Proceedings

Low Frequency 2002

10th International Meeting
on
Low Frequency Noise and Vibration and its Control

York, England, 11-13 September 2002

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The series of conferences on Low Frequency Noise has been as follows:

1973	Paris, France
1980	Aalborg, Denmark
1985	London, UK
1987	Umea, Sweden
1989	Oxford, UK
1991	Leiden, Netherlands
1993	Edinburgh, Scotland
1997	Gothenborg, Sweden
2000	Aalborg, Denmark
2002	York, UK

The first conference in Paris was for invited delegates only, but subsequent ones have been open to all interested persons.

The organisers are always pleased to receive proposals for locations for future conferences.

Multiscience Publishing Co Ltd and the Journal of Low Frequency Noise, Vibration and Active Control became closely associated with the conferences from 1985.

The Proceedings for the 10th Conference are arranged, where possible, in the sequence in which the papers will be presented at the meeting. However, this is affected by late papers and changes to the programme which may be necessary.

Geoff Leventhall
Proceedings Editor

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on
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An investigation of the perception thresholds of complex low frequency noises: influence of spectrum

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Summary

Perception thresholds of complex low frequency noises have been investigated in a laboratory experiment. Sound pressure levels that were just perceptible by subjects were measured with three complex noises and three pure tones. The complex noises had a flat constant spectrum over the frequency range 2 to 10, 20, or 40 Hz and decreased with rate of 15 dB per octave at higher frequencies. The frequencies of the pure tones used in this study were 10, 20 and 40 Hz. The perception thresholds were obtained with an all-pass filter, one-third-octave band filters, and the G frequency weighting defined in ISO 7196. The G-weighted sound pressure levels obtained were compared with 100 dB which is described in ISO 7196 as the G-weighted level corresponding to the threshold of sounds in the frequency range 1 to 20 Hz. The perception thresholds of the pure tones measured in this study were comparable to the results available in various previous studies. The one-third octave sound pressure levels obtained for the thresholds of the complex noises tended to be lower than the measured thresholds of the pure tones. The G-weighted sound pressure levels obtained for the thresholds of the complex noises appeared to be lower than 100 dB.

Introduction

For the assessment of infrasound and low frequency noise in dairy living environment, the understanding of the characteristics of the human response to those noises are required. It is accepted in some countries that the level of environmental infrasound and low frequency noise must be below the human perception thresholds so as to avoid the effect of those noises, including complaints and adverse effects on health, although this may be a subject of controversy.

There have been previous studies in which the perception thresholds of infrasound and low frequency noise were determined by using pure tones, such as Yeowart *et al.*[1], Yeowart and Evans[2], and Watanabe and Moller[3]. In the assessment of real-life noises, the characteristics of the perception thresholds of complex low frequency noises are relevant information besides the thresholds of pure tones. Laboratory investigations of the perception thresholds of complex low frequency noises with environment and stimuli controlled are useful so as to understand the characteristics of the thresholds of complex noises. However, there have been a few studies of those kind[4,5] and the characteristics of the thresholds of complex low frequency noises are not well understood.

The objective of the present study was to investigate the characteristics of the perception thresholds of complex noises having major frequency components in the infrasound range. In Japan, the Environment Agency (now the Ministry of Environment) has been conducting a nation-wide survey to obtain the information on environmental infrasound and low frequency noise since 2000[6]. The survey includes the collection of the G-weighed sound pressure levels defined in ISO 7196[7] in various environment. It may be, therefore, useful to discuss the relation between the G-weighted sound pressure levels and the perception thresholds based on the results obtained in this study.

Method

An experiment involving human subjects was conducted with the infrasound experiment system within the National Institute of Industrial Health, Kawasaki, Japan[8]. A schematic diagram of the plan of the experimental facilities is presented in Figure 1. The capacity of the test chamber was about 25 m^3. Twelve loud speakers, Pioneer TL-1801, having a diameter of 46 cm, were installed in a wall of the test chamber where subjects were exposed to low frequency noises during the experiment. The loud speakers were covered with jersey cloth so that subjects could not detect the movement of the speaker diaphragms visually.

The perception thresholds were measured with three pure tones and three complex noises. The frequencies of the pure tones used in the experiment were 10, 20 and 40 Hz. Source signals for the pure tones were generated by a function generator. It was found in a preliminary test that it was unlikely that harmonics of those pure tones had an effect on the determination of perception thresholds. The complex noises generated by a computer had a nominally flat spectrum over the frequency range 2 to 10, 20, or 40 Hz and decreased at higher frequencies. The rate of the decrease in the spectra of the complex noises at high frequencies was determined to be 15 dB per octave because when this rate was greater than 15 dB/oct audible noises at high frequencies where there were no significant frequency components in the source signals were produced within the sound generation system which could interfere with the determination of thresholds. The source signals for the pure tones and complex noises were recorded in a DAT that was then used to feed input signals into the sound generation system shown in Figure 2. An audio mixer, Roland BOSS BX-60, was used to adjust the magnitude of stimulus by subjects while a graphic equalizer,

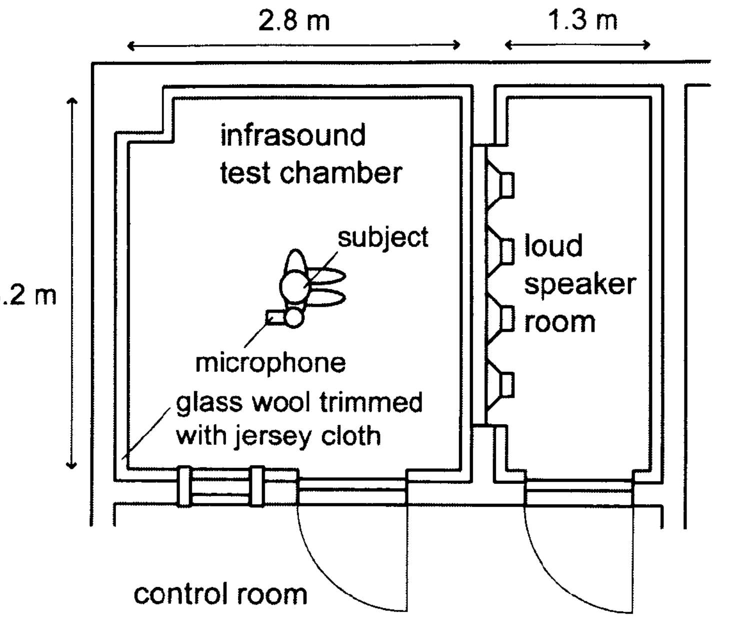

Figure 1. Schematic diagram of the plan of the experimental facilities used in this study.

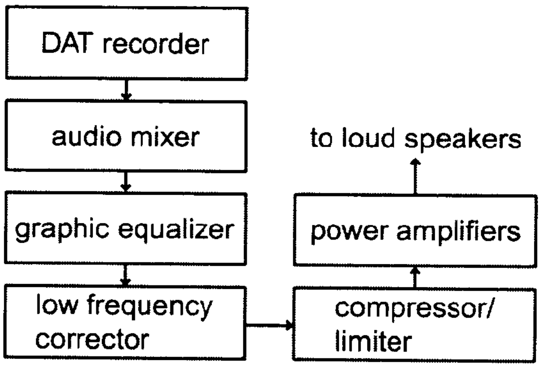

Figure 2. Sound generation system used in the experiment.

SONY MU-E311, was used by the experimenter to adjust the stimulus magnitude. The details of the other components of the sound generation system are available in Takahashi *et al.*[8]

Ten male volunteers, aged from 21 to 24 yrs, took part in the experiment. All subjects appeared to have a normal hearing function in the hearing test at each octave centre frequencies from 125 to 8000 Hz conducted prior to the experiment. The perception thresholds of the six input stimuli were determined by the method of adjustment: subjects were asked to determine the magnitude of each stimulus by adjusting the audio mixer shown in Figure 2 so that they could just detect the presence of the stimulus. The measurement of perception threshold was repeated four times for each stimulus: the measurement that started with the sound pressure level at which subjects definitely detected the stimulus was repeated twice and the measurement that started with the sound pressure level at which they could not detect the stimulus was repeated twice. The order of the presentation of the six input stimuli were varied between subjects.

The measurement of sound pressure was made near the centre of the test chamber at a height of 1.2 m by using a low frequency sound level meter, RION NA-17. Subjects were seated on a flat chair without backrest located at the centre of the test chamber during the experiment (see Figure 1). The height of the chair was adjusted so that the height of the ears of each subject were 1.2 m from the floor. The position of the microphone was about 0.1 m right from the right ear of the subject.

There were no significant frequency components at frequencies above 100 Hz compared to frequency components at lower frequencies in all stimuli used in the experiment. Signals from the low frequency sound level meter corresponding to time histories of the sound pressure were, therefore, acquired in a computer at 1000 samples per second. Overall sound pressure levels, third-octave band sound pressure levels, and G-weighted sound pressure levels were then calculated for each record. Third-octave band filters used in the calculation were within the margins of error given in JIS C 1513[9]. For the G frequency weighting, the parameters defined in ISO 7196[7] were used to calculate weighted values.

Results

The perception thresholds for each of the six stimuli were determined in four measurements as described in the preceding section. It was found that the differences in the values obtained in four measurements were not statistically significant ($p>0.1$, Wilcoxon matched-pairs signed ranks test). The averages of the four measurements for each stimulus are, therefore, presented as the perception thresholds in the following parts of the paper.

Figure 1 shows the median and inter-quartile ranges of the perception thresholds determined for the three pure tones. The reference thresholds of hearing defined for frequencies above 20 Hz in ISO 389-7[10] are also shown in Figure 1. The median threshold for the pure tone at 20 Hz measured in this experiment was almost equal to the value given in the standard. Although the measured threshold for the pure tone at 40 Hz was greater than the standard value by about 5 dB, it was comparable to the

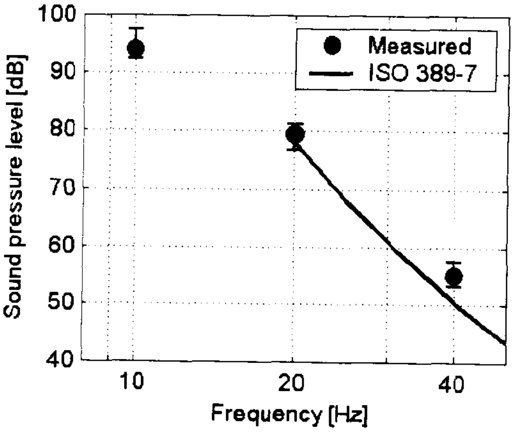

Figure 1. The median and inter-quartile ranges of the perception thresholds determined for the pure tones in this experiment. The reference thresholds of hearing defined in ISO 389-7 is also presented.

data reported in the previous studies[1-3,11]. The measured threshold for the pure tone at 10 Hz was also comparable to the previous results. The measurement method used in this study might, therefore, be reasonable to determine the perception thresholds.

The median and inter-quartile ranges of the 1/3 octave band sound pressure levels obtained for the three complex noises at the perception thresholds are presented in

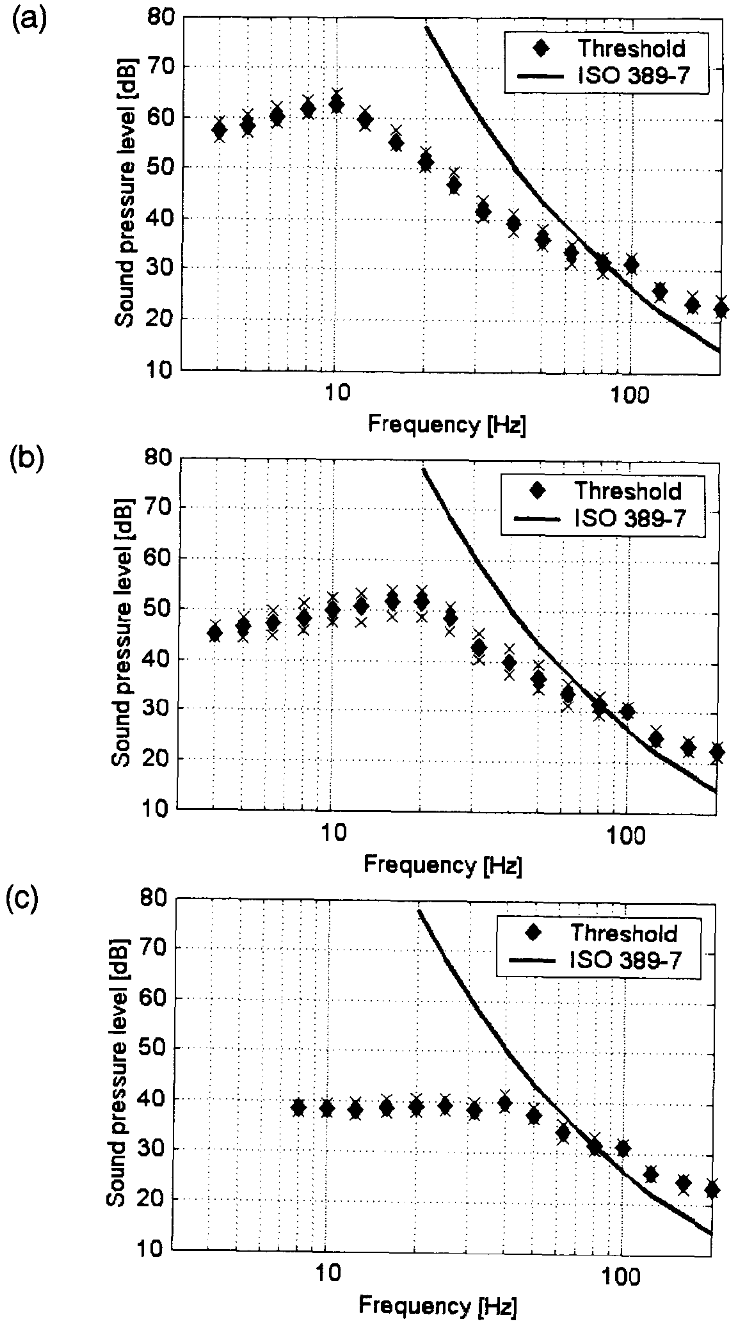

Figure 2. The medians and inter-quartile ranges of the 1/3 octave band sound pressure levels at the perception threshold determined for the complex noises with a cut-off frequency of (a) 10 Hz, (b) 20 Hz and (c) 40 Hz. The reference thresholds of hearing defined in ISO 389-7 is also presented.

the frequency range between 4 and 200 Hz in Figure 2. The measured thresholds are compared with the reference thresholds of hearing defined in ISO 389-7[10]. In the course of the experiment, the background noise in the test chamber was measured several times. For the complex noise with a cut-off frequency of 40 Hz, the 1/3 octave band sound pressure levels at the threshold are shown at frequencies above 8 Hz because the 1/3 octave band sound pressure levels at the thresholds were almost the same as the background noise levels at lower frequencies.

The inter-quartile ranges of the thresholds of the complex noises were about 5 dB which were similar to the inter-subject variability observed in the perception thresholds for the pure tones. For all the complex noises used in this experiment, the 1/3 octave band sound pressure levels at the perception thresholds tended to be greater than the values in ISO 389-7[10] at frequencies above 80 Hz.

The median 1/3 octave band sound pressure levels at the perception thresholds for the complex noises are compared with the median perception thresholds for the pure tones in Figure 3. The reference threshold of hearing defined in ISO 389-7[10] is also presented in Figure 3. It was found that, for the complex noises, the 1/3 octave sound pressure levels at frequencies where the sound pressure level decreases with increasing the frequency were almost the same for the three complex noises: above 20 Hz, the sound pressure levels for the complex noise with a cut-off frequency of 10 Hz were almost the same as those for the complex noise with a cut-off frequency of 20 Hz, and above 40 Hz, the sound pressure levels were almost the same values for the three complex noises. At 10, 20 and 40 Hz, the 1/3 octave band sound pressure

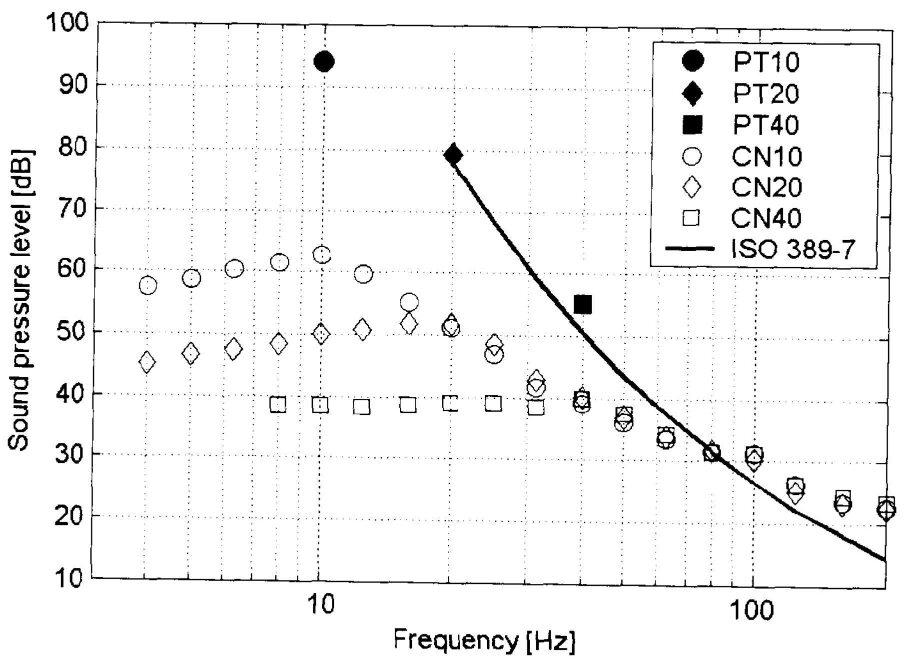

Figure 3. The median perception thresholds for the pure tones and the median 1/3 octave band sound pressure levels at the perception thresholds for the complex noises. The reference threshold of hearing in ISO 389-7 is also presented. Legend: PT10, pure tone at 10 Hz; PT20, pure tone at 20 Hz; PT40, pure tone at 40 Hz, CN10, complex noise with 10 Hz cut-off; CN20, complex noise with 20 Hz cut-off; CN40, complex noise with 40 Hz cut-off.

levels for the perception thresholds of the complex noises were lower than the perception thresholds for the pure tones.

Table 1 shows the median and inter-quartile ranges of the G-weighted sound pressure levels calculated for the perception thresholds for all six stimuli. It is stated in ISO 7196[7] that "in the frequency range 1 Hz to 20 Hz, sounds that are just perceptible to an average listener will yield weighted sound pressure levels close to 100 dB". The median G-weighted sound pressure level of the perception threshold measured with the pure tone at 10 Hz was 94.0 dB, lower than the value given in the standard by 6 dB, and the median G-weighted level for the threshold for the pure tone at 20 Hz was 88.2 dB, lower than the standard value by about 12 dB. The threshold of the pure tone at 40 Hz was out of scope of the standard, so that the measured G-weighted level of the perception threshold was much lower than 100 dB. The G-weighted level of the perception thresholds for the complex noises were lower than 100 dB by more than 30 dB.

Discussion

It was found that, for the three complex noises used in this study, the median 1/3 octave band sound pressure levels at the perception threshold tended to be greater than the reference thresholds of hearing defined in ISO 389-7[10] at frequencies above 80 Hz. Although the perception threshold of the pure tone at frequencies higher than 80 Hz were not measured with the subjects used in this study, it could be assumed that the thresholds of the subjects might have been similar to those given in ISO 389-7[10]. The 1/3 octave band sound pressure levels for the thresholds were similar at frequencies above 40 Hz for all the complex noises and at frequencies above 20 Hz for the noises with a cut-off frequency at 10 Hz and with a cut-off frequency at 20 Hz.

It might be possible to hypothesise that in the perception of complex noises the noise component in the frequency range where the 1/3 octave band sound pressure level is greater than the threshold level obtained with pure tone contribute to the response of subject. If this hypothesis is valid, the perception of all the complex noises used in this study might be interpreted as the contribution from the frequency components at higher frequencies above about 80 Hz, although there are more significant sound energy inputs at lower frequencies.

The A frequency weighting was applied to the recorded data for the perception

Table 1. The median and inter-quartile ranges of the G-weighted sound pressure levels at the perception thresholds measured in this study. PT10, pure tone at 10 Hz; PT20, pure tone at 20 Hz; PT40, pure tone at 40 Hz, CN10, complex noise with 10 Hz cut-off; CN20, complex noise with 20 Hz cut-off; CN40, complex noise with 40 Hz cut-off.

G-weighted sound pressure level [dB]	Pure tone			Complex noise		
	PT10	PT20	PT40	CN10	CN20	CN40
25th percentile	92.4	85.4	46.0	67.7	61.3	50.9
Median	94.0	88.2	48.1	68.7	64.3	52.2
75th percentile	97.3	89.9	49.4	70.8	66.6	53.6

thresholds of the complex noises so as to investigate the effect of the frequency components in the audible range to the threshold, although the highest 1/3 octave band centre frequency used in the calculation was 400 Hz due to the limit of the equipment used in the measurement. The calculated values should not be used in discussion about the absolute A-weighted value but could be used to compare the thresholds of the three complex noises measured because it could be expected there was no significant difference in the sound pressure level between the three complex noises at higher frequencies where no data were available (see Figure 3). The nominal A-weighted sound pressure levels calculated for the median thresholds were between 23.0 dB and 24.0 dB for the three complex noises, this might support the interpretation of the data obtained that the frequency components above 80 Hz may contribute to the perception thresholds of the complex noises used in this study.

Although the data described above supported the hypothesis that the noise components at frequencies above about 80 Hz contributed to the perception of the complex noises, the effect of the noise components at lower frequencies on the perception may not be ignored. It was reported by the subjects and recognised by the experimenter that the three complex noises used in this study was perceived as different noises when the noises were just noticeable and clearly heard: when the cut-off frequency of the complex noise was lower, the noise was perceived as a "lower sound". There were differences in the 1/3 octave band sound pressure level between the noise with a cut-off frequency of 10 Hz and that with a cut-off frequency of 20 Hz mainly at frequencies below 20 Hz. If these differences were major factors that had an effect on how the subject perceived the noises, the frequency components below 80 Hz, and even below 20 Hz, might be perceived by the subjects, although the 1/3 octave band sound pressure levels at these frequencies were lower than the thresholds measured with pure tones. It was reported that at the perception thresholds of complex noises consisting of a few tonal components the sound pressure levels of those noises at frequencies of each tonal component could be lower than the thresholds obtained with pure tones at the corresponding frequency[4,5]. It might not be, therefore, reasonable to ignore the effect of low frequency components on the perception of the complex noises used in this study. However, it was not possible to understand the mechanism how and to what extent low frequency components had effects on the perception from the available experimental proofs.

The measurement of the background noise in the test chamber was made several times during the period of experiment, as mentioned in the preceding section, some variation of the sound pressure levels of the background noise was found. In all measurements made, the 1/3 octave band sound pressure levels of the background noise were greater than the reference threshold of hearing in ISO 389-7[10] at higher frequencies. This was observed at frequencies above 100 Hz in some measurements. It is difficult to compare the measured thresholds with those background noise levels directly because the background noise level varied and was not measured in each experimental session. However, it was found that, in some background noise records, the 1/3 octave band sound pressure levels of background noise at frequencies above 100 Hz were comparable or greater than the 1/3 octave band sound pressure levels obtained for the perception thresholds.

The pure tones at 10 and 20 Hz and the complex noises used in this study, particularly those with a cut-off frequency of 10 Hz and 20 Hz, had major frequency components in the frequency range below 20 Hz, so that it was reasonable to assess those stimuli by using the G frequency weighting. For the pure tones, the median G-weighted sound pressure level for the threshold measured at 20 Hz was lower than that measured at 10 Hz by about 6 dB (see Table 1), although these were expected to be at almost the same level. The median G-weighted value of 88.2 dB for the threshold at 20 Hz may be inconsistent with the statement in ISO 7196[7] that "weighted sound pressure levels which fall below about 90 dB will not normally be significant for human perception". The median weighted value obtained for 20 Hz was close to, for example, the "recommended limit for environmental infrasound" in Denmark, 85 dB, which was determined based on "the average hearing threshold for infrasound" of about 96 dB in association with an inter-subject variability of about 10 dB[12]. For the complex noises, the G-weighted sound pressure levels shown in Table 1 were lower than the just perceptible level, 100 dB, defined in ISO 7196[7] and even lower than Danish recommended limit, 85 dB. This may imply that there were no contribution from the noise components in the infrasound frequency range to the perception thresholds of the complex noises used in this study. This may be consistent with the hypothesis that the subjects perceived the noise components at frequencies above about 80 Hz only in this experiment, as described above, but inconsistent with the fact that the subjects reported that the three complex noises were perceived differently.

Conclusions

The perception thresholds of pure tones measured at frequencies of 10, 20 and 40 Hz were comparable to those obtained in the previous studies. The G-weighted sound pressure levels obtained for the thresholds of the pure tone at 10 Hz for individuals were lower than the weighted value for the threshold stated in ISO 7196 by about 6 dB, and those at 20 Hz tended to be lower than the standard value by about 12 dB.

At the perception thresholds of the complex noises including significant frequency components in the infrasound range, the 1/3 octave band sound pressure levels at frequencies above 40 Hz were similar for all the noises used in this study. The 1/3 octave band sound pressure levels at frequencies above 80 Hz at the perception thresholds tended to be greater than the reference thresholds of hearing defined in ISO 389-7. These data may imply that the perception thresholds of those complex noises were determined by the noise components at those higher frequencies. However, the subjects recognised the differences between those complex noises by means of their perception, which might suggest that there were some contribution from the low frequency components. Further investigation is required for the interpretation of the results obtained for the complex noises.

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Thresholds and acceptability of low frequency pure tones in sufferers

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SUMMARY

To investigate sensory thresholds and subjective evaluations of low frequency pure tones in noise sufferers who complain of annoying environments in their everyday life, sound pressure levels of sensory thresholds and subjectively acceptable maximum SPL levels for a living room were measured in a low frequency chamber. These measurements were made by a psychophysical experiment using eleven pure tones at low frequencies from 10Hz to 100 Hz as stimuli, and a psychophysical method of subject adjustment was used for the measurement. Twelve members of the noise-sufferer society in Japan participated as subjects (referred to as participants in the following) in the measurement experiment. The results show that all the participants' acceptable maximum sound pressure levels were relatively low, and nearly equal to their sensory thresholds. These results are characteristic of the participants and differ from the previous results obtained from the other adults.

INTRODUCTION

Our previous paper[1] reports sensation thresholds, equal unpleasantness contours of low frequency sound and the acceptable limits of SPL for some living situations of 39 adults aged from 20 to 55 on pure tones at frequencies from 10 Hz to 500 Hz and the obtained means were well predicted by a polynomial function. In addition, similar but somewhat different results were obtained from older adults aged 60-75 and the results were reported in another paper[2]. However, there are fairly large individual differences in sensations and evaluations of low frequency sound. Especially when participants are exposed to and complain of annoying environments in their daily lives, their responses in sensations and evaluations to low frequency sound are expected to differ from those of other adults. We recently measured the sensation thresholds and acceptable limits of SPL for some members of the noise-sufferer society in Japan. This paper investigates characteristics of