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LOW FREQUENCY HEARING THRESHOLD AND EQUAL LOUDNESS CONTOURS

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1 INTRODUCTION

Knowledge of human hearing sensitivity and loudness perception is essential in a number of applications within noise assessment and audiology. At present, data on binaural loudness perception of pure tones in a free field are given in the standard ISO 226 of 1987 [1]. For the frequency range 20-12500 Hz this standard covers minimum audible field and equal loudness level contours in the level range up to 100 phon. ISO 226 is based on experimental data made by Robinson and Dadson in 1956 [2]. However, a number of later experiments [3,4,5,6,7] have not been able to reproduce the equal loudness level contours given in ISO 226, nor to get comparable results from different laboratories. Figure 1 shows the difference between ISO 226 and the mentioned later experiments for the 40 phon level. The standardized levels are significantly lower than what any other experiments have shown, especially at frequencies below 1 kHz. For a fixed frequency, e.g. 63 Hz, loudness levels can be plotted versus sound pressure levels as shown in figure 2. Relatively larger deviations are found between the measured loudness levels than the hearing thresholds found in the lower left side of the curves.

The working group ISO/TC43/WG1 has decided to make a revision of ISO 226. In order to get more consistently data from different laboratories a number of preferred test conditions have been specified for both threshold and loudness experiments [8]. As regards the free field hearing thresholds, which showed relatively good agreement, are now standardized in ISO 389-7. A similar work on loudness data are now in progress.

The aim of this experiment is to produce data for the standardization work, hence the preferred test conditions are followed strictly. In the final experiments free field hearing thresholds will be measured for 25 otological normal subjects at each of the 1/3 octave frequencies from 20 Hz to 20 kHz. Loudness level measurements are planed to include the frequencies below 1 kHz only, at levels ranging from 20 phon to 100 phon. In the following the psychometric method used for loudness level measurements are considered based on experiences from a methodology study in psychometric functions used for threshold measurements [9] and results from other investigations of equal loudness contours.

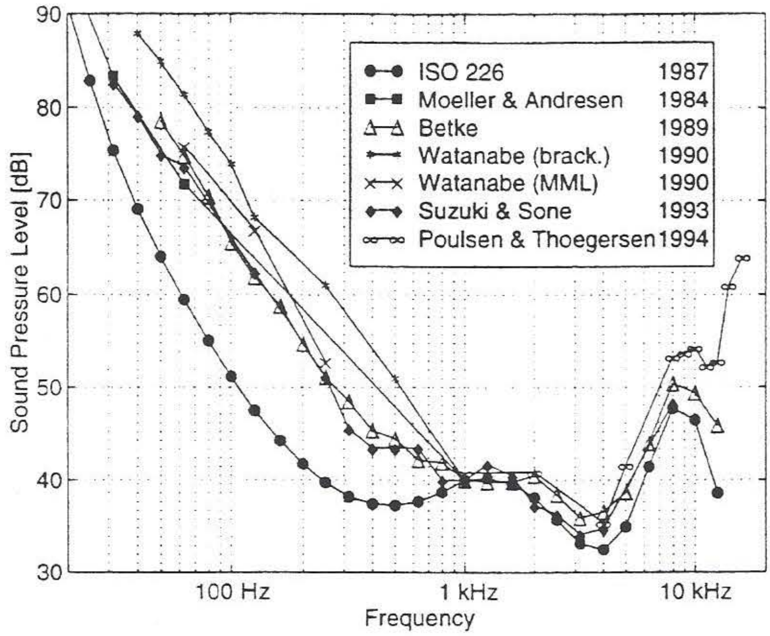

Figure 1. Equal Loudness data for 40 phon from ISO 226 and newer experiments.

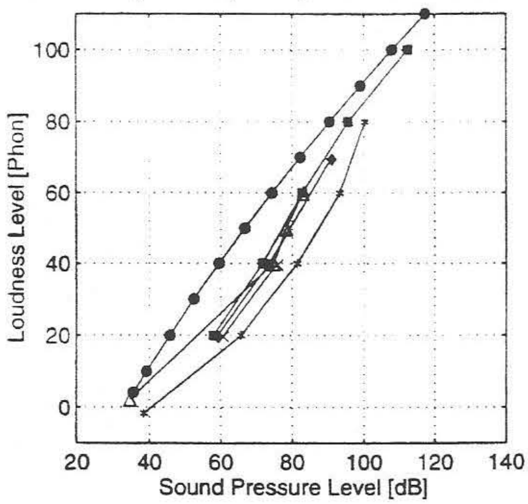

Figure 2. Equal loudness data for 63 Hz from ISO 226 and newer experiments. The use of symbols are similar to those used in Figure 1.

For threshold measurements, the preferred test conditions specify the use of the ascending or the bracketing method as standardized in ISO 8253-1 [10]. We have previously found good agreement between results from these methods [9]. The methods were based on simple detection where the subject pressed a button if he/she was able to hear a tone presentation. However, the preferred test conditions does not specify a psychometric function for loudness experiments except that it should be implemented as a 'Two Alternative Forced Choice' method. This is usually done by presenting pairs of tones for the subject separated by a short pause. One tone is the reference tone with fixed level and a frequency of 1 kHz, the other is the test tone with a different frequency and variable level. The test tone and the reference tone are presented in random order. The subject has to indicate by pressing a button which of the first or the second tone second tone was perceived as the loudest. When the test tone is just as loud as the reference tone, the point of subjective equality (P.S.E.) is found.

1.1 Literature study

Usually the method of constant stimuli has been used as the psychometric method for loudness experiments. An experiment performed by Gabriel *et al.* [11] has shown that different intervals of stimuli levels used by a constant stimuli method can produce different P.S.E.'s. It was possible to reproduce data from two earlier german experiments with a internal difference exceeding 10 dB on a 30 phon curve. The results of Gabriel's experiment showed a bias on the P.S.E for the method towards the gravity point of the presentation level interval.

Only a few investigations have used an adaptive psychometric method for loudness measurements. Møller and Andresen [3] used the Method of Maximum Likelihood based on estimation of the mean value, μ and standard deviation, σ of the psychometric function. After each presentation of a tone pair a new estimates of μ and σ were calculated and the next stimulus was randomly chosen among the 5 levels: μ, $\mu\pm\sigma$ and $\mu\pm2\sigma$. The estimates of μ and σ were restricted to integer values and the method terminated when each of the 5 dynamic changing levels had been presented. Data from this experiment is mainly covering the infrasonic frequencies but for 31.5 Hz and 63 Hz they show a good agreement with other experiments.

Another experiment which has used an adaptive method is Watanabe [5]. Here a bracketing method is made with a step size of 2 dB. The first presentation level for the test tone was chosen 15-20 dB above the ISO 226 level and it was usually evaluated as the loudest tone. This started a descend. After each change in the responses during an descend (ascend) a jump of 4-5 dB were made in the same direction and a ascend (descend) was following. The data from Watanabe's work are in general placed at a higher sound pressure level than other data. Again a bias towards the gravity point of the presentation levels can be expected and give an explanation of the relative high levels of the P.S.E.'s. Watanabe also measured some loudness points with a method similar to the method used by Møller and Andresen. This gave lower values compared to the bracketing method, see Figure 1.

2 METHOD

A system for hearing threshold and equal loudness level measurements in free field has now been made in our laboratory. In order to present sound pressure levels for measurements of a 100 phon curve at low frequencies, a small pressure field chamber has been build. The difference between free field and pressure field data at low frequencies are negligible since the Head Related Transfer Functions, the HRTF's are almost 0 dB in this region [12]. Watanabe [5] has also shown this independencey of the type of sound field for low frequencies. The newly constructed pressure field chamber can be used for presentations up to 135 dB SPL between 20 Hz and 50 Hz. The sound field inside the 1 m^3 volume made for the subject are uniform up to 125 Hz which determines the upper limiting frequency. By using the pressure field chamber it is possible to examine one of the more extreme areas of the auditory area, which seldomly has been included in loudness experiments.

Before the main experiments of this work will be carried out, some pilot experiments are needed to test and improve the design of a psychometric method for equal loudness measurements. Based on the literature study an adaptive method is preferred. Two pilot experiments are planed with adaptive methods to examine the effect of the start point and to examine biasing effects in the method.

In the first pilot experiment 3 different methods will be tested at 50 phon, 100 Hz with start points at 40, 55, 70, 85 and 100 dB SPL for the test tone chosen in random order. A bracketing method very similar to the method used by Watanabe will be used together with a bracketing method using 5 dB step size. The latter using an interlacing of the levels to improve the resolution of the presented levels. The methods will be terminated after 6 ascends and descends. The third method is the Method of Maximum Likelihood used by Møller and Andresen. To start this method some initial presentations are needed for the estimation of μ and σ, so an ascend and a descend with 10 dB steps are placed at first.

In the second pilot experiment the 50 phon level at 100 Hz is measured with the interlaced bracketing method. The start point is the ISO 226 level and the first ascend/descend is using 10 dB steps, the following 6 ascends/descends are using 5 dB. One repetition is made. The individually measured P.S.E. at 100 Hz is next used as the reference tone to measure the P.S.E. at 1 kHz, to see whether it is possible to return to 50 dB. The idea is that if tone *A* is just as loud as tone *B* then *B* must be just as loud as *A*. Otherwise the method used to measure the point of equality is biased.

3 RESULTS

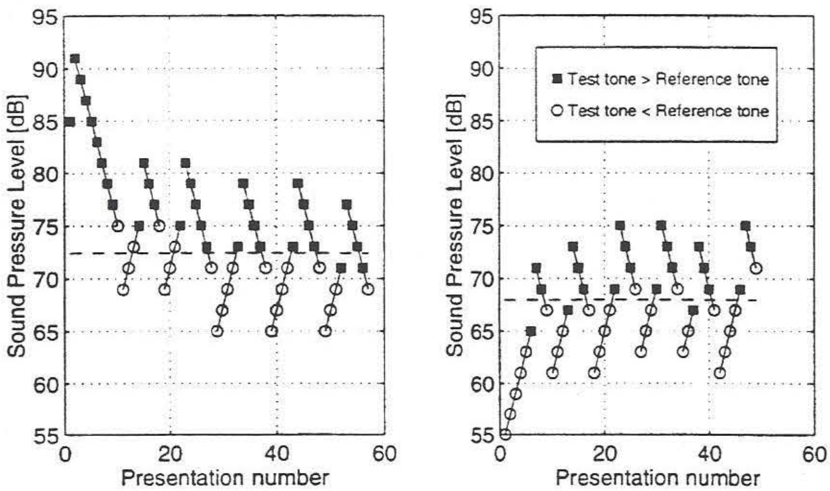

Figure 3. Example of two runs for the same subject in the first pilot experiment with a bracketing procedure at 50 phon with 2 dB step size, starting with an ascend. To the left side the start point of the test tone is 85 dB and to the right side it is 55 dB. The broken horizontal line is the P.S.E. based on a maximum likelihood estimate. A pause of 30 sec. separated the two runs.

Results obtained until now is of very preliminary character since only 6 subjects have participated. A tendency shown by the first pilot experiment can be illustrated by two presentation is far away from the P.S.E. it seems to bias the result. A decay of the transition levels is seen during the run of the method with a high start level and for the method with a low start level the transition levels are increasing.

Table 1 shows the average of measured levels of P.S.E.'s based on a maximum likelihood estimate for the three different methods and the 5 different start points including the 6 subjects. It is seen that methods with low start points are producing lower P.S.E.'s than the methods with high start levels. The tendency is strongest for the bracketing procedure with small step sizes.

Table 1. Measured P.S.E. levels for 5 test tone start levels and 3 methods. [dB]

Start Point	Bracketing 2 dB	Bracketing 5 dB	Max. Likelihood
40	69.6	70.9	68.8
55	70.1	70.0	70.4
70	72.1	72.6	69.6
85	75.7	72.1	71.2
100	78.0	75.8	72.6

The second pilot experiment seems to show a small bias in the interlaced bracketing method, which is accumulated during the run. On average the point of 54.8 dB at 1 kHz is reached instead of the 50 dB after two successive runs of the method. A bias of 2-3 dB may be expected for a single measurement. This bias may be caused by an asymmetric design which places the gravity point of the presented levels above the P.S.E. The results have shown the need for minor improvements on the psychometric method.

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