NEW DATA ON THE SPECTRUM OF SONIC AND ULTRASONIC FREQUENCIES EVOKING ACOUSTIC PERCEPTION IN MAN

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In previous investigations [2, 3, 5], the authors showed that the range of frequencies perceptible by the human ear may be very considerably extended at its upper limit. When bone conduction is present, the auditory perception of ultrasound may extend to 200, or even 222 kc.

The object of the present investigation was to measure the auditory sensitivity (the thresholds of stimulation) for sounds in the lower part of the spectrum of perceptible frequencies and for frequencies in the ultrasonic part of the spectrum, and then to draw up a complete audiometric curve of human auditory perception throughout its range.

EXPERIMENTAL METHOD

Auditory sensitivity to ultrasound in the presence of bone conduction was determined by means of a type G3-7A generator, giving a wide spectrum of frequencies, and a set of ceramic lead zirconate–titanate ultrasonic converters working at definite resonance frequencies. The ultrasonic converter was applied firmly to the subject's head in the mastoid region. The contact medium was mineral oil. One of the essential conditions for the accurate determination of the thresholds of ultrasonic stimulation is measurement of the intensity and the surface of the converter. Satisfaction of these conditions may be extremely difficult, for the infinitesimally low intensity of ultrasound capable of producing an acoustic sensation in man cannot be recorded by existing methods. For this reason, the authors developed a method of measuring minimal intensities of ultrasound [1, 5, 6]. The measurements and calculation of the intensity of ultrasound necessary for producing an acoustic sensation were made separately for each definite frequency used in the investigations. The absolute intensity values obtained (in W/cm^2) were subsequently converted into relative values, namely to decibels above the threshold of acoustic pressure for a tone of 1000 cps, taken as 0.000 204 bar. The threshold values of ultrasonic stimulation for the subjects were determined by changing from smaller intensities of ultrasound to larger.

Auditory sensitivity to sounds in the lower part of the spectrum of perceptible frequencies was studied by means of a generator and a low-frequency type N 445 oscillator (England) giving oscillations with a frequency of between 1 and 1000 cps. A high-ohmic electrodynamic earphone was used as the sound transducer. The perception of low tones was investigated in the conditions of air conduction, and for this purpose the earphone was placed in firm contact with the auricle. The thresholds of acoustic stimulation were expressed in units of potential at the output of the generator, and subsequently converted into decibels, as is done normally in audiometric investigations. Before determining the thresholds of acoustic stimulation, the lower limit of perceptible frequencies with maximal intensity of generated tones was determined in all the subjects. The auditory sensitivity was then determined for different tones in the lower part of the spectrum by gradually increasing the intensity from subthreshold to threshold.

EXPERIMENTAL RESULTS

The auditory sensitivity to ultrasound was investigated in 20 subjects aged from 20 to 40 years with normal hearing. The thresholds of ultrasonic stimulation were recorded for five fixed frequencies: 30, 47, 85, 130, and 225 kc. The auditory sensitivity to sounds in the lower part of the spectrum was also studied in 20 persons aged from 20 to 40 years. The thresholds of stimulation by tones in the lower part of the sonic spectrum were recorded for these subjects relative to seven fixed frequencies: 32, 20, 16, 14, 12, 10, and 8 cps.

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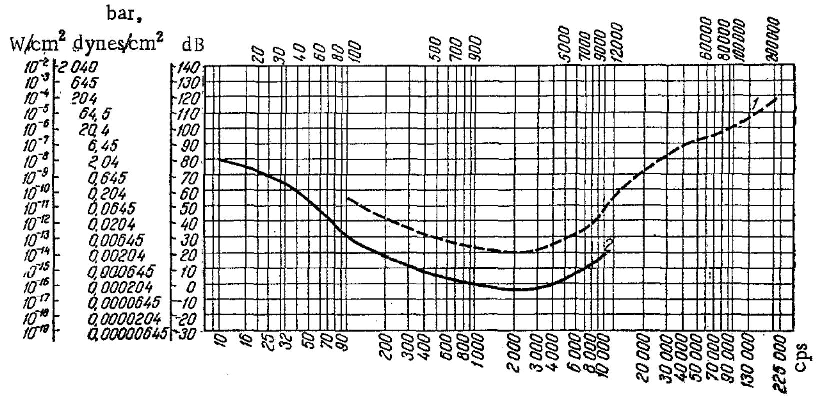

Fig. 1. Auditory sensitivity (thresholds of stimulation) in man to sounds of different frequency in normal conditions. 1) Curve of thresholds of stimulation for bone conduction of sounds; 2) curve of thresholds of stimulation for air conduction of sounds.

It was found that the upper limit of perceptible frequencies with bone conduction was 225 kc for all the subjects.

So far as the lower limit of perceptible frequencies with air conduction is concerned, 4 of the 20 subjects perceived sound with a frequency of 8 cps, 8 with a frequency of 10 cps, and the other 8 with a frequency of 12 cps. It thus appeared that the mean lower limit of frequencies perceptible by the human ear is 10 cps. However, to give a final answer to this question, allowance must be made for the fact that the possibility of perception of even lower tones – infrasound – is determined by the degree of their amplification.

From the results obtained, the range of auditory sensitivity could be plotted in the form of the curves shown in the figure. The middle part of these curves, reflecting the thresholds of auditory stimulation for sounds ranging from 100 to 10,000 cps, with both air and bone conduction, was plotted from the mean data taken from the literature. The right and left portions of the curve, reflecting the auditory sensitivity to ultrasounds with bone conduction and to sounds of the lower part of the spectrum with air conduction, were plotted from the measurements described above.

It is clear from the information given in the figure that the shape of the threshold curve of auditory perception is marked by a considerable, yet uniform elevation in the region of ultrasonic frequencies from 30 to 225 kc. The magnitude of the thresholds of stimulation by ultrasounds of any frequency used in the investigations exceeded the thresholds of stimulation by sounds of the audible spectrum. In particular, for a frequency of 30 kc, the threshold was 0.15 ± 0.007 μW/cm^2, or 82 dB; for 47 kc the figure was 0.063 ± 0.03 μW/cm^2 or 88 dB; for 85 kc it was 0.41 ± 0.11 μW/cm^2 or 96 dB; for 130 kc it was 1.97 ± 0.52 μW per cm^2 or 103 dB; and for 225 kc it was 75.26 ± 31 μW/cm^2 or 119 dB, whereas the maximum of the thresholds for tones of 10 kc was 0.00005 μW/cm^2 or 55 dB for bone conduction and 10^{-9} μW/cm^2 or 30 dB for air conduction.

The thresholds for sounds with a frequency below 64 cps with air conduction increased in a similar way. For the lowest perceptible frequency (10 cps) the mean threshold was 0.01 μW/cm^2 or 80 dB, and for a frequency of 32 cps it was 0.0009 μW/cm^2 or 68 dB. Within the limits of these frequencies the thresholds of acoustic stimulation also increased relatively evenly.

Hence, in contrast to the ideas put forward in the physiological and audiological literature, the auditory sensitivity of the human ear can be depicted by a curve covering the range of frequencies from 8-11 cps to 220-225 kc, with a perfectly definite configuration, determined by the difference between the thresholds of stimulation.

These facts can only be compared with the results of investigations of auditory sensitivity to ultrasounds carried out in recent years [7, 9]. Only Deatherage and co-workers [9] have attempted to measure the thresholds in one subject in relation to a fixed ultrasonic frequency of 60 kc, and Corso [8] has made measurements on many subjects in relation to ultrasonic frequencies up to 95 kc.

Finally, it is important to recognize that the study of the auditory sensitivity of the human ear over the whole range of frequencies, the subject of the present communication, is not only of theoretical but also of practical importance, for it can improve the prospects of diagnosis of various forms of hearing disturbances in patients [3, 4].

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