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LOUDNESS OF INFRASOUND

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INTRODUCTION

For nearly 20 years researchers and environmental authorities have been worried about possible extra-auditory effects of infrasound, such as disturbance of equilibrium and influence on the circulatory system. Experimental findings are not very concordant, but in general the effects seem to have been exaggerated [1].
However, lack of direct physiological effects from infrasound does not mean that infrasound is insignificant from an environmental point of view. Infrasound can be detected by the human ear, and when it becomes sufficiently loud it can be annoying. Some investigations indicate that a possible "threshold of annoyance" would be only slightly above the hearing threshold [2, 3].
A number of experiments deal with the hearing threshold at infrasonic frequencies [2, 4, 5, 6], but the loudness function has previously been the subject of only one investigation [5]. The present study describes the determination of equal loudness curves for pure tones in the frequency range 2-63 Hz and the loudness range 20-100 phon. Preliminary results from a pilot study were presented at Internoise 81 [7], and the essential findings were confirmed in the main experiment.

METHOD

Subjects

20 students (16 male and 4 female) between 18 and 25 years participated as subjects. An audiometric test ensured normal hearing.

Experimental design

The references for loudness curves are pure tones at 1 kHz. However, it is very difficult to compare tones that are spaced as far in frequency as infrasound and 1 kHz, and in this investigation a supporting point was introduced at 63 Hz. Thus, for every subject values were measured at 63 Hz at the beginning of the experiment, and these values were used

as individual references throughout the rest of the experiment. Loudness curves at the 5 loudness levels 20, 40, 60, 80 and 100 phon were determined at the following 5 frequencies: 2, 4, 8, 16 and 31.5 Hz. The order in which the subjects received the 5 frequencies was counterbalanced in a latin square design, and so was the order in which the subjects received the 5 loudness levels within each frequency.

Psychometric method

A point on an equal loudness curve was determined in the following way: Successive pairs of reference and variable tones were presented to the subject. The tones had a duration of 2 seconds and they were separated by an interval of 1 second. After each pair of tones the subject indicated which one he perceived as loudest. The variable levels presented were dependent on previous answers from the subject. After a sufficient number of presentations the Method of Maximum Likelihood was applied to find the most probable underlying psychometric function, i.e. the probability of obtaining the answer "the variable was the loudest" as a function of variable level. The psychometric function was assumed to be an accumulated normal distribution of which the mean represents the point of equal loudness.

Apparatus

The comparisons between 1 kHz and 63 Hz were carried out in an anechoic chamber where the sound was produced by conventional loudspeakers driven by two 120 W power amplifiers. The subject was seated in a chair 1.1 m from the loudspeakers. The comparisons between 63 Hz and infrasound were done in a 5 cubic metre test chamber where 16 electrodynamic loudspeakers produced the sound. At the frequencies 2-16 Hz the maximum obtainable sound pressure level was 133 dB, and 125 dB could be reached at 31.5 Hz.

The systems were calibrated by measuring the sound pressure at the position of the subjects head, but without a subject present.

The presentation of the tones was controlled from an HP 21MX computer by means of two attenuators (0 to -120 dB with 1 dB resolution) and two switches that gradually turned the signal on and off within periods of 500 milliseconds. The computer also recorded the answers and made the calculations.

RESULTS

Points of equal loudness are given in Table 1. At the highest loudness levels some subjects had points of equal loudness above the dynamic range of the test chamber. Thus, these values could not be determined, and in case of missing values results are estimated according to the procedure for a censored normal distribution [8]. Any point where more than 50% are missing is omitted.

The results are shown graphically in Figure 1. The loudness curves run almost parallel in the infrasound region, but much closer than in the audio region. For example, the distance between the 20 and the 80 phon curves has decreased from 60 dB at 1 kHz to approximately 16 dB at 8 Hz.

Table 1. Points of equal loudness in the frequency range 2-63 Hz

Loudness level phon	Frequency Hz	Mean value dB	Standard deviation dB	Number of subjects	S.e. of mean dB
20	63	58.0	6.6	20	1.5
20	31.5	75.1	6.5	20	1.5
20	16	95.1	5.8	20	1.3
20	8	109.4	5.9	20	1.3
20	4	120.7	5.2	20	1.2
20	2	127.6	3.5	20	0.8
40	63	71.7	6.1	20	1.4
40	31.5	83.4	7.3	20	1.6
40	16	101.3	8.4	20	1.9
40	8	114.3	6.4	20	1.4
40	4	124.8	5.7	19	1.3
40	2	129.7	4.1	16	0.9
60	63	82.8	4.8	20	1.1
60	31.5	90.9	7.4	20	1.7
60	16	106.9	7.8	20	1.7
60	8	118.1	6.6	20	1.5
60	4	127.4	5.5	18	1.3
60	2	132.6	5.0	11	1.3
80	63	95.6	4.3	20	1.0
80	31.5	102.5	9.0	20	2.0
80	16	116.5	8.6	19	1.9
80	8	125.6	8.6	18	2.0
80	4	132.6	6.3	10	1.7
100	63	112.3	3.7	20	0.8
100	31.5	119.5	7.3	16	1.7
100	16	128.4	7.8	15	1.8

Consequently, infrasound only a few dB above the hearing threshold will seem loud and possibly annoying. It is also possible to explain the fact that a small change in the infrasound content of a complex sound may change the loudness of the sound considerably.
Collins et al. [5] have given curves of equal loudness in the frequency range 3.15 Hz to 50 Hz. The slope of these curves is very close to that of the present study, but in [5] no individual comparisons were made with 1 kHz, and the frequencies used were not the standardized octave frequencies, so a direct point to point comparison is not possible.

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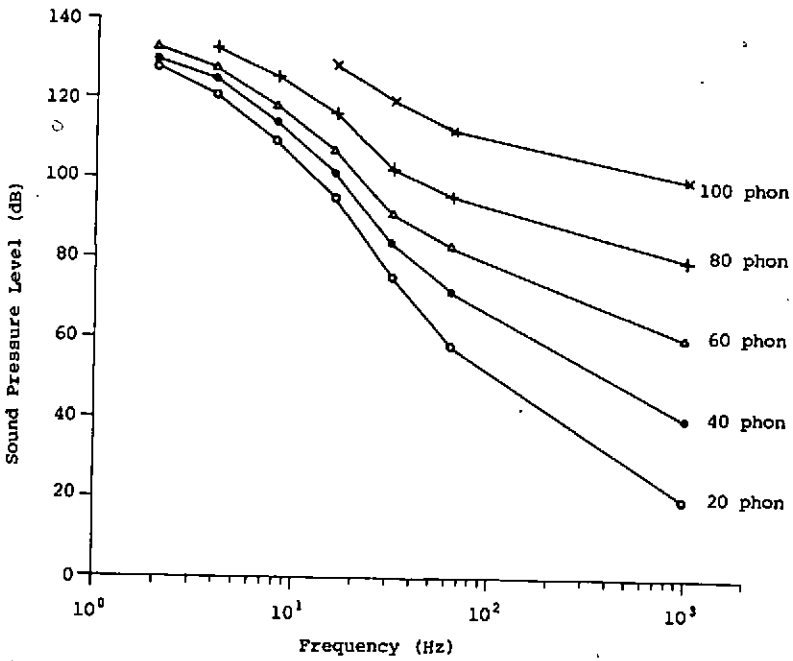

Figure 1. Curves of equal loudness. Means of 20 subjects.