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ANALYSIS OF THE INITIAL FRACTION OF BÉKÉSY RECORDINGS IN THE THRESHOLD AUDIOMETRY*

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Statistical analysis of initial transients in the threshold Békésy tracings, observed mostly at higher rates of the signal level control (i.e. 10 dB/s and 30 dB/s), is given. The transients reach several dB and last about 10 s. Possible background of psychological nature is discussed.

1. Introduction

The new automatic audiometer [8], since its first application more than six years ago in conventional audiometry and psychoacoustical research, has been recognized as a useful tool, having many advantages over commercially available Békésy audiometers [1, 7].

In particular, these are the means used for signal level control, the range of signal control rates, the possibility of increasing the accuracy by using various recording potentiometers to suit the actual demand and, last but not least, integration of the recording and thus its automatic interpolation.

For the proper interpretation of Békésy tracings obtained using the new audiometer, the necessity of gathering statistically significant data pertaining to the normal and (in a limited measure) to pathological hearing was obvious. Among other factors affecting the results in automatic audiometry, the rate of signal level control shows a substantial influence on the tracing. In the new audiometer, the rate of signal level control is changeable over a range much wider than in the commercially available equipment used heretofore, in fact much wider than could be expected to be necessary.

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The present work is aimed at the normalization of the threshold audiograms for normal hearing at a rate of signal level control 10 dB/s, i.e. 2 to 3 times higher than commonly used in Békésy audiometry in its classic form, and at constant frequencies (disconnected scanning).

2. Apparatus

The audiometer used in the present measurements was set up using standard Brüel and Kjaer equipment [8, 9, 11] and some relatively simple additional units designed in the laboratory. A block diagram of the experimental arrangement is presented in Fig. 1.

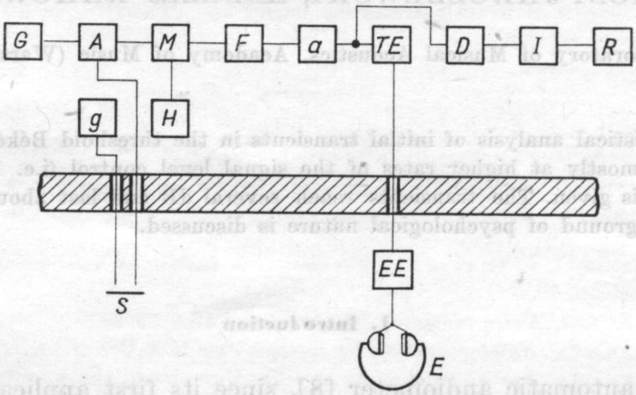

Fig. 1. Block diagram of the audiometric set-up

G – oscillator, A – band-pass volume control amplifier, M – mixer, H – heterodyne, g – control signal generator, S – control switch, F – low-pass filter, a – amplifier, TE – threshold equaliser, EE – earphones equaliser, D – detection unit, I – integrator, R – level recorder, E – earphones

The signal level from the oscillator G in this system is automatically controlled by the band-pass volume control amplifier A. The control signal from a separate external generator G, depending on the position of the (push-button) control switch activated by the subject (the listener), varies the amplification factor of the volume control amplifier A in such a way that the output signal level varies, i.e. increases or decreases at a predetermined constant rate.

The test signal is obtained from the mixer M as a result of mixing signals from the oscillator G and from the heterodyne H. Although the signal amplitude from the oscillator G is controlled by the volume control amplifier A, the signal amplitude from the heterodyne H is constant.

The signal frequency from the oscillator G is 100 kHz and constant, whereas the signal frequency from the heterodyne can be tuned over a range from 100 to 120 kHz, which produces test signals covering the auditory range. The test signal is obviously a frequency difference signal. Signals of the other frequencies resulting from the mixing are filtered out by the low-pass filter *F*. Thus the nonlinear distortions which are usually present in the output of simple volume control amplifier systems are eliminated from the amplitude controlled test signal. Only the isophonic threshold equaliser *TE* and the headphones' frequency response equaliser *EE* for TDH-39 MX-41/AR are used as additional units.

The test signal level, kept near the threshold by the subject by successive reversals of the volume control amplifier action (pushing and releasing the control push-button switch), is automatically recorded by the level recorder *R* operating on the principle of voltage equilibration, after detection and integration in the units *D* and *C*, respectively.

3. Method and subjects

Threshold signal level tracings obtained using the described audiometric system show a transient process in their initial fraction, whose general character may be given by the tracing presented in Fig. 2. Such transients are observed particularly at higher rates of signal level control, i.e. higher than commonly used in the present-day automatic audiometry.

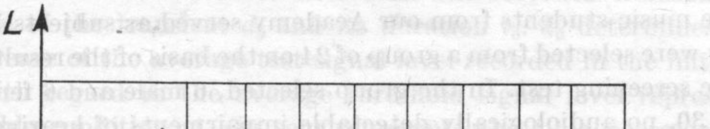

Fig. 2. Initial transient in threshold Békésy tracing

d_0 – amplitude of the transient, t_0 – duration of the transient. Rate of signal level control 10 dB/s

At 1 dB/s the transient is not observed, at 3 dB/s it can be just distinguished in most cases, but at 10 dB/s it is observed quite clearly. The systematic error (constant error) due to the reaction time of the subject at a rate of 10 dB/s should be sufficiently small [6, 10] not to affect the result, and at the same time the operation of the control switch by the subject is not too tiresome even over long periods.

The subjects employed were tested in 30 sessions lasting 1 hr each distributed over a time span of two months. Immediately prior to the measurements each subject was left in a sound isolated booth for 5 min for them to reach the stable threshold after separation from sound sources [2, 3, 4].

In each session up to ten or twenty threshold tracings were usually obtained, each tracing lasting at least 30 s. After each tracing a 5 to 10 min interval was introduced before starting the next one. The duration of the break between the tracings was determined individually by the subject within the specified time limits. The tracings were taken at a constant rate of test signal control, i.e. 10 dB/s, and constant frequencies 40, 80, 160, 300, 500 Hz and 1, 2, 4, 8, 10, 14 kHz.

The frequencies of the test signal were changed from one tracing to the next in a semi-random manner so that the subject did not know which frequency (or pitch) he would hear when starting a new tracing. In that way about 700 tracings were obtained.

Twelve music students from our Academy served as subjects in the experiment. They were selected from a group of 24 on the basis of the results of a routine audiometric screening test. In the group selected, 6 male and 6 female students aged 20 to 30, no audiologically detectable impairments of hearing were observed. Most of them, i.e. 5 male and 5 female students had at least 12 months experience in automatic audiometry, the remaining two had two 1-hour practice sessions.

Before the experiments each subject had to learn the following instruction: «Put on the headphones so as to obtain the best possible contact with the cushions and to have the aperture in front of the ear canal. If the headphones do not stay in position properly, adjust the bow spring suitably.

With the headphones on and the control switch depressed you will hear a pure tone increasing in intensity. However, you can make the intensity of this tone decrease if you release the control switch. If you depress the control switch again, the intensity of the tone will also increase again. During the measurement follow these rules: with the control switch depressed listen very carefully and as soon as you hear the tone release the control switch but only for so long as is necessary for the tone to fade so that you cannot hear it. As soon as the tone has faded so that you cannot hear it, depress the control switch but only until the moment when the tone appears again; then release the control switch, etc. It is of vital importance for the measurement to keep a rhytmic sequence of increasing and decreasing the intensity of the tone between the limits when you begin to hear the tone and when you are not longer able to hear it. Never allow the tone to become loud and, on the other hand, never allow it to disappear for too long. Release the switch when you just hear the tone and depress it when you just cannot hear it».

To show how much the initial fraction of the threshold tracings is affected by the rate of signal level control, a series of measurements were performed with one very experienced subject. These measurements cover the range of rates of signal level control from 1 dB/s to 30 dB/s. For each rate 50 tracings were taken using the same experimental procedure. The measurements were performed at 10 different frequencies in the range from 40 Hz to 10 kHz. As in the main experiment, the frequencies were set quasi-randomly so that the subject did not know what pitch he would hear after depressing the control switch at the beginning of each tracing.

4. Results

The results of measurements, in the form illustrated in Fig. 2, were further processed according to the commonly used rules, i.e. interpolated (averaged) between the extremes of the recorded spikes. In most cases the curve thus obtained had an exponential character.

Two parameters were used to determine the recorded transients, namely the amplitude of the transient d_0 and its duration t_0. d_0 determines in dB the transient increase of the average test signal level recorded in the initial fraction of tracing with regard to the average threshold signal level representing the following stable condition, t_0 (in sec) represents the time necessary to reach this condition.

Median values of d_0 and t_0 computed for 60 tracings (each point) are presented as a function of frequency in Figs. 3 and 4. It appears that d_0 and t_0 are almost independent of frequency and, almost over the whole auditory range, are equal to approximately 6 dB and 9 s, respectively. Vertical lines in the figures represent interquartiles.

The influence of the rate of signal level control on the threshold tracing in its initial fraction is determined by the curves presented in Fig. 5. Each point on the curves represents the median value of the 50 tracings taken from one subject. The tracings were taken at rates of 1 dB/s, 3 dB/s, 10 dB/s and 30 dB/s for the 10 quasi-randomly changed test signal frequencies in the range 40 Hz to 10 kHz.

5. Discussion

The experimental data presented determine normal transients at the begining of threshold Békésy tracings, with stimulation starting from below the threshold, in the frequency range 40 Hz to 14 kHz and at a rate of signal

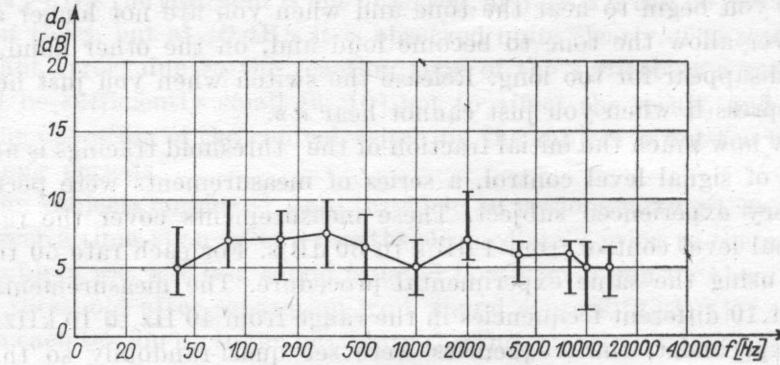

Fig. 3. Initial transient amplitude d_0 in threshold Békésy tracings as a function of frequency at a rate of signal level control 10 dB/s

Frequencies: 40, 80, 160, 300, 500 Hz and 1, 2, 4, 8, 10, 14 kHz. Twelve subjects. Circles are median values and vertical lines interquartiles of 60 tracings each

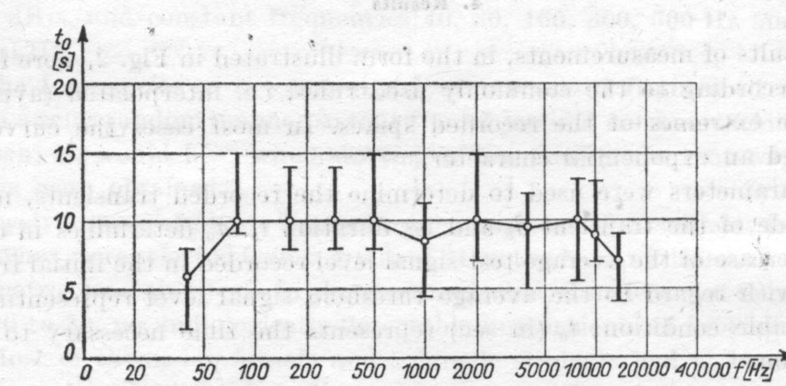

Fig. 4. The duration of the transient t_0 in threshold Békésy tracing at a rate of signal level control 10 dB/s. Subjects, frequencies and symbols as in Fig. 3

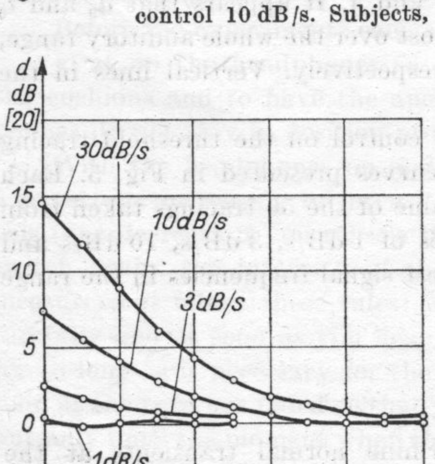

Fig. 5. The dependence of transient amplitude d in threshold Békésy tracings on the rate of signal level control. Circles are medians from 50 tracings from one subject. Frequencies changed semi-randomly in the range 40 Hz - 10 kHz, unknown to the subject; d_0 refers to $t = 0$

level control 10 dB/s. The observed median values of d_0 and t_0 are only a little lower than those obtained earlier from a group of subjects having no experience in automatic audiometry and are practically constant in the frequency range investigated.

These data could lead to the conclusion that, for the detection of a simple tone of unknown frequency, the intensity of this tone must be about 6 dB higher than the intensity at which it could be heard after the detection. In other words, some kind of progressive threshold improvement amounting to about 6 dB seems to take place. However, such an interpretation would be possible only with the assumption that over the whole period of the tracing, the initial fraction included, the tracing produced by the subject represents his «true» threshold, in other words, the tops of the spikes on the tracings always correspond to equally loud sound pulses.

For this reason a control experiment was performed in which pairs of 1 kHz tone pulses with a triangular envelope (analogy to Békésy spikes) of 50 to 100 ms duration and with 250 ms separation were presented to each subject each 3.75 s. The pulses were presented at a level near to the threshold. The subjects had the means to adjust the intensity level of the first pulse in a pair so as to make them equally loud. The results of this experiment showed that equal intensity in the successive pulses corresponded to equal loudness. Thus it seems evident that the transients in Békésy tracings representing intensity changes cannot be assigned to changes of loudness with time.

It seems probable that the mechanism of the process observed could have resulted from a very intense «scanning» of the whole range of the threshold physiological noise, so as to immediately react to the stimulus just as it appeared, but having no information in which region of the frequency scale it can be expected (subjects were not informed which frequency is to be used in the successive tracings). This mechanism, however, differs in its nature from that used after the detection of the stimulus and recognition of its pitch and, subsequently, appearing to the listener in a semi-rhytmic manner which, to some extent at least, could be predicted (regular spikes in the tracing after reaching the stable condition).

In order to get a clearer insight into these mechanisms and, particularly to judge the probability of the «scanning» mechanism suggested, another control experiment was performed with another very experienced subject. This experiment used essentially the same procedure as the main experiment but with two variants, i.e. using semi-randomly varied frequencies unknown to the subject, and using constant frequencies, so that the pitch of test signal to appear was well known to the subject.

Median values of the tracings obtained from the same subject (30 tracings each) for the two variants are presented in Figs. 6 and 7. It can be seen that in the case of a known stimulus, the transient amplitude d_0 is substantially smaller and, at the same time, t_0 shorter. This results probably from the «scanning» being limited to the frequency range proximal to the stimulus frequency, instead of the «scanning» over the whole auditory range. It seems to indicate that the underlying mechanism is rather of a psychological than a physiological nature.

The discrepancies between the data presented in Figs. 5, 6 and 7, particularly with respect to the time scale, result from the fact that in both cases

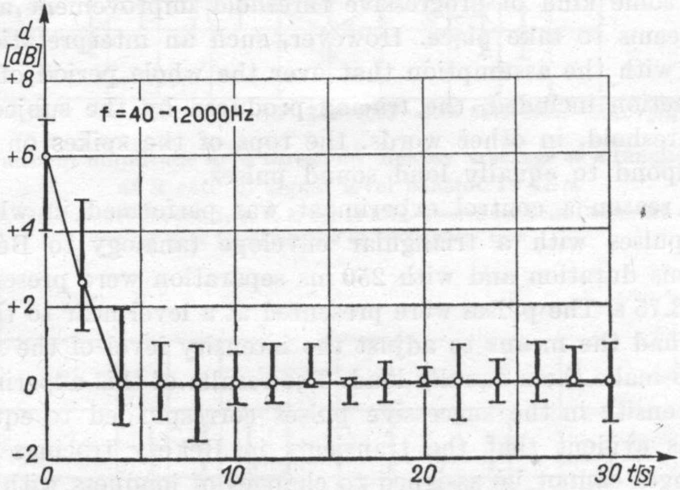

Fig. 6. Transient amplitude d in threshold Békésy tracing. Frequencies changed in the range 40 Hz - 12 kHz. Rate of signal level control 10 dB/s. Data from one subject — 30 tracings. Symbols as in Figs. 3 and 4

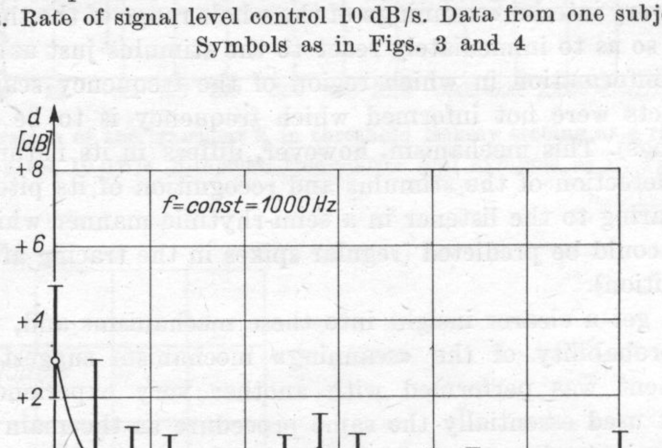

Fig. 7. Transient amplitude d in threshold Békésy tracing at a constant frequency of 1 kHz. Rate of signal level control 10 dB/s. Data from one subject — 30 tracings. Symbols as in Fig. 6

the tracings were taken from one subject only, but that different persons served as subjects in the two experiments.

Still remaining to be discussed is the transient observed even in the tracings at known frequencies. The amplitude of this transient at a rate of signal level control 10 dB/s amounts to about 3 dB. It seems that this transient can be assigned to the reaction times of the subject.

According to SIEGENTHALER [10] the subject's reaction time to pure tone signals at frequencies 250, 1000 and 4000 Hz is of the order of 0.2 s. Thus the transient amplitude of the order of 3 dB at the rate of signal level control 10 dB/s could well have resulted from this factor. It may also be pointed out that Siegenthaler's experiments were carried out at *SL* 40 dB and it is well known that near threshold levels the reaction time is substantially greater.

6. Conclusion

Results of this experiment determine the normal initial transients observed in threshold tracing in automatic audiometry at high rates of test signal level control.

The observed transients seem to result from the specific conditions of the experiment, particularly from the experimental procedure used and high rate of signal control. With regard to the procedure, the presentation of the signals in a semi-random manner over the frequency scale seems to be of importance. The occurrence of these transients can be explained by assuming a «scanning» mechanism in the detection of the test signal embedded in the physiological noise, and the reaction time of the subject (0.2 s), according to SIEGENTHALER. The results presented illustrate well the features of the new audiometer, particularly with respect to the accuracy of the threshold level determination. This is easily achieved by the use of interchangeable recording potentiometers of different ranges and the selection of the suitable rate of signal level control.

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