RELATIONSHIP BETWEEN THE AUDIOGRAM AND THE DURATION OF THE TONE MEASURING THE THRESHOLD

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In 1947 Garner and Miller [9] stated, not without reason, that the relationship between the threshold intensity (i) and duration of a tone (t) had received hardly any study [4, 12]. Since that time, several investigations have been undertaken [8, 10-15], on the subject of the strength–duration curves for threshold tones of different frequencies. These have shown that the auditory threshold, like the visual, is dependent on a duration of up to 2-3 sec. It has been demonstrated [10] that the form of this relationship varies: in the region of the smallest values of t (<10-18 millisec) the actual formula is $it^{1/2} = C_1$, for values of t between 10-18 and 100-280 millisec it is $it = C_2$, and for t > 100-20-millisec the formula is $it^{3/2} = C_3$ (C_1, C_2, C_3 – different constants). It is evident that the mechanisms of accumulation of the threshold energy are different for the different values of t, and that the strength–duration curve of the visual or auditory adequate stimulus is complex [2].

In order to obtain a complete strength–duration curve, it has been suggested [3] that the sensory threshold be measured in three characteristic zones: in the zone of longest durations, close to the useful time, in the zone of near-chronaxie durations, and in the zone of short durations for a stimulus of high intensity. These zones are evidently close to the three zones of Green, Birdsall and Tanner [10].

The study of the strength–duration curve of hearing has given unusual results. Miscolczy-Fodor [14, 15] has shown that in the presence of a lesion of the hair cells of the inner ear accompanied by recruitment, i.e., a very rapid increase in loudness in the affected ear, the strength–duration curve was considerably flattened, even to the extent of being converted into a straight line parallel to the abscissa (the time axis). This property of the recruiting ear may be a valuable diagnostic sign in a bilateral lesion, when Fowler's test [6, 7], based on the comparison of the loudness in the affected and healthy ears, is inapplicable. Flattening of the curve may also occur in persons with normal hearing as the result of the after-effect of a strong white sound [13] or of simultaneous masking by a strong sound of the same frequency [1].

When we examined the strength–duration curves for tones of different frequencies we were struck by the fact that the same data could be used to construct for any person a whole family of audiograms, the parameter of which would be the duration of the tone used for measuring the threshold. Such audiograms could be constructed, for example, on the basis of the findings of Garner [8], who obtained a series of strength–duration curves for different frequencies and established the relationship between their course and the spectral composition of the short tones. For very short tones, of course, the audiogram ceases to be indicative of the relationship between threshold and frequency, for a very short tone is converted, on account of the complexity of its spectrum, into a noise stimulus (assessable by the listener as a "whisper," "crack," or "knock"). Even for a very short tone, however, the maximum of the stimulating energy is concentrated on the frequency applied, and the form of the resulting audiogram, for all its conventional meaning, is not without interest. Since the results obtained from the study of strength–duration curves were not sufficiently systematic for the construction of complete audiograms, we made a special investigation of the relationship between the course of the audiogram and the duration of the tone used for measuring the threshold.

EXPERIMENTAL METHOD

The source of sound stimuli was the ZG-10 sound generator, connected to an electronic switch which could vary the duration of the tones from fractions of a millisecond to 850 millisec. The durations of the tones were graduated by means of an ENO-1 oscillograph with a slave sweep. The rise and fall of the tones were almost instantaneous.

The subject was placed in a quiet, insulated room and listened monoaurally to the applied sounds through the earpiece of a TD-6 electrodynamic telephone. The tones were applied in rhythmic series: the longer (850 and 100 millisec) at the rate of 1 in 4 sec, tones of 20 and 5 millisec at the rate of 1 per sec, and tones of 2 and 0.5 millisec at the rate of 2 per sec. The level of the acoustic pressure of the tones was measured relatively to 0.0002 bar.

Six persons were investigated: three with good hearing, two with poor hearing due to old age in the region of 1000-3000 cps, and one with severe bilateral deafness.

EXPERIMENTAL RESULTS

Audiograms of ten ears for durations of 0.5, 2, 5, 20, 100, and 850 millisec were constructed on the basis of a large number of measurements, analyzed statistically. The ages of the subjects were: R – 50 yr, S – 47 yr, K – 49 yr,

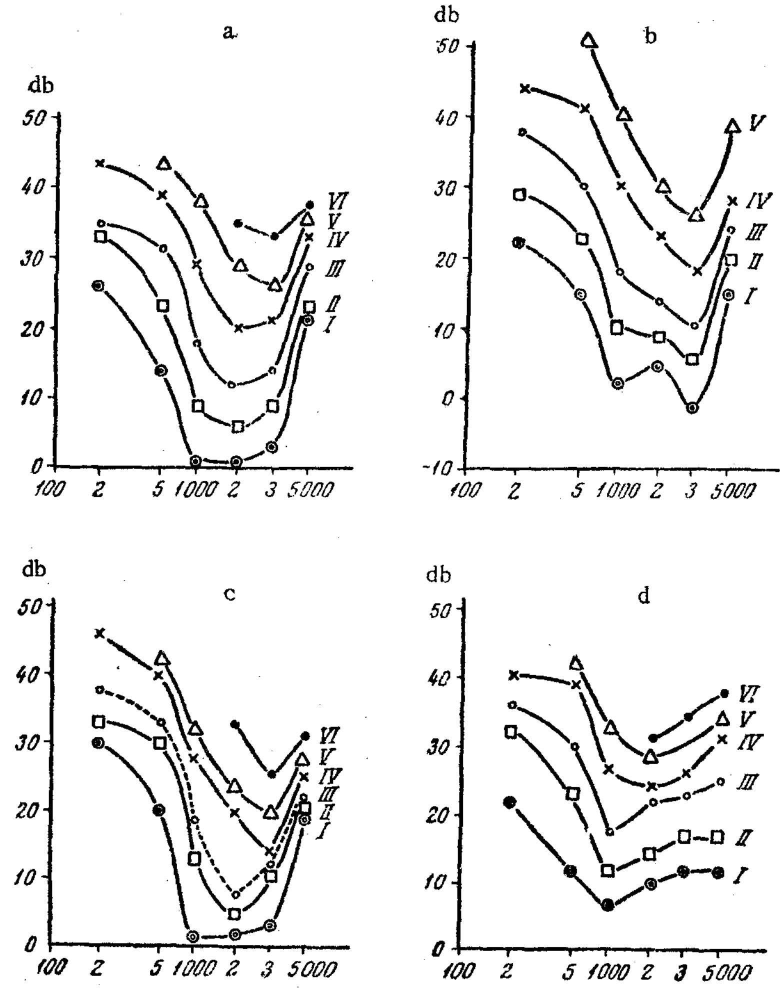

Fig. 1. Relationship between the audiogram and the duration of the tone used for measuring the threshold in the case of normal hearing. Along the abscissa – frequency (in cps); along the ordinate – level of acoustic pressure (in decibels) relatively to 0.0002 bar. Audiograms: I) for a tone of duration 850 millisec; II) for 100 millisec; III) for 20 millisec; IV) for 5 millisec; V) for 2 millisec; VI) for 0.5 millisec; a and b) audiograms of subject P for the right and left ears; b) the same for subject K, for the left ear; d) the same for subject L for the right ear.

P – 23 yr, and L – 22 yr. The minimal duration used for each particular frequency was 1 period (5 millisec for 200 cps, 2 millisec for 500 cps, 0.5 millisec for 2000 cps). The resulting audiograms are shown in Fig. 1 (for 4 healthy ears) and Fig. 2 (for 6 ears with a hearing defect of varying severity). It will be clear from Fig. 1 that the audiograms measured with a tone shorter than 20 (Fig. 1, a), 100 (Fig. 1, b), and even 850 millisec (Fig. 1, c) differed markedly in their form from the typical audiogram measured by a longer tone (Fig. 1, a, III; b, II, and c, I). This difference mainly concerned the zone of the minimum. For t = 5 millisec, there was a difference everywhere: the point for 1000 cps lay on the left, ascending portion of the audiogram, while the points for 2000 and 3000 cps formed the fairly pointed zone of the minimum. For t = 20 millisec, at which the tonal character of the sounds of 500 and 1000 cps could undoubtedly be perceived by the ear, the audiogram began to assume a form increasingly like that associated with more prolonged sounding of the tones. As the duration of the tone for measuring the threshold increased, the point corre-

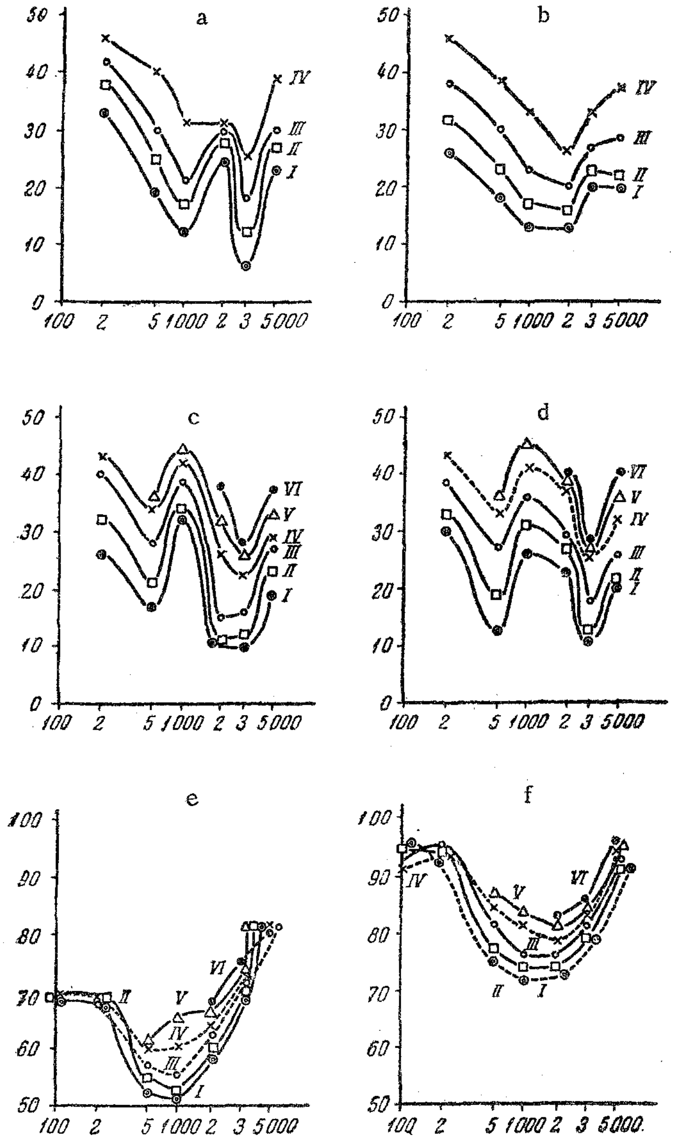

Fig. 2. The same relationship as in Fig. 1 in the case of a hearing defect due to age (1-d) and to severe inner ear disease (e, f). Legend as in Fig. 1. a, b) audiograms of subject R for the right and left ears; c, d) the same for subject S ; e, f) the same for subject M.

sponding to 1000 cps moved from the left, ascending portion of the curve to the right, into the center of the region of the minimum (Figs. 1 and 2, b). It will be seen in Fig. 1 that (corresponding to the findings of Garner [8]), the strength–duration curve was steepest for 1000 cps: the range of the change in threshold from 2-5 to 850 millisec extended in four subjects with normal hearing from 1-7 to 36-40 db (relatively to 0.0002 bar), and for 200 cps–from 21-30 to 40-47 db. It must be pointed out that in all four audiograms,(for healthy ears) the threshold for nearly all frequencies decreased considerably when the duration was changed from 100 millisec to 850 millisec. In all six audiograms of persons with disturbances of hearing (see Fig. 2) the curves for 100 and 850 millisec were closer to each other.

Hence the characteristic pattern was found to be typical to some extent of the normal audiogram when the tones used for measuring the threshold were very short in duration (2 and 5 millisec). The principal change in the audiogram as the testing sound was lengthened was a conversion from a V-shaped curve with a pointed minimum to a curve with a wide region of minimal values of the threshold in the 800-3000 cps zone. This conversion was due to a sharp increase in sensitivity when the tone was prolonged in the 1000 cps region, causing a widening of the zone of minimal threshold to the left, towards the low frequencies. With loss of hearing due to age, the form of the audiogram was modified as a result of partial hearing defects at certain frequencies, and its outline became irregular. In the cases which we investigated, a characteristic deformation of the audiogram was seen with the tones of shortest duration (see Fig. 2, a, c, d).

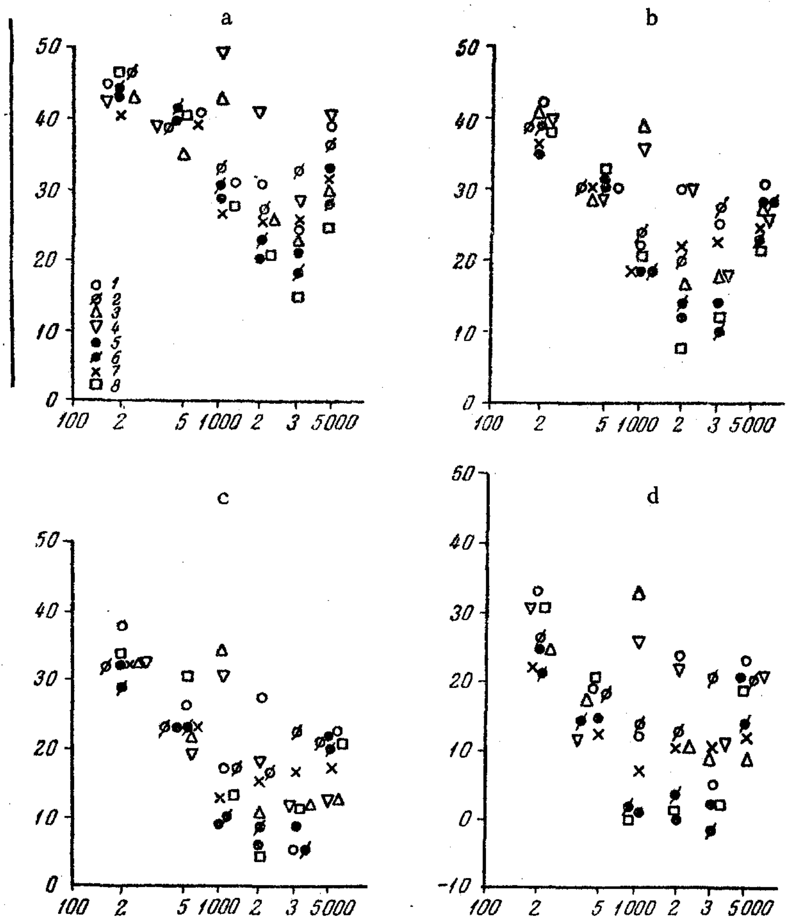

Fig. 3. Scatter of threshold values for a tone duration of 5 millisec (a), 20 millisec (b), 100 millisec (c), and 850 millisec (d). Along the abscissa and ordinate—as in Fig. 1. 1) Subject R, right ear; 2) the same, left ear; 3) subject S, right ear; 4) the same, left ear; 5) subject P, right ear; 6) the same, left ear; 7) subject L, right ear; 8) subject K, left ear.

In Fig. 3 we show diagrammatically the scatter of the auditory thresholds for different frequencies for three persons with normal hearing and for two with a hearing defect due to age. In subject S, hearing on the right was diminished for 1000 cps, and on the left for 1000 and 2000 cps, while in R, hearing was diminished on the right for 2000 cps. When the testing tone was of short duration (Fig. 3, a, b) the thresholds of subjects S and R for 1000 and 2000 cps were slightly closer to those in persons with normal hearing than at durations of 1000 and 850 millisec; the scatter of the results for 5 subjects (8 ears) for 1000 cps at t = 5 millisec was 27-49 db, and at t = 850 millisec

1-35 db; for 2000 cps at t = 5 millisec it was 20-41 db, and at 850 millisec 0-25 db. The increased threshold with an age defect of hearing in two subjects was associated with a marked flattening of the strength– duration curves at the corresponding frequencies, in agreement with the results obtained by Miscolczy-Fodor [14, 15].

In Fig. 2, e, f, we show the audiograms of subject M, who had a severe hearing defect of traumatic origin. At first glance these audiograms were quite regular in form but displaced considerably upward. The perception of extreme frequencies–100, 200 and 5000 cps–was particularly severely disturbed: the threshold for the right ear for 100 and 5000 cps remained unchanged when t was increased from 5 to 850 millisec, i.e., the strength–duration curve was converted into a straight line parallel to the abscissa. The patient could not stand loud sounds (recruitment and flattening of the strength–duration curves, as Miscolczy-Fodor pointed out, are two aspects of the same process). In fact, the curve for 200 cps with normal hearing, according to Garner's and our own findings, is flattened by comparison with that for 1000-3000 cps: the loudness for 200 cps, correspondingly, is known to rise more rapidly than for the other frequencies. The conclusion that a "natural recruitment of loudness" may take place as a frequency of 200 cps was reached some time ago by many workers. In the subject M the strength–duration curves for the middle frequencies were significantly flattened, but integration of energy took place at frequencies from 500 to 3000 cps, whereas at 200 and 5000 cps integration of energy was completely absent, i.e., the increase in duration did not compensate for the decreased intensity of the threshold stimulus.

It was noteworthy that the degree of the lowering of the threshold when a change was made from a duration of 100 millisec to one of 850 millisec in persons with normal hearing differed with the frequency: as a rule it was greater for 500 and 1000 cps than for 2000, 3000, and 5000 cps (for 200 cps the results were inconsistent). In both persons with loss of hearing due to age, the lowering of the threshold during the change from 100 to 850 millisec was less marked than in persons with normal hearing, and this was true, moreover, not only for those frequencies at which the hearing was impaired. In view of the small number of investigations we cannot justifiably reach any final conclusions, but if this in fact took place it casts doubt on the explanation of the lowering of the threshold for sensory stimuli of long duration given by Crozie [5], and Green, Birdsall and Tanner [10]. In their opinion, the true useful duration of a sensory stimulus is 100-200 millisec; the accumulation of threshold energy in the nervous apparatuses reaches the limit during this period of time. A further increase in the duration of the stimulus leads to a lowering of the threshold on account of an increase in the number of responses made by the nervous system as a whole: during 1 sec from 5 to 10 responses will be made, from which the more favorable mean resultant will be deduced (since the sensitivity is changing all the time). If, however, the lowering of the threshold at longer durations is the result of the activity of the centers, it is surprising that the laws governing this operation are dependent on a defect of the receptors due to age or some other cause, and on their character. Admittedly, the following answer may be given: in the case of a hearing defect the increased time thresholds vary less than if hearing is normal, so that the mean resultant (the conclusion about the threshold) must be less dependent on the excessive duration of the stimulus. So far as the dependence on the frequency of stimulation is concerned, this may be explained by the fact that height, as the characteristic of a high-frequency signal, becomes detectable to the listener with shorter durations than the height of a low-frequency signal. It is evident that the useful duration of high-frequency tones (from 3000 to 5000 cps) is shorter than that of tones of lower frequency. In other words, it is possible that the three zones of Green, Birdsall, and Tanner, are different for different frequencies: for higher frequencies, the "useful duration" of the stimulus is shorter. This hypothesis, of course, is purely provisional in character.

In this paper we have tried to engage the interest of researchers studying hearing in laboratory or clinical conditions in the possibility of measuring the fundamental classical characteristic of hearing–the audiogram–with tones varying in the parameter of time. It is to be hoped that further researchers along these lines will lead to tangible results, especially in clinical otology, where the audiogram is a customary diagnostic procedure.

SUMMARY

In addition to the data on intensity-duration curves of the threshold tones, the threshold audiograms are constructed for the different durations of the threshold measuring tone. The durations 0.5; 2; 5; 20; 100 and 850 msec and frequencies 200, 500, 1000, 2000, 3000, and 5000 cps were used. Even when the duration of the testing tone is so short, that this tone becomes a noise, the pattern of an audiogram in cases of normal hearing has some resemblance to the typical audiogram. But the great remoteness of the point for 1000 cps from the minimum zone draws attention. As the duration of the testing becomes longer, the audiogram of a person with normal hearing is gradually transformed from a V-shaped curve with a sharp minimum into a typical curve with an elongated minimum zone, and the point for 1000 cps shifts from the left ascending branch of the audiogram to the center of the minimum zone.

Several audiograms are obtained for 2 patients with a partial hearing loss, resulting from growing age, and 1 patient with a severe hearing loss of traumatic origin. Peculiar changes in these audiogram could be clearly seen at the least durations of the testing tone used. The diminishing of absolute threshold, when the tone duration is prolonged from 100 to 850 msec, is less for the listeners with impaired hearing.

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