NOTES ON THE MEASUREMENT OF AUDITORY THRESHOLD

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Introduction

The auditory threshold is often measured both for practical and experimental use, and measuring it is one of the most generalized procedures of research in acoustics. Though it is much generalized, the methods of measurement have no accordance. Then those who concerned are confused in deciding which method is to be used, for the data deviate with the variety of method, and there is no theoretical foundation to relate these different data. It seems important to decide how the auditory threshold is to be defined and what method should be adopted to measure it, but the authors restrict their consideration out of this problem and concentrate on the more practical phases.

Practically, it is desirable that the measuring method is very simple in its operation, that the time consumed is small and that the values measured are stable and highly accurate. In such measurement as that of the auditory threshold, in which the persons play the parts of instruments and cause the deviation of data because of their psychic or physiological factors, those requisites for the methods are considerably of importance. It seems, therefore, virtually indispensable to determine how to operate the experiments minimizing fluctuation, suppressing the redundant factors. Then, our chief purpose for this work is to modify the conventional method along these requirements.

Experiments

As the authors intend to study nothing but the measuring method, pure-tonal sound no less than 1000 c.p.s. is used as a signal. The schematic diagram of the circuits used is shown in Fig. 1. A tone generated from the beat oscillater is filtrated with low pass filter to eliminate the higher harmonics and sent into the next amplifier. Where the grid bias voltage of electronic tube is changed by means of the rotary switch, and pure tone is made arbitrarily intermittent or continuous. The first attenuater is fixed and determines the base level of signals and the second attenuater is variable and is

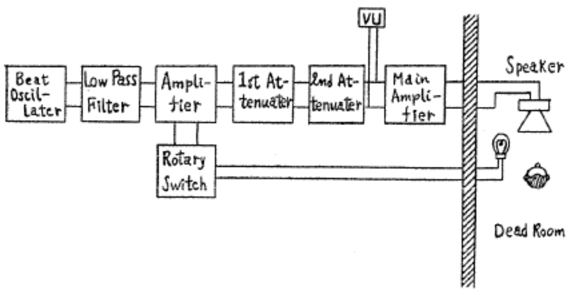

FIG. 1. Schematic diagram

controlled by the observers or the experimenters to determine the threshold. Through the main amplifier, the signals controlled in level are reproduced from the loud speaker in the dead room, where the observers face the speaker one meter distant. To the pulsatory (or intermittent) signals, the signal lamp is synchronized by means of rotary switch.

I. Continuous or Pulsatory

First we compare two methods of presenting signals, one is continuous and the other is intermittent. Two young male observers, F and I (who are twenty six and twenty five years of age) are engaged. The second attenuater is controlled by the observers. The results are tabulated in Table 1, where the values in the threshold column are the sum of decibels of first and second attenuater, so the mean thresholds are relative values. (In all the experiments hereafter, the

TABLE 1. Values of Threshold and Deviation in db

	Continuous case		Pulsatory case	
Threshold	123	122	120	124
Deviation	4.5	2.7	1.8	1.2
Observer	F	I	F	I

relative values are used.) The duration of a pulsation is 2.5 seconds and the interval between the pulsations is also 2.5 seconds. These results show that the pulsation of the signal is much conducive to decrease the deviation of data. According to the introspective reports from the observers, the continuous signal exhausts them much to be apprehended at low level, and, taking them long, it becomes even painful for them to observe. From these points of view the authors conclude that the intermittent (or pulsatory) signal is more desirable.

II. Operator Control System

In the experiments as described above, the observers control the attenuater. Though this *subject control system*, when the signal is intermittent, is rather effective for its simplicity, it still is not enough in its accuracy or sensitivity by reason of the observers' controlling the attenuater. There may be a scope for the redundant psychological factors. To avoid this, the attenuater must be *controlled* by the experimenter.

(*a*) *Limiting Method*

In this case, the 2nd attenuater is controlled by the experimenter only in the unidirection, from the audible level to the unaudible level and *vice versa*. The level of signal is changed every one decibel, and one level step is for one pulse. To every pulse tone, two same observers listen and record on the score sheets one by one as often as they judge it audible. Five series for each of two directions, from upward to downward and *vice versa*, are given in one sitting. Then each observes the one level-step tone ten times in one sitting. Four sittings are assinged to every observer. One of these results is shown in Fig. 2, where the abscissa denotes the attenuation-level and the ordinate shows the percentage of

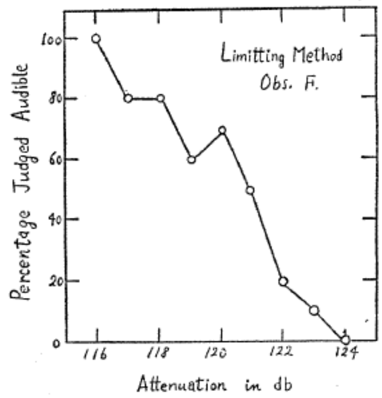

FIG. 2. The curve shows the transition from audible to unaudible state.

cases judged audible. The curve in figures shows the transition from the audible state to the unaudible state. These two states at either end of the transition, where the percentages of cases audible would be 100 and 0 respectively, seem to be stable, and we assume that the threshold is at the mid-point between these two stable states where the percentage of cases audible is equal to 50. In conformity to this assumption, we first calculate, by inverse interpolation, the values of threshold in every sitting, which correspond to 50% audibility, and average these values. Next we consider the *level distance* between two stable states. To denote this distance, the authors temporarily define the following quantity. Denote with p_i the percentage of the audible tone, the level of which is L_i db. In case $p_i > 50$, they replot the ordinate of corresponding level with $q_i = 100 - p_i$, and calculate the next formula.

$$S^2 = \frac{\sum_{p_i \leqq 50} p_i(L_i - L)^2 + \sum_{k \neq i} q_k(L_k - L)^2}{\sum_{p_i \leqq 50} p_i + \sum_{k \neq i} q_k}$$

where

$$L = \frac{\sum_{p_i \leqq 50} p_i L_i + \sum_{k \neq i} q_k L_k}{\sum_{p_i \leqq 50} p_i + \sum_{k \neq i} q_k}$$

Quantity S is to denote the distance. Mean threshold and distance are calculated of each observer and tabulated in Table 2.

TABLE 2. Values of Threshold and Distance in db

	Threshold	Distance	Threshold	Distance
(a) Limting-method	129	3.2	119	3.2
(b) At-random method	124	4.4	118	4.3
(c) Final method	122	1.9	118	2.1
Observer	F		I	

For the assumption above it is necessary that the percentages of two audible stable states should be exactly or approximately equal to 100 and 0 respectively. But this is not always attained by this method as shown in Fig. 3. And the systematic changes of level may cause the systematic error such as expectation error. These points have to be improved.

(*b*) *At-Random Method*

To avoid the systematic error, the attenuation-level should be arranged *at random* in time. From this point of view, another experiment is carried out of

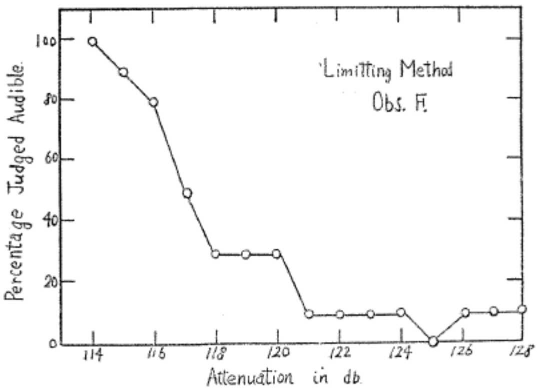

FIG. 3. The curve shows the fluctuation of judgment at unaudible state.

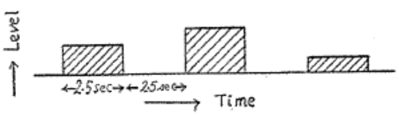

FIG. 4. Signal arrangement in time. The order of signal level in time is at random.

the same observers.

Here seven attenuation-levels, which include infinite attenuation and is marked every two decibels, are used. These attenuation-level tones are presented at random in time as shown in Fig. 4. Every attenuation-level tone is presented ten times in one sitting. Each observer takes charge of four sitting repeatedly. The adjustment of data is same as before. The results are tabulated in Table 2.

Comparing the results of (a) with those of (b), we find that (a) method seems superior to (b) method in the threshold and distance values. But this is not true. It is conceived that the systematic operation of method (a) gives the rise of the lower threshold and the reduction of deviations. This is considered as the systematic error rather than the higher accuracy or the finer sensitivity. Besides, from the statistical view point, the at-random method is considered as the most principal one and the limiting method is more complex. The time consumed is much the same, about fifteen minutes a sitting, and the curves of transition are not steady in either case.

(*c*) *Level Range*

To check on the effect of level range of signal the more detailed experiment is designed and carried out. In the above two cases, the signal levels (or attenuation-levels) cover the constant range (range width is 10 db). In this case, three different ranges, the width of which are same (10 db) but are different in their positions on the attenuation scale by three decibel from each other, are used of two same observers. Experimental procedure is just the same as the at-random case unless ten sitting of each range for Obs. F and eight sittings of each range for Obs. I. The results of Obs. F is in Fig. 5, where three different curves correspond respectively to the three different level ranges.

Inspecting these figures, it is first noticed that there are distinct differences in the form of curves from range to range. Only the heavy line curve, which identifies those of high level range, seems to be a normal transition curve, though it does not fall on 0% line in the unaudible state. Others are not appropriate to determine the threshold. Though it is too early to induce any conclusion out of this, yet it may be said, taking into account the introspective reports by the observers, that the excessively high or low level ranges disturb the observers' con-

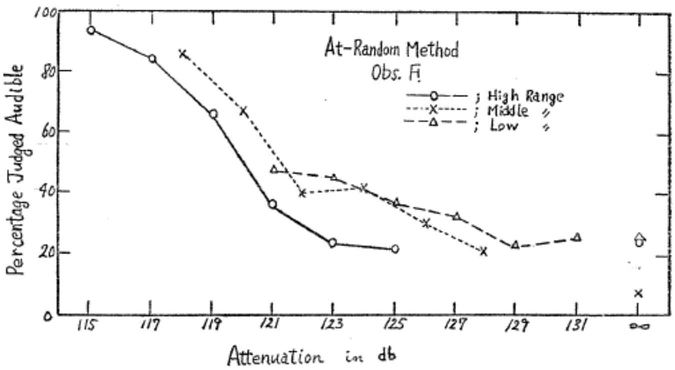

FIG. 5. The form of transition curve depends at the positions of the level range on the attenuation scale.

ditions and results in the deteriorated form of the curves.

(*d*) *Final Method*

To determine the threshold, the normal transition curve is needed. From the experiments described above, it is seen that the at-random method properly designed is able to be suitable to considerable degree for this end. But not less fluctuation of the form of the curves from sitting to sitting is unavoidable. This requires necessarily a number of sittings to obtain the reliable results. To avoid these fluctuations in the at-random method, the final method as follows is designed. From the preliminary experiments, 100% audible but not too audible attenuation-level is selected for each observer and is determined as the base of level range. The rest of operation are just the same as before unless each signal is always accompanied by two referential signals, one is 100% audible and the other is infinitely attenuated. The former is to ascertain the audible criteria, the latter is for the unaudible criteria. Because the signal lamp synchronizes with every signal tone, the observers can receive the infinitely attenuated signals. The order of presenting signals is as shown in Fig. 6, where A is perfectly audible, B is unaudible (infinitely attenuated) and X is to be judged. And observers are instructed to judge whether the X tone is audible or not refering to both A and B. This method takes about 25 minutes a sitting. The results of four sittings for Obs. I is shown in Fig. 7. Inspite of the smallness of sampling, the curve has the considerably fine form, and this accounts for small fluctuations. The highest level tones are judged to be 100% audible and the infinitely attenuated tones to be exactly 0% audible, and this accounts for the fact that the observers keep the judging criteria definitely and are in the steady conditions. The values of threshold and distance are calculated and tabulated in Table 2. Comparing with the at-random method, there is little difference in the

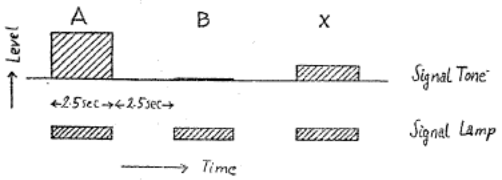

FIG. 6. Order of presentation of signals.

A is perfectly audible, B is unaudible and X is to be left to personal discernability.

threshold values while the distance values are markedly improved for either observer, though the unequality of the number of samples does not allow to propose any decisive conclusion.

The steadiness of the data allows the smallness of the case sampling. Then, though this method takes us longer time than that for conventional methods, and since the time consumed can be cut short by the automatic operation, it may be concluded that this method is considerably satisfactory for the measurement of the auditory threshold.

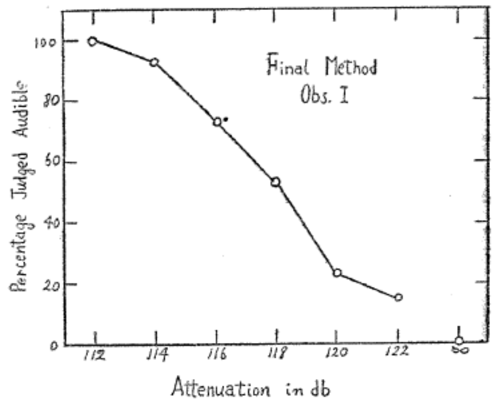

FIG. 7. The smoothness of curve means the adequacy of the final method.

Recapitulation

The pulsatory signal is desirable for the measurement of the auditory threshold. Though the *subject control system* is convenient for the simplicity of procedure and is indispensable for the practical use such as clinic, the *operator control system* must take place of it to avoid the inevitable error and to obtain the finer sensitivity. In the operator control system the signal levels have to be arranged at random in time. Conceiving the threshold, when the at-random method is used, as the mid-point of the transition from the audible to the unaudible state, and these two terminal states are stable, the percentages of audible phases in either state should be exactly or approximately 100% and 0% respectively, and the transition curve with little fluctuation must be obtained. To obtain such curve experimentaly, the adequate level ranges are determined for each observer and every signal is accompanied by two referential signals to fix the observers'. judging criteria. These operational devices produce good results.