# An investigation of the perception thresholds of band-limited low frequency noises: influence of bandwidth

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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 for 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 at 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 using 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 appeared 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.

## 1. INTRODUCTION

For the assessment of infrasound and low frequency noise in the daily living environment, an understanding of the characteristics of the human response to those noises is required. It is accepted in some countries that the level of environmental infrasound and low frequency noise must be below the human perception thresholds determined in laboratory experiments so as to avoid the effect of those noises on people, 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 Møller [3]. In the assessment of real-life noises, the characteristics of the perception thresholds of complex low frequency noises are relevant information as well as those of pure tones. Laboratory investigations of the perception thresholds of complex low frequency noises in which the environment and stimuli are controlled are useful so as to understand the characteristics of the thresholds of complex noises. However, there have been few studies of this kind [4, 5] and the characteristics of the thresholds of complex low frequency noises are not yet 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 conducted a nation-wide survey to obtain information on environmental infrasound and low frequency noise since 2000 [6]. The survey includes the collection of the G-weighted sound pressure levels defined in ISO 7196 [7] in various environments. It may, therefore, be useful to discuss the relationship between the G-weighted sound pressure levels and the perception thresholds based on the results obtained in this study.

## 2. METHOD

An experiment involving human subjects was conducted with the infrasound 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 the subject could not detect any movement of the speaker diaphragms visually.

The perception thresholds were measured for 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. A preliminary test was conducted so as to evaluate the quality of the pure tones produced in the experimental system: the sound pressure levels of the fundamental frequency component and its harmonics produced by the experimental system were compared with the perception thresholds of pure tones reported in the previous studies (e.g. [1–3]). It was unlikely that, when the sound pressure level at the fundamental frequency was at the perception threshold, those of the harmonics were also at, or exceeded, the perception thresholds at the corresponding frequencies. 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. This was 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 on 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, SONY MU-E311, was used by the experimenter to adjust the stimulus magnitude. The details of 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.

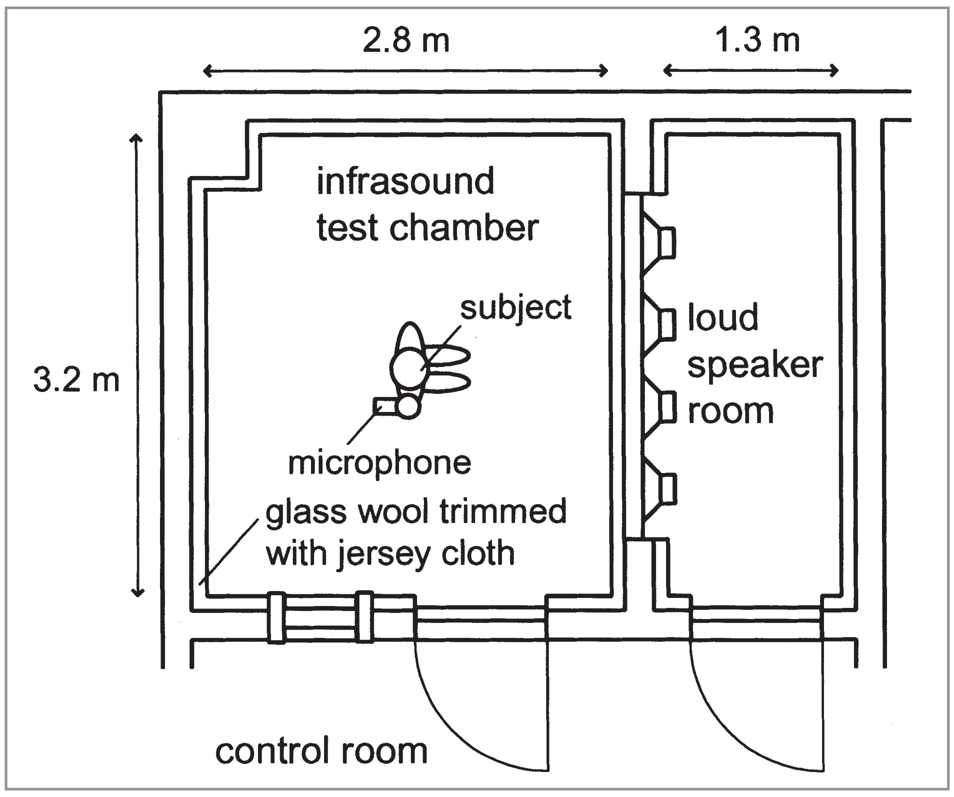


*Figure 1. Schematic diagram of the plan of the experimental facilities used in this study*

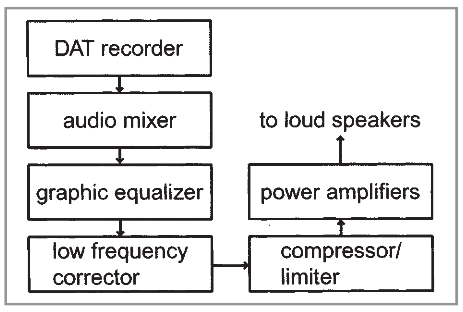


*Figure 2. Sound generation system used in the experiment*

All subjects appeared to have normal hearing in the hearing test at each octave centre frequency 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 a sound pressure level at which subjects definitely detected the stimulus was repeated twice and the measurement that started with a 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 a 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 was 1.2 m from the floor. The position of the microphone was about 0.1 m from the right ear of the subject.

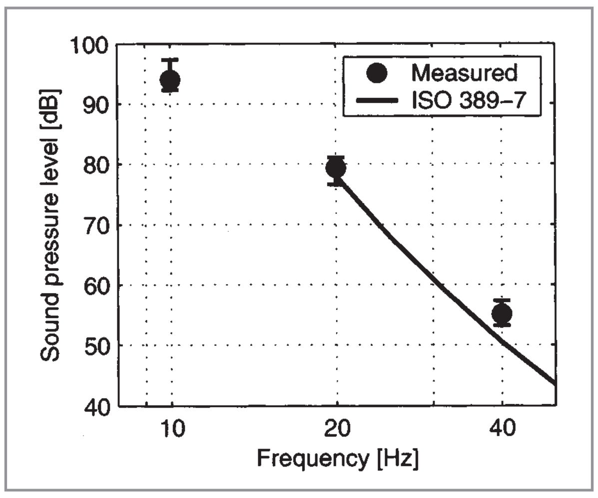


*Figure 3. The median and inter-quartile ranges of the perception thresholds determined for pure tones in this experiment. The reference threshold of hearing defined in ISO 389-7 is also presented*

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, one-third octave band sound pressure levels, and G-weighted sound pressure levels were then calculated for each record. One-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.

## 3. 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 the 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 3 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 3. 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 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. It can be, therefore, concluded that the measurement method used in this study was reasonable to determine the perception thresholds.

The median and inter-quartile ranges of the one-third octave band sound pressure levels obtained for the three complex noises at the perception thresholds are presented in the frequency range between 4 and 200 Hz in Figure 4. 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 one-third octave band sound pressure levels at the threshold are shown at frequencies above 8 Hz because the one-third octave band sound pressure levels at the thresholds were almost the same as the background noise levels at lower frequencies. Other characteristics of the background noise measured are discussed in a later section.

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 one-third octave band sound pressure levels at the perception thresholds tended to be greater than the values in ISO 3897 [10] at frequencies above 80 Hz.

The median one-third 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 5. The reference threshold of hearing

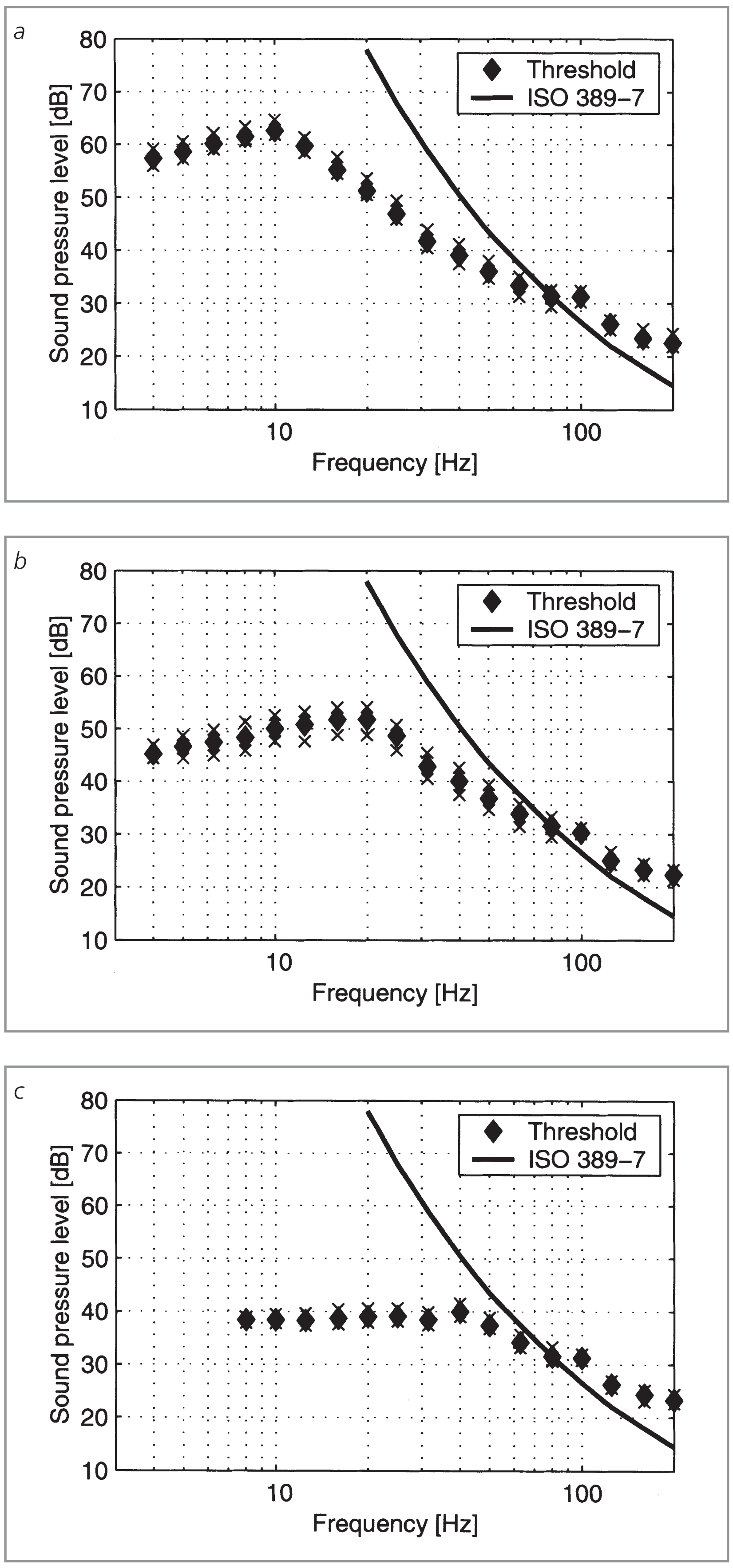


*Figure 4. The medians and inter-quartile ranges of the one-third octave band sound pressure levels at the perception threshold determined for the complex noises with cut-off frequencies of (a) 10 Hz, (b) 20 Hz and (c) 40 Hz. The reference threshold of hearing defined in ISO 389-7 is also presented*

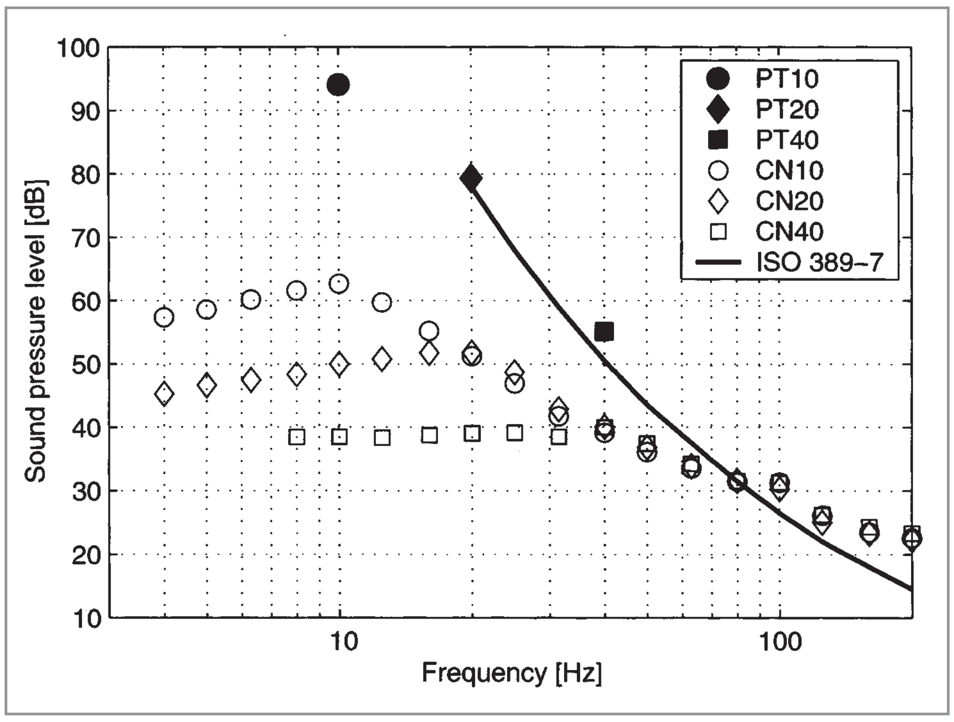


*Figure 5. The median perception thresholds for the pure tones and the median one-third octave band sound pressure levels at the perception thresholds for the complex noises. The reference threshold of hearing in ISO 389-7 is also presented. Legend: PT10, pure tone at 10 Hz; PT20, pure tone at 20 Hz; 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*

*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*

| | Pure tone | | | Complex noise | | |
|---|---|---|---|---|---|---|
| **G-weighted sound pressure level [dB]** | **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 |

defined in ISO 389-7 [10] is also presented in Figure 5. It was found that, for the complex noises, the one-third octave sound pressure levels in the frequency range 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 for the three complex noises. At 10, 20 and 40 Hz, the one-third octave band sound pressure 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.

## 4. DISCUSSION

It was found that, for the three complex noises used in this study, the median one-third 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 one-third 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 one-third octave band sound pressure level is greater than the threshold level obtained with pure tone contributes to the response of the 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 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 one-third 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 that 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 5). 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 measured data that the frequency components above 80 Hz may contribute to the perception thresholds of the complex noises used in this study.



**EU DEAF STUDY**

To mark world deafness day on 1 September, the Commission has highlighted the results of an EU funded project which identifies the genes responsible for deafness. The ‘hereditary deafness’ project received 2.12 million euro under the Quality of Life section of the Fifth Framework Programme. The main objective of the project was to increase understanding of the hearing process and identify the genetic determinants of deafness. Commenting on the current situation in Europe, Philippe Busquin, European Research Commissioner, highlighted the importance of investing in research into the different aspects of deafness: ‘The number of patients suffering from such hearing impairments is growing due to increased noise pollution and an ageing population. So far, aside from hearing aids, there is no remedy for deafness,’ he said. ‘Developing new therapies requires the best researchers from different countries and disciplines to work together in order to improve our knowledge on the hearing process and to identify the causes leading to deafness. This is precisely what the EU is making happen through its research programmes,’ added the Commissioner.

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 experimenters 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 one-third octave band sound pressure level between the noise with a cut-off frequency of 10 Hz and that with a cutoff 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 one-third 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 the 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 from the available experimental proofs to understand the mechanism of the influence of low frequency components on the perception.

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 one-third 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 of 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 one-third octave band sound pressure levels of background noise at frequencies above 100 Hz were comparable or greater than the one-third 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 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 was 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.

## 5. 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 one-third octave band sound pressure levels at frequencies above 40 Hz were similar for all the noises used in this



### NOISE RULE IS THE PITS FOR ORCHESTRAS

The 1812 Overture will never sound quite the same again. Orchestras have been told to tame the timpani and cap their crescendos to protect the hearing of musicians and classical music lovers. Cannons, a regular in Tchaikovsky's best-known work, are a definite no-no. The move comes ahead of the introduction of an EU directive which will force symphony orchestras to cut their maximum sound level from an eardrum-rattling 98 decibels to a more sedate 85 decibels. The warning to turn down the volume comes from the Association of British Orchestras (ABO), which has produced a report highlighting the risk to classical musicians. Until now, it had been assumed that the main threat was to rock stars and their fans. However, the ABO's study reveals that hearing problems are common among their more genteel musical counterparts. As well as deafness, classical musicians exposed to excessive volume can suffer tinnitus or diplacusis, a condition which makes them hear a single tone as two different pitches. The move to lower the volume has led to discord among music lovers who fear audiences will suffer as orchestras temper their performance to stay on the right side of the law. Arts impresario Richard Demarco, a devotee of classical music, said: "This is absolute nonsense. They will have to ditch the Proms for a start. "When the arts world is controlled by laws such as this, you might as well just pack the whole thing in. Daniel Pollitt, spokesman for the Royal Scottish National Orchestra, expressed doubts that the new law could be policed. He said: "It will be interesting to see how they manage to enforce this. Are they going to have representatives at every single concert checking the levels?"

study. The one-third 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 the complex noises used in this study 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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noise notes

**ZERO TOLERANCE**

New Yorker George Pulido was walking home from a birthday party with his wife and two sons. The boy let the balloon the boy was holding get away from him and it popped when it hit the sidewalk. Three police officers on the corner heard the noise and one called him over. He was given a ticket for the noise. An incredulous Pulido says he'll fight the ticket in Queens Criminal Court.

### NOISE POLICE IN LIBRARIES

Singapore now has noise police to keep volumes down in its public libraries. Lee Siew Hoon, a National Library Board spokeswoman, said more than 10 people now patrol six of the island's libraries urging users to pipe down and switch off their cell phones as part of a "library etiquette campaign." "The volunteers go around the library during the noisiest times and speak to people who are talking on their cell phones, kids who are shouting or those who are chatting away," Lee said. They do not have the power to fine or ask people to leave the library, she said. The noise police can only ask them to stop talking, sometimes just slipping a note to the noisemakers asking them to "spare a thought for others." Lee said people asked to keep quiet tend to be "genuinely apologetic."

### MAN DRIVEN TO DEATH BY NOISE

A court recently ordered a factory to pay a total of 13,495 yuan (US$1645) to the relatives of a man who was driven to suicide by noise coming from a factory in Qian'an, Hebei, China. It was the first reported case in China where anyone had been driven to suicide by noise, the China News Service said. The dead man, Wan Tianlin, a farmer, was the neighbour of a man surnamed He, who set up a beverage factory in his yard. Wan had often been awakened by the noise of wagons carrying bottles to He's factory and the noise of the production line. Wan had spoken with He, who refused to do anything about the noise. The noise became even worse as He expanded his business. After living with the noise for eight years, Wan developed a neurosis and could no longer work properly. Wan hanged himself at a small wood near his home in 2001. His family then filed a lawsuit against the factory. A local court in Qian'an ruled that the factory had infringed upon the rights of Wan and his family by emitting noise louder than was permitted. The factory was ordered to pay the compensation and immediately stop the noise.

### TEENAGER SHOT

In North Carolina, The Cleveland County Sheriff's Department said a man apparently angry about the noise made by teenagers driving on his road early Friday is accused of the shooting to death of one of the boys and the wounding of another. The shooting happened after 16-year-old Jonathan Perry Beck, of Waco, and 15-year-old Paul Allen, along with Allen's 11-year-old brother, stopped about 1 am at the house of Ricky Van Mellon, whose teenage son knew the boys. Mellon told investigators the boys had been spinning the car's wheels, honking the horn and making other noise. Cleveland County Sheriff Raymond Hamrick says that made Mellon angry. Mellon fired three shots from a nine-millimeter pistol and two hit the car. One hit Beck in the head. The car then rolled 200 yards from the house and into an embankment. Allen was in serious condition at Carolina's Medical Center late Friday after emergency surgery to remove a bullet from his ear canal.