The threshold of audition for short periods of stimulation

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It is shown that, in common with that for other sensory stimuli, the threshold of audition rises as the time of presentation of the stimulus is decreased. Investigation of the law relating change of threshold to period of stimulation suggests that it has a form similar to that found in the case of other sensory mechanisms.

Introduction

The threshold value of a sensory stimulus depends upon the period of time for which the stimulus is presented, only approaching a steady minimum value if that period is sufficiently great. This fact, and the complementary dependence of the intensity of a sensation upon the time during which the stimulus is applied, has long been known. In the case of vision, the classic experiments of Broca & Sulzer (1902) showed that the brightness of a small source of light increases considerably with the time of its exposure when that period is very short, reaches a maximum as the time of exposure is further increased, and thereafter falls off asymptotically towards a steady value for long-continued stimulation. This course of events runs parallel to the variations in the frequency of the pulses of action current in sensory nerve fibres; Adrian & Matthews (1927) have noted the similarity for the conger eye. The frequency of discharge plotted against the time after the beginning of steady stimulation shows the same rapid rise to a maximum and the same asymptotic fall to constancy. A similar phenomenon appears in the data given by Hallowell Davis (1935) for the auditory action currents of the cochlear nerve.

The rise of threshold as the time of stimulation is reduced is readily observed in the case of hearing. If an intermittent note is presented to the ear for, say, \( \frac{1}{2} \) sec., and decreased in intensity until it is just inaudible, it will be clearly heard when it is made continuous. The change is of the order of 3 or 4 db. The present paper describes measurements made to show the existence of the phenomenon, and gives an account of attempts to find the law governing this change of threshold with period of stimulation for pure tones of various frequencies.

Apparatus

The pure tones were produced by a heterodyne oscillator followed by an amplifier of maximum output about 500 mW incorporating two independent controls of intensity. The sound was presented by a telephone earpiece forming part of the output network of the amplifier and connected to it for the required time by the switch described below. The output circuit is shown in figure 1.

The observer sat in a 'sound-proof' chamber, with a sponge-rubber pad between his ear and the earpiece to ensure complete comfort in protracted periods of
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listening; a small aperture in the pad allowed sound to reach the ear. A switch enabled him to cut off the sound when necessary. A microphone enabled him to communicate with an assistant outside who controlled the apparatus and who could also signal back to the observer when he was about to begin a set of stimuli.

![Amplifier output circuit diagram](image)

**Figure 1.** Amplifier output circuit.

The switch for presenting the note for a definite period consisted of two disks of insulating material, 3 in. in diameter; to each of these were bolted semicircular pieces of sheet metal to which had been soldered metal strips, 0·5 in. wide, to form a semicircular flange 4 in. in diameter. The metal was cut away at the centre of the disks, and bush wheels were bolted to the latter so that they could be mounted on a common axle. The flanges were balanced by lead weights bolted to the disks. Each flange was faced with thin copper foil, and two strips of flexible spring about 3 in. long were fixed by terminal screws to an insulating base to act as brushes, each making contact with the copper foil of one flange during half the period of rotation of the corresponding disk. The flanges were electrically connected, so that the time for which a conducting path existed between the terminals could be varied by adjusting the relative angular positions of the disks on their common axle. The maximum time was thus about half the period of rotation of the disks. These were driven (through reduction gearing) by a synchronous motor operating from the 50 cyc./sec. a.c. mains, and revolved once in every 1·42 sec. Seven different time-settings were provided by fitting a peg in one disk into one of seven holes in the other; changes of duration of the note heard could thus be readily made and repeated. These seven durations were determined by a kymograph and a time-marker recording fiftieths of a second. The traces could thus be measured to 0·005 sec. with ease. Five groups of three consecutive switchings were timed for each position of the peg; all were mutually consistent. The seven durations used in the experiments were usually 0·063, 0·117, 0·177, 0·241, 0·427, 0·611 and 0·739 sec. In earlier experiments the surfaces of the flanges were lightly lubricated.
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with vaseline; later, amalgamation of the surfaces was found to give better results. The switch timings were remeasured after amalgamation. Either method gave freedom from stray clicks in the earpiece at make or break, but the latter perhaps maintained this for longer runs without attention.

Procedure

The determination of the settings of the intensity controls at the monaural threshold was carried out as in previous work (Hughes 1938). A series of such settings was made for any one frequency, starting with the shortest presentation of the note, and passing progressively to the longest, finally returning to the shortest as a control upon the set of determinations. If the initial and final measures for this shortest presentation differed by more than 2 db, the whole set was rejected. This criterion was adopted on the basis of an uncertainty of 0·5 db. found previously (Hughes 1938) for individual settings for a given time of stimulus. During the whole series of readings the observer remained undisturbed in the chamber and did not change the position of the telephone upon his ear, thus avoiding possible variations from this source. Determinations were made by two observers (J. W. H. and J. H. S.) at frequencies of 250, 500, 1000, 2000 and 4000 cyc./sec. At each of these frequencies ten series of readings were made by the former, and five by the latter. The mean of the two settings for the shortest duration was taken as the reference level, and the readings for the other (longer) durations were expressed as decibels below this level.

Results

The average value of threshold, in decibels below the reference level, was calculated for each duration of each note separately for each observer. These averages, when plotted against the duration of the note, were found to lie on a smooth curve. When the averages in decibels were converted to energy ratios, i.e. the ratios of the threshold intensity at any duration to that at the shortest duration, and these ratios were plotted against the reciprocals of the times of presentation, the curves became straight lines. This is shown in figures 2 a and b.

Thus, if the threshold intensity for any duration t sec. is I, and that for the shortest is $I_0$, it appears that the relation between these quantities is of the form

$$\frac{I}{I_0} = b + \frac{a}{t},$$

where $a$ and $b$ are constants for the given frequency.

If it be assumed that the law holds when the presentation of the note is continuous, i.e. when $t = \infty$, and that the threshold intensity is then $I_\infty$, then $b = I_\infty/I_0$, so that

$$I = I_\infty(1 + a/\beta t) = I_\infty(1 + \tau/t),$$

(1)

where $\tau$ is a constant of the dimensions of time.

Save that $I$ and $I_\infty$ are energies per sec. instead of current strengths, this is of the same form as the chronaxie equation of Lapicque (1926), and $\tau$ may be regarded
as a pseudo-chronaxie for the sensory mechanism concerned, i.e. the time required for stimulation by an intensity twice that of the basic threshold intensity for a continuous stimulation.

**Discussion**

In the case of the observations for each single frequency, all the data satisfy equation (1) within the limits of experimental error. It is more difficult to draw definite conclusions as to the variations of $a$, $b$ or $\tau$ with change of frequency. In the first place these different frequencies were necessarily studied at intervals of several hours, usually on different days, and the individual threshold is certainly subject to appreciable, though not very large, changes under such circumstances. Secondly, the linear form suggested may not hold for long periods of presentation; this point was not tested, as the experiments were completed before any plotting other than that of decibels had been attempted, and the linear relation had not yet been noticed. (The outbreak of war prevented further work.) Even more important is the fact that though the relative level in decibels during a series was definite, the absolute level with respect to a fixed physical standard was much less sure. Hence, though the slope of the straight lines is relatively accurate in all the graphs, the intercepts with the axes are less determinate. In other words, the constant $a$ of equation (1) can be found with fair precision, but the value of $b$, and therefore of $\tau$, is more uncertain.

These conclusions would appear to be borne out by the results. The readings made with J. W. H. as observer were carried out with the greatest care and with every precaution of leisurely determination. Those made with J. H. S. were of the nature of a general confirmation, were fewer in number (five sets at each frequency instead of ten) and were made much more rapidly. Now the slopes found for J. H. S. are nearly equal to those for J. W. H.'s results, but his intercepts are much more irregular; in fact, some suggest that the line passes near the origin or even intercepts the intensity axis at small negative values. But if attention is confined to the data found for J. W. H., it appears that the intercepts are more consistent, though there is a distinct rise in their value at the extremes of the frequency range investigated. Without further experimental evidence, however, it would be unwise to make any remarks as to the possible significance of this.

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**References**

Adrian, E. D. & Matthews, R. 1927 *J. Physiol.* 63, 378.