to the tones from a musical bass instrument.

2. Stimuli

The double-bass was chosen to represent the bass instruments. Six tones in the frequency region 40-200 Hz were recorded in an anechoic room and analyzed by an audio-frequency spectrograph. A typical spectrum is shown in Fig. IV-A-2. The tones were synthesized according to
Fig. IV-A-1. Values of difference limen (DL) for frequency obtained by various experimenters:
Fig. IV-A-2. Typical double-bass spectrum. The solid line shows the spectrum envelope of the synthesis used in the experiments, see text.
the source-filter model, Fig. IV-A-3. A pulse generator providing a pulse train with a spectrum envelope of the form \( \sin \frac{f}{f} \) was used as a source. A small amount of white noise was added to the pulse train. The pulse generator was triggered by a voltage-controlled sinus generator which determined the fundamental frequency. To obtain a vibrato the fundamental frequency was frequency modulated with low-frequent sinus wave (4 Hz). Four LC-circuits with adjustable resonance frequencies and bandwidths served as filter. The spectrum envelope of the synthesis of the tone in Fig. IV-A-2 is indicated by the solid line in this figure. The general impression was that the synthesized tones sounded as typical double-bass tones.

Two additional types of stimuli were used in the listening tests, a standard spectrum and sinusoids. The standard spectrum consisted of a low-pass filtered pulse train with a spectrum envelope slope of -6 dB/octave.

3. Method

The investigation was carried out in the form of series of listening tests. Nine subjects with varying degree of musical training, four professional musicians and five amateurs, took part in the experiment. The subjects' task was to adjust the frequency of a variable response tone until its pitch corresponded to the pitch of a given reference tone. The tone-pair was repeatedly presented until the subject had made a pitch match to his own satisfaction. Then, the subject triggered an electronic equipment by pressing a button, which interrupted the stimulus presentation and registered the result on punched paper tape. Thereafter the response frequency was slightly changed and the procedure was repeated. Each subject made at least 10 settings for each reference frequency. The test sessions had a maximal duration of one hour including several pulses. The subjects were seated in an ordinary room. The tone-pairs were binaurally given to the subjects by means of two loudspeaker-sets at the distance of 30 cm from the subjects' ear approximately. This arrangement gave rise to listening sensations similar to those of earphone listening. Earphones could not be used since they were unable to reproduce low-frequency stimuli in an acceptable way. The sound pressure level re. .0002 dyne/cm\(^2\) (SPL) was 80 dB corresponding to loudness levels between 60 and 80 phones, depending on the fundamental frequency and spectrum.
Fig. IV-A-3. The source-filter model.
Fig. IV-A-4. The electronic instrumentation used in the listening tests.
4. Apparatus

The electronic equipment for the listening tests is shown in Fig. IV-A-4. The reference frequency and the response frequency are produced by two voltage controlled sine wave generators (1, 2), both slightly frequency modulated by a sinus generator (7). The pulse generator (5) is triggered by the sine waves. White noise (6) is added to the pulse train before it passes through a pre-emphasis amplifier (8), four resonance circuits (10), and power amplifiers (11, 15) which feed two loudspeaker-sets (17, 18). The standard spectrum is produced by leading the pulse train through a low-pass filter (13). The analog gates (3, 4, 14) determine the stimulus duration (Fig. IV-A-5) which was 2.0 sec with a pause of 0.4 sec between reference and response stimuli. The pause before next reference stimulus was 1.9 sec. The fall and rise times of the tones were 100 msec, long enough to cause no clicks in the loudspeakers.

Fig. IV-A-5. Stimulus duration.

The test subject adjusted the response frequency from a test box in his hand. The result was registered when the subject pushed a button which triggered a frequency counter (21). The binary outputs from the counter, corresponding to seven decimal digits, were connected to a paper-tape punch (23) via a multiplexor (22). The tape with the results was later processed by a computer (24). Thus, all registration and calculation of data were completely automatic and caused the author no work at all, apart from constructing and building the multiplexor.
Fig. IV-A-6a. Mean deviation from the reference frequency for nine subjects as a function of the reference frequency.

Fig. IV-A-6b. Mean DL's for nine subjects as a function of the reference frequency.
5. Results

The standard deviation of the settings was used as the measure of DL. Mean DL's for the nine subjects expressed as least discriminable change in frequency, and mean deviation from the reference frequency $\Delta$, are plotted in Fig. IV-A-6. The vertical bars in Fig. IV-A-6b give intersubject variability showing the standard deviation of the nine subjects.

It is seen from Figs. IV-A-1 and IV-A-6 that the result is in close agreement with the data of J. Nordmark\(^7\). The influence of the shape of the stimulus spectrum on DL is evident, sinusoids giving approximately twice as high values as complex tones. The data for the double-bass synthesis and the standard spectrum fit fairly well to a straight line defining 3 cents. No difference between amateur and professional musicians could be seen in the data. During the test sessions, however, the professionals showed more assured manners, obviously relying on their musical skill.

Our data are about a tenth of the often quoted data of Shower & Biddulph\(^3\) and Zwicker & Feldtkeller\(^6\), derived from sinusoidal frequency modulation. It seems clear that those data bear little or no relation to DL for frequency in the low frequency region.

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BASIC MECHANISMS IN HEARING

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