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DIRECTIONAL DEPENDENCE OF LOUDNESS AND BINAURAL SUMMATION

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SUMMARY

Present noise measurements are based on a single microphone with equal weighting of sound from all directions. This technique does not take into account directional dependence in the complex human binaural sound perception. The importance of this problem is not known, since the variation of loudness with direction to the sound source has not been thoroughly examined. Calculations based on knowledge about sound transmission to the ears and the assumption that the brain summarizes the binaural signals on a simple power basis, indicate that more than 10 dB deviation in sensitivity relative to the front direction could be expected. In the present ongoing investigation binaural threshold and loudness data for the frequency range 500-12500 Hz will be determined for 6 directions to the sound source. Both monaural and binaural thresholds and loudness will be determined for 12 test subjects enabling examination of the binaural summation. Altogether, these data will enable an evaluation of the deficiency of the present noise measurement technique, when spatial aspects are considered, including an assessment of the necessity of introducing artificial heads for future measuring standards.

INTRODUCTION

Standards for measuring noise for estimation of its annoyance or loudness prescribe use of a single microphone with equal weighting of sound from all directions. This technique does not take into account that humans perceive sound with two ears, each performing a complex weighting of the sound depending on direction to the sound source. However, the significance of this is not known precisely, since the variation of loudness with direction to the sound source is only very briefly described in the literature [1], [2]. As a result of this, the present standard concerning equal loudness contours, ISO 226 [3], only contains data for frontal and random sound incidence. In the audiometric standard, ISO 8253-2 [4], reference hearing thresholds for 45° and 90° azimuth are given only in terms of corrections derived from the physical transmission to the closest ear. Thus, the binaural summation is not described, and the true binaural thresholds are not known.

It is the aim of the present investigation to obtain data for the directional dependence of hearing thresholds and perception of loudness.

ESTIMATION OF DIRECTIONAL DEPENDENCE OF LOUDNESS

An estimate of the directional dependence can be calculated assuming that the hearing summarizes the signals at the ears on a simple power basis - corresponding to summation of uncorrelated signals. The calculation requires knowledge on the physical sound transmission to the ears from various directions of sound incidence, that is the Head-Related Transfer Functions (HRTFs). HRTFs were previously measured on 40 subjects at our laboratory [5].

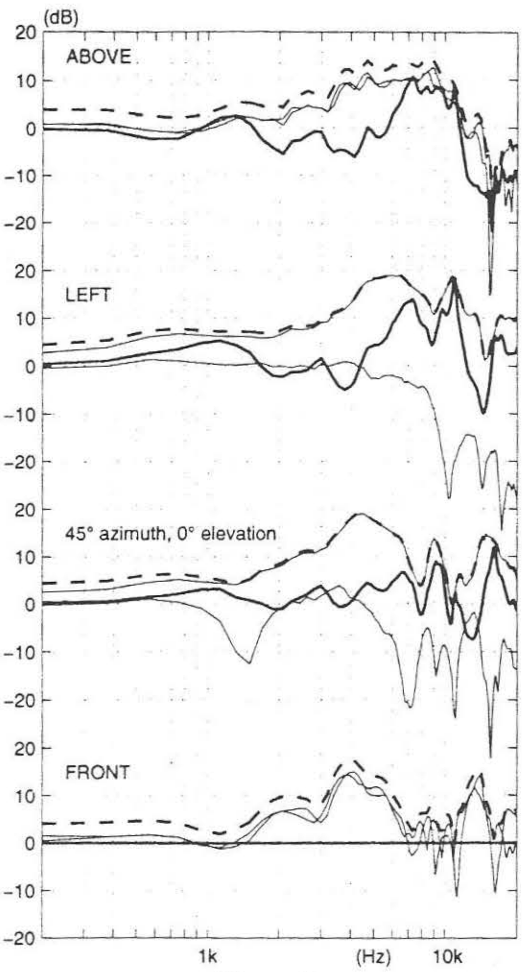

Figure 1

The thin curves show HRTFs for both ears of a single subject. The dashed curve is the binaural sum calculated on a simple power basis. The bold curve shows this power sum relative to that for the front direction. For each set of curves the direction of sound incidence is indicated.

Figure 1 shows the HRTFs for both ears of a single subject with sound from various directions (thin lines). As it is seen, there is a considerable directional dependence of HRTFs for each ear, with up to 40-50 dB difference between ears at high frequencies. The directional dependence of the calculated binaural power sums (dashed lines), is much less. For the directions in front and above the HRTFs are nearly identical at the two ears, and it is obvious that the power sum corresponds to the assumption that we are 3 dB more sensitive when listening binaurally as compared to monaural listening. For the left direction the difference between the ears is large, especially at high frequencies. In this case the power sum is dominated by the ear with the highest level corresponding to the assumption that the sensitivity equals the sensitivity of the ear nearest the sound source.

Also shown in Figure 1 is the binaural power sum relative to that for the front direction (bold lines). From this it is seen that for the frequency range 6-10 kHz we could expect a sensitivity around 10 dB higher with sound coming from left and above than from front. On the other hand at 2-5 kHz and above 12 kHz the front direction is the most sensitive of the directions presented.

Data for 40 subjects have been inspected and the characteristics described are valid in general.

PSYCHOACOUSTIC EXPERIMENTS

It is interesting that, with the assumptions described in the previous section, there may be directions of sound incidence, where we are 10 dB more sensitive than for frontal incidence - at certain frequencies even more. This means that the annoyance of noise from these directions may be underestimated using descriptions of hearing sensitivity based on frontal sound incidence. This is an obvious reason for collecting psychoacoustic data in order to test, whether the assumptions about the binaural summation are valid.

In the ongoing investigation binaural thresholds and 60 phon loudness data will be determined for 12 test subjects and for 6 directions. In order to test the described assumptions about binaural summation the HRTFs as well as monaural thresholds and loudness will be determined. To eliminate differences in sensitivity of the subjects' two ears, monaural data for both left and right ear are required. As seen in Figure 1 the interesting frequency range is above 1 kHz. Therefore, 9 pure tones in the range 500 to 12500 Hz are included in the study.

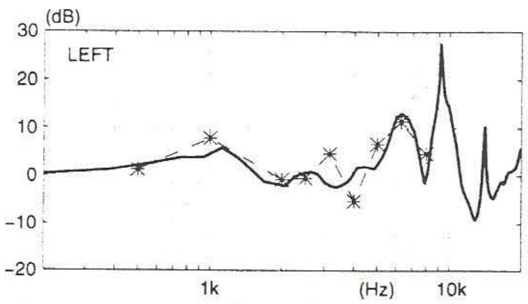

Figure 2

Preliminary threshold data for a single subject with sound from the left side and from the front. The asterisks indicate the difference in pure tone thresholds, while the solid curve shows the calculated difference in binaural power sum, based on measured HRTFs.

Figure 2 shows the result of a pilot experiment where the binaural thresholds were determined for a single subject. The figure shows thresholds for sound from the left relative to that for the front direction (asterisks). In addition, the calculated binaural power sum relative to that for the front direction is shown, based on the subject's HRTFs. For this single example there seems to be a fair agreement between the change with direction in sound transmission and the corresponding change in sensitivity at threshold.

However, if the binaural power assumption is to be evaluated, precise and efficient methods for determining thresholds and equal-loudness are needed. Therefore, the choice of psychometric threshold procedure for the experiments will be based on a thorough investigation including 8 different methods [6].

CONCLUSION

Based on measurements of the physical transmission to the ears from a certain direction [5] the binaural sum has been calculated using simple power summation. Assuming that the human brain summarizes the signals at the ears in a similar way, these calculations can be used to estimate the directional dependence of the binaural hearing sensitivity. The calculation have revealed that for frequencies above 4-5 kHz more than 10 dB difference could be expected relative to frontal sensitivity. A brief pilot experiment has verified this result.

Therefore, binaural as well as monaural threshold and loudness data will be determined for different directions of sound incidence enabling an evaluation of the spatial aspects of the present noise measuring technique.

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