noise
notes

# The effect of fluctuations on the perception of low frequency sound

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Results of laboratory tests are presented in which 18 subjects, including some low frequency noise sufferers, were presented with low frequency sounds with varying degrees of fluctuation. Thresholds of acceptability were obtained for each sound and each subject, using the method of adjustment. These thresholds were then normalised to individual low frequency hearing threshold. It was found that sufferers tend to set thresholds of acceptability closer to their hearing threshold than other subject groups. Also, acceptability thresholds were set on average 5dB lower for fluctuating sounds. It is proposed that a sound should be considered fluctuating when the difference between $L_{10}$ and $L_{90}$ exceeds 5dB, and when the rate of change of the 'Fast' response sound pressure level exceeds 10dB/s.

## 1. INTRODUCTION

The aim of this paper is to investigate the effect of fluctuations on the disturbance caused by low frequency noise (LFN). Secondly, it is to derive a method, suitable for use by Environmental Health Officers to enable the effect of fluctuations to be quantified. The questions addressed are:

- Should fluctuating low frequency sounds be penalised compared with steady sounds, and if so by how much?
- What measured parameter(s) should be used to determine when and if such penalties should be applied?

## 2. TEST METHOD AND DESIGN

The basic approach was to use the method of adjustment in the laboratory to obtain 'thresholds of acceptability' for a number of fluctuating and steady sounds. The 'threshold of acceptability' is defined as the level of a particular sound that the subject judges to be just acceptable for an assumed day or night time situation. In order to obtain these thresholds subjects were read the following instructions while relaxing in a simulated living room into which pre-recorded low frequency sounds were subsequently played:

> *"Imagine you are at home during the day. Press the button whenever you consider the sound is not acceptable to live with and keep it pressed. Whenever you consider the sound is acceptable to live with, release the button."*

An operator then adjusted levels using similar techniques to those used in audiometry, i.e. by reducing the level of the sound gradually when the button was pressed until it was released. Each sample lasted 90 seconds, which had been found during preliminary tests to be sufficient time to obtain a reliable threshold. It was found by experience that, after an initial training period, the threshold levels were repeatedly set to within 1 dB. For the 'night time' tests the main lights were switched off and the first sentence of the instruction was replaced by: *"Imagine you are at home at nigh and trying to get to sleep."*

A combination of real and synthesised sounds was played to all subjects. The advantage of real sounds (i.e. recorded in the dwellings of LFN sufferers) is that they are more easily accepted as realistic. However, it was necessary to ensure that all parameters except the amount of fluctuation (tonality, frequency content etc.) were kept constant. This made it difficult to include results from different locations. However, several samples were taken from a single case study where the suspected source was about 1.5km away, so that the sound varied with wind and other factors, whilst the frequency content remained approximately constant. We were able to select a number of short recordings from the five-day record in which the source was essentially the same, but the degree of fluctuation of the sound varied. From this set, the best five samples were chosen by a combination of analysis and preliminary listening room tests. In preliminary tests it was found that most of the sounds drifted in level over a period of a minute or so, making it difficult to establish a proper threshold. Hence, a ten second sample of each sound was taken and ‘looped’ so as to produce a recording of 3 minutes duration but with a homogeneous content throughout. The ‘joins’ between the looped segments were disguised by cross fade techniques so that even expert listeners could not tell that it had been looped.

A set of beating tones was also synthesised so as to allow us to test the reaction to fluctuations in sounds of different frequencies in a controlled way. These were synthesised by combining two steady tones of similar frequencies as shown in Table I.

The frequencies of 40Hz and 60Hz were chosen because these are frequencies which often occur in complaints about LFN.

Eighteen subjects took part, the profile of the subject group being summarised in Table II. Each subject took part in three listening sessions and one training session, each lasting 20 minutes.

## AUDIOMETRIC TESTS

A conventional audiometric test was conducted on each subject over the frequency range 250Hz-6kHz so as to show up any hearing defects that could affect the results. In addition, low frequency audiometric tests were carried out in an anechoic chamber using pure tones played through a loudspeaker at the third octave band centre frequencies between 31.5 and 160Hz.

*Table I Details of how the beating tones were synthesised*

| 40Hz beating tone | 60Hz beating tone |
|---|---|
| Formed from two tones: | Formed from two tones: |
| 40Hz at 0dB | 60Hz at 0dB |
| 41.5Hz at-8dB | 61.5Hz at-8dB |

*Table II Make up of subjects for laboratory tests by group*

| Group | Average ages | Sex | Total | |
|---|---|---|---|---|
| Group 0 | 62 | 3F | 3 | subjects known to be disturbed by low frequency sounds |
| Group 1 | 60 | 5M, 3F | 8 | subjects with the age profile of typical sufferers (55-70 year old) but without a history of disturbance by low frequency noise |
| Group 2 | 32 | 2M, 5F | 7 | subject from a younger age group chosen at random |
| All | 50 | 7M, 11F | 18 | |

## 3. TEST RESULTS

### 3.1 THRESHOLD OF ACCEPTABILITY FOR REAL SOUNDS

The thresholds of acceptability for the real sounds are shown in Figure 1 for all subjects in the 'night time' situation. Note that the ordinate is given in terms of the time averaged sound pressure level, or $L_{eq}$. There is a wide spread of results which might be expected given the wide range of hearing thresholds. However, the lines are surprisingly parallel, which shows that all subjects responded in a similar way to the various sounds, but at a different overall level.

Figure 2 shows the same data as Figure 1, but averaged by group. We see that group O (sufferers) is less sensitive in absolute terms than the other two groups, by about 2dB. There is no significant difference in the responses of the other two groups. Subjects were generally more tolerant of track 1 (which displayed the smallest fluctuations) by about 5dB, and judged the other four sounds to be similar in terms of their acceptability.

We would expect the acceptability thresholds set to depend on the hearing thresholds. Therefore, it is useful to look at the difference between these two thresholds for each subject. These figures are given in Figure 3 for night time and Figure 4 for day time. Two interesting points come out of these figures:

- sufferers tend to set acceptable levels close to their threshold of hearing, both day and night

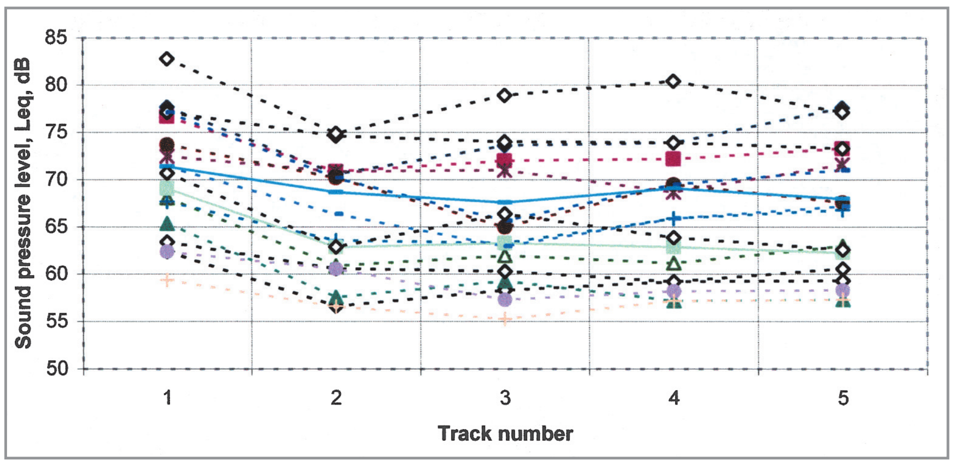


*Figure 1* *Night-time thresholds of acceptability to real sounds, all subjects*

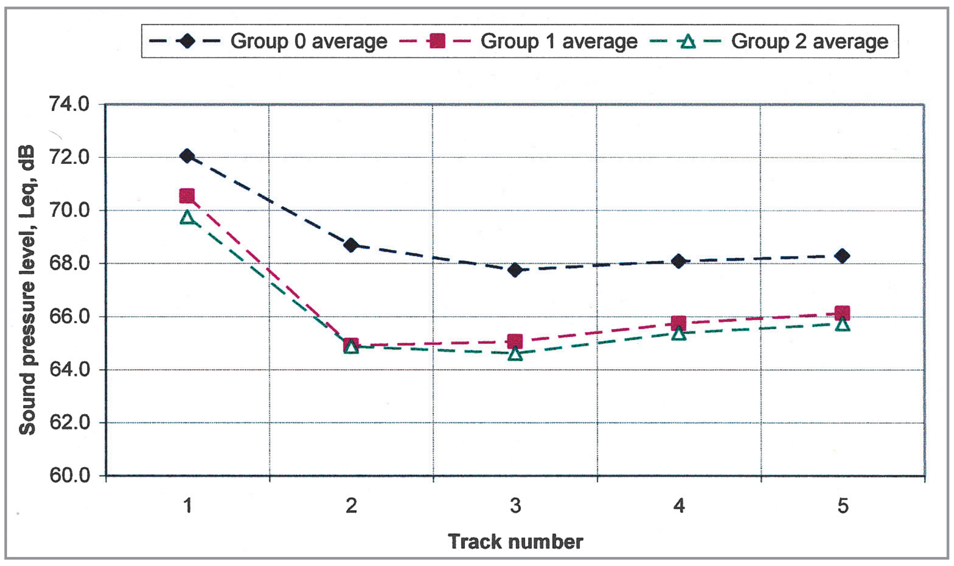


*Figure 2* *Night-time thresholds of acceptability to real sounds, averaged by group*

- the youngest group was most tolerant, and the older group less so to these sounds.

On average respondents set the night time thresholds 2dB lower than for the day. The difference between day and night was almost identical for each sound, which gives some confidence that there is not a qualitative difference in the sounds, with some sound being relatively more disturbing at night.

## 3.2 THRESHOLD OF ACCEPTABILITY FOR 'BEATING' TONES

In Figure 5 and Figure 6 are shown the night and daytime thresholds respectively, averaged by group. There are several clear trends.

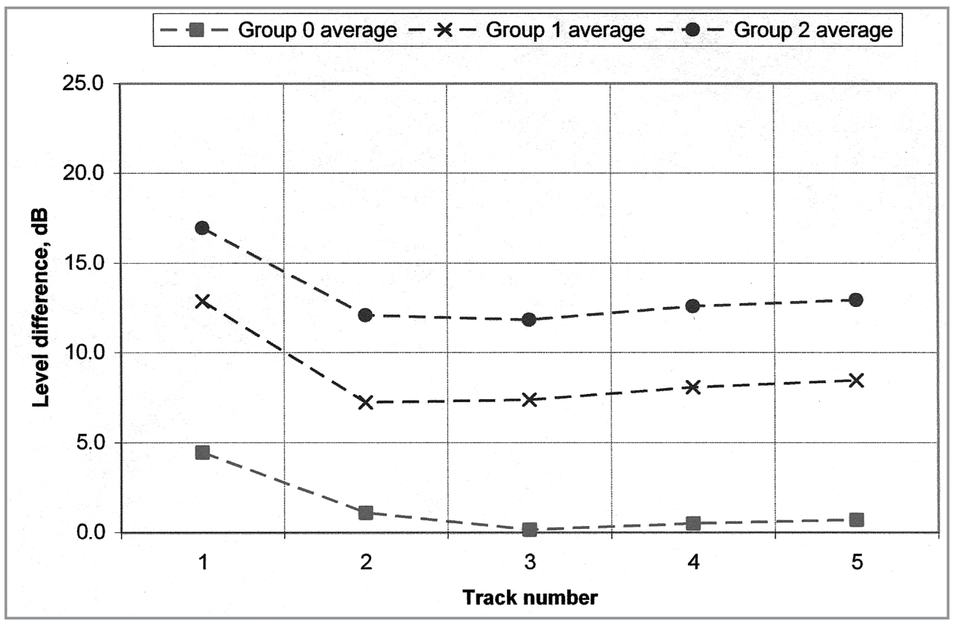


*Figure 3* *Night-time thresholds of acceptability relative to hearing threshold for real sounds, all subjects*

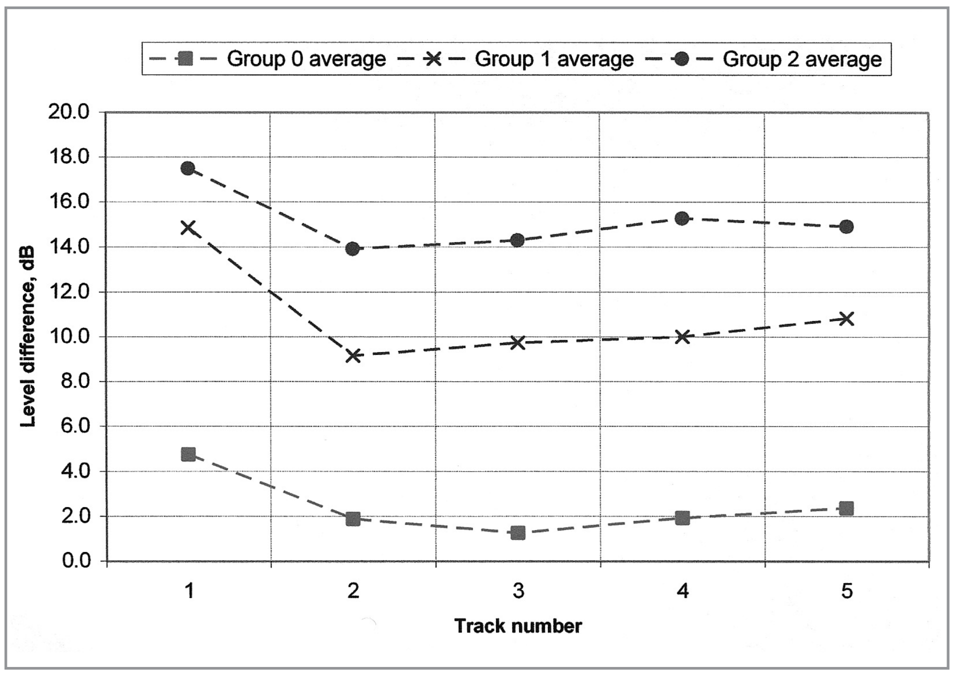


*Figure 4* *Day-time thresholds of acceptability relative to hearing threshold for real sounds, by group*

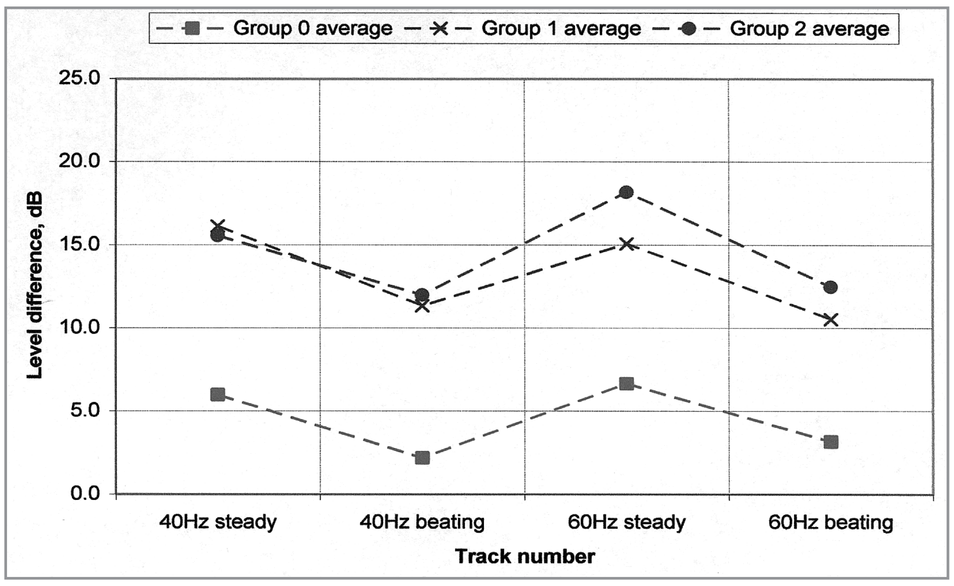


*Figure 5* *Night-time relative acceptability thresholds for beating tones by group.*

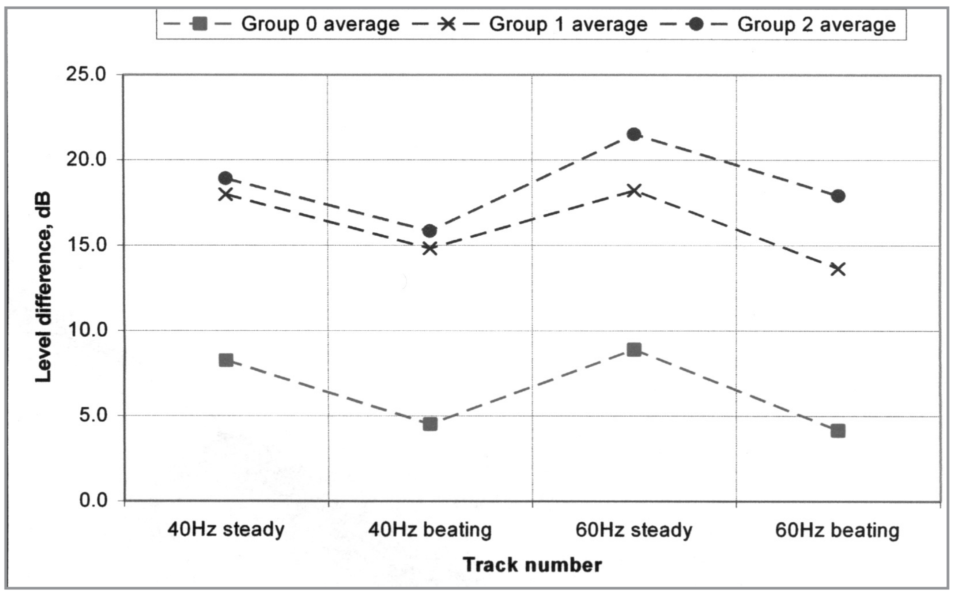


*Figure 6* *Day-time relative acceptability thresholds for beating tones by group.*

Firstly, as before, Group O (sufferers) is the most sensitive group in relative terms, setting the acceptability threshold only 2-3dB above audibility threshold for night time beating tones. Secondly, subjects were more tolerant of the steady tones than of the corresponding beating tone by 3-5dB. Thirdly, daytime levels were set an average of 3-4dB higher than the corresponding night time levels. Lastly, the effect of the beating on the response was essentially the same for day and night. These last two points are emphasised further in Figure 7.

## 4. QUANTIFYING THE EFFECT OF FLUCTUATIONS

Having quantified subjective response to fluctuating sound, in this section an objective parameter is sought that reflects the responses. The fluctuation strength [Terhardt] was evaluated for sounds from the field studies, but was found to give no correlation with a subjective sense of fluctuation. Therefore, although it sounds promising, this parameter (primarily used in the vehicle industry) was not considered further.

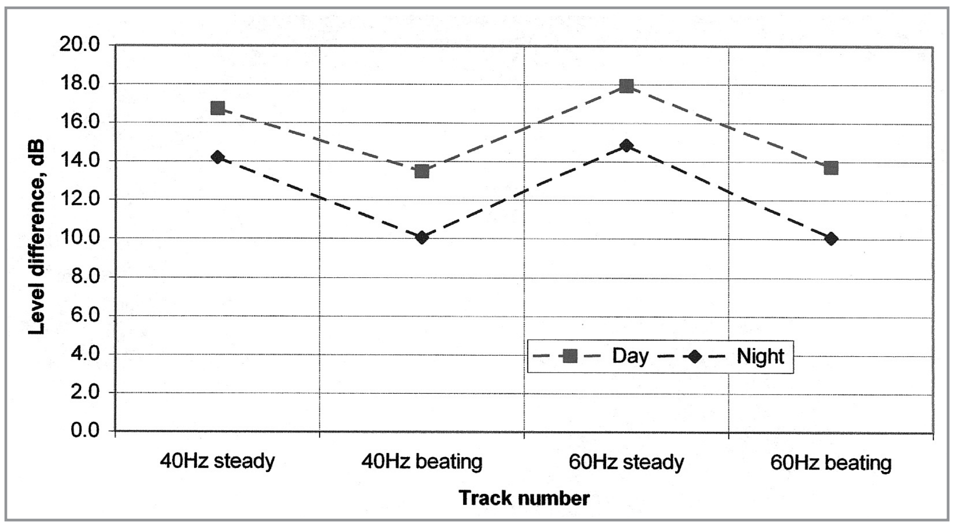


*Figure 7* *Comparison of day and night-time relative acceptability thresholds for beating tones, average of all subjects*

An alternative measure of the fluctuations is to look at the statistical distribution of the sound pressure level sampled at set intervals. Figure 8 shows the probability distribution plots from a 30 second sample of the 5 real sounds normalised to a mean level (Leq) of 60dB. The height of each bar represents the length of time spent at a particular sound level. The width of the distribution is a measure of the variation in the sound. For example, Track 1 shows the least variation, the sound level varying only by ±3dB from the mean, apart from a small 'tail' of lower levels, whereas track 4 has a wider spread*. The spread of the results can most conveniently be described by the difference between the statistical parameters $L_{10}$-$L_{90}$ (sometimes called the noise climate). These parameters are available on most modern sound level

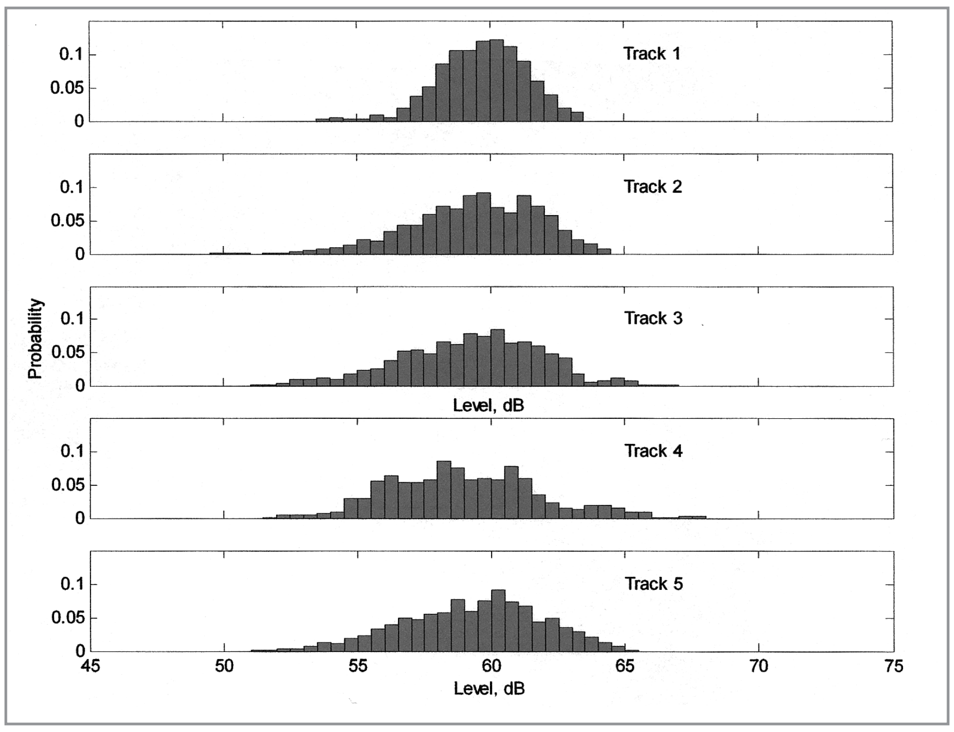


*Figure 8* *Distribution plots for sound levels for real sounds, Tracks 1-5*

*Sounds can be heard on http://www.acoustics.salford.ac.uk/lfn.htm meters. The values for the five real sounds are shown in Table III. Comparing with Figure 3 and Figure 4 there seems to be some correlation with the thresholds of acceptability. In particular, track 1 has a highest threshold of acceptability typically 5dB higher than the others and also the lowest value of $L_{10}$-$L_{90}$.

The relative thresholds of acceptability are plotted in Figure 9 against the value of $L_{10}$-$L_{90}$ for the each sound. The points are the average for all subjects. Included on the plot are the values for the five real sounds (diamonds), pure tones at 40 and 60Hz (circles) and beating tones (squares – there are two points for beating tones at 40 and 60Hz, but they are so close together they cannot be distinguished).

In interpreting Figure 9 it is helpful to describe some findings from one of the preliminary tests. Here subjects were played a sequence of beating tones with varying degrees of fluctuation. We found that the thresholds of acceptability were set at about the same level for the various beating tones, but that there was a clear difference of about 5dB from those for the steady tones. Arguably, Figure 9 also displays this trend: the most fluctuating sounds, represented by points to the right, were given a 'penalty' of about 5dB compared with steady sounds on the left. This penalty does not go on increasing as the $L_{10}$-$L_{90}$ increases, but 'bottoms out' above $L_{10}$-$L_{90}$ greater than about 6dB. There is a transition region for $L_{10}$-$L_{90}$ of between 4 and 6dB where the penalty varies on a sliding scale between 0 and 5dB (as marked in dotted lines). The overall trend can be simplified without much loss of accuracy by ignoring this short transition range. The simplified trend can then be described as follows:

- $L_{10}$-$L_{90}$<5: no penalty
- $L_{10}$-$L_{90}$≥ 5: penalty of 5dB.

This is in a form that could be used by environmental officers to decide whether to apply the 5dB penalty.

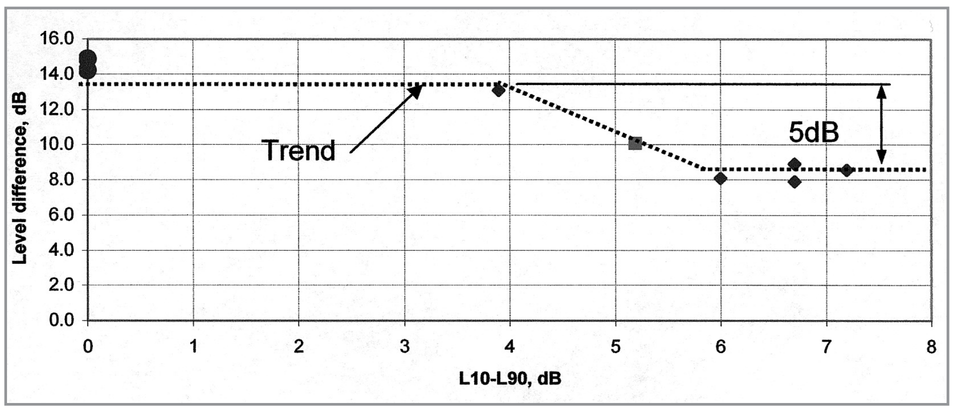


*Figure 9* *Night-time relative acceptability thresholds for real sounds and beating tones for all subjects: variation with $L_{10}$-$L_{90}$.*

*Table III L10, L90 and rate of change of level for a 30 second sample of the real sounds used in the laboratory tests*

| | Track 1 | Track 2 | Track 3 | Track 4 | Track 5 |
|---|---|---|---|---|---|
| L10,dB | 61.6 | 62.2 | 62.4 | 62.8 | 62.5 |
| L90,dB | 57.7 | 56.2 | 55.7 | 55.6 | 55.8 |
| L10-L90,dB | 3.9 | 6.0 | 6.7 | 7.2 | 6.7 |
| Average magnitude of rate Of change of level, dB/s | 15.6 | 23.6 | 24.4 | 22.4 | 22.7 |

## PROMINENCE

Although the above looks promising, the difference $L_{10}$-$L_{90}$ is not a foolproof parameter because it does not include any effect of the rate of fluctuations. The same value of $L_{10}$-$L_{90}$ can be obtained for a slowly varying and a rapidly varying sound, whereas experience suggests that they would be judged differently in terms of a threshold of acceptability. The main purpose of this section is therefore to find a way to distinguish between rapidly varying sounds (which should be given a penalty) and sounds that vary sufficiently slowly that they are to all intents and purposes steady, and which therefore should not be given a penalty.

A parameter has been investigated known as prominence [Pedersen]. This has been suggested for evaluation of impulsive sounds using the overall A-weighted sound level. In its original form it is not therefore suitable for low frequency sound. However, we can take part of the concept and adapt it for the current problem, namely the idea of assessing the rate of change of the rms Fast sound pressure level. (In fact the idea of using the rate of change of level has been around since at least the 1970s [Jacobsen]). In the method the start of an impulse is defined when the sound pressure level starts to vary by more than 10dB per second. We would like to establish whether this is an appropriate figure for our purposes.

Figure 10 shows the rate of change of level for a 30 second sample of the real sounds used in the laboratory. The time-averaged magnitude is also given in Table III. The sound level varies by considerably more than 10dB per second. This was true also for the beating tones, where the maximum slope was about 30dB/s, and the mean value 17dB/s. Thus, all the sounds used in the laboratory tests, except for the steady tones exceeded the 10dB/s value and would be classed as containing impulses according to the prominence method. However, for slowly varying sounds the 10dB/s value would not be exceeded. On the basis of these results then, the figure of 10dB/s seems suitable for the current purposes. Consequently, it is suggested that a sound only be considered to be fluctuating if the slope of the sound level (rms fast) curve exceeds 10dB/s. Fluctuating sounds would attract a 5dB penalty if the value of $L_{10}$-$L_{90}$ exceeds 5dB as described above.

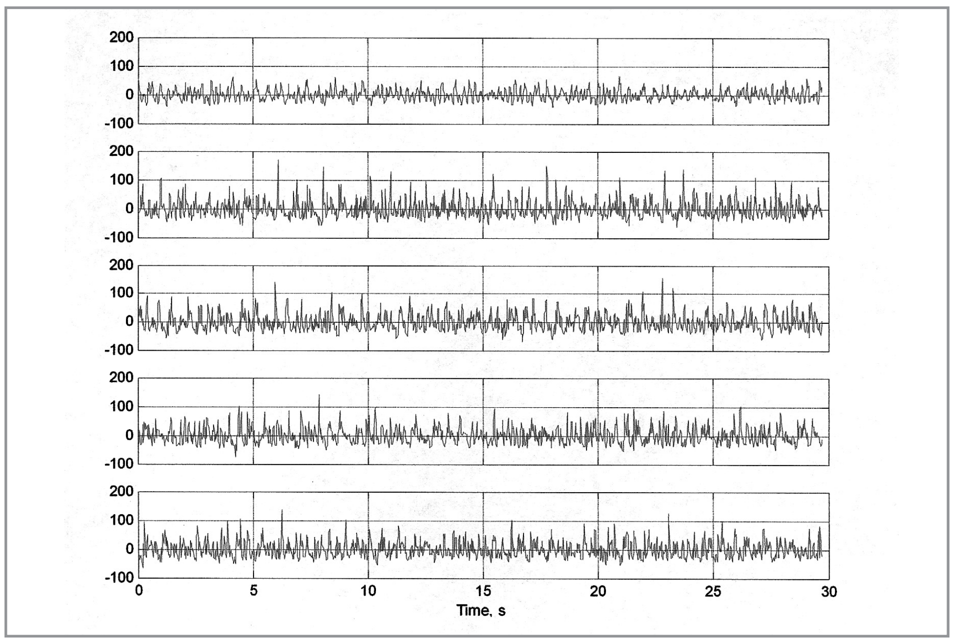


*Figure 10 Rate of change of rms Fast sound level in d/Bs for a 30 second sample of real sounds*

## CONCLUSIONS

In absolute terms, the sufferers in these tests were the least sensitive group to low frequency sounds. A major factor in this is that their thresholds of hearing were higher than other groups. We should avoid strong general conclusions because only three sufferers were tested, and there was variation between them. Nevertheless, this finding contradicts the view sometimes expressed that LFN problems are a result of exceptional sensitivity.

In relative terms, sufferers tend to set the threshold of acceptability much closer to the threshold of hearing than other groups. Whether this is because they are naturally less tolerant, or have become sensitised by exposure is not known and probably never will be.

Thresholds of acceptability were set typically 4-5dB higher for sounds with strong fluctuations than for steady sounds. This is consistent with the Danish standard method of adding a 5dB penalty for impulsive noise, as well as existing UK guidelines for other types of noise (not low frequency) where a 5dB penalty is added for noise with noticeable features. It is also consistent with previous published research [Bradley]. Therefore, we conclude:

- it is appropriate to penalise fluctuating sounds compared with steady sounds
- 5dB is an appropriate level for any such 'fluctuation penalty'.

The 'fluctuation strength' parameter is not successful at quantifying low frequency fluctuations. The most successful parameter was found to be the difference $L_{10}$-$L_{90}$ which has the additional advantage that it is generally available on sound level meters. Results suggest that a penalty for fluctuations is appropriate when this value exceeds 5dB. In addition, a sound should only be considered fluctuating when the rate of change of the rms fast sound level in the third octave band of interest exceeds 10dB per second.

Night time thresholds of acceptability were set 2-3dB lower than the corresponding day time limit. This is a slightly lower difference than the 5dB day-time relaxation used in the German standard. However, it is likely that, if anything, this difference is underestimated in the laboratory tests, see [Inukai et al] due to difficulty in reproducing realistic night-time conditions in the laboratory. The figure of 5dB is an appropriate amount by which to relax the limits for sounds only present during the day.

There was consistency in the effect of fluctuations for day and night. Therefore, the procedure used to assess fluctuations can be applied equally to night and day.

## ACKNOWLEDGEMENTS

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http://www.defra.gov.uk/environmen/noise/research/lowfrequency/index.htm

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**LOW FLYING COMPENSATION**

A total of £4.1 million was paid out following complaints about low-flying military aircraft. Out of a total £67 million compensation paid out by the MoD last year, £4.1 million was for complaints about noise from low flying aircraft. Within that was £126,565 to a farmer for the loss of pedigree cattle after Chinook helicopters were sent into demolish hilltop sites in South Armagh, Northern Ireland, and in the Balkans a payment made to a beekeeper whose hives were disrupted by aircraft noise.

**DANGEROUS MUSIC**

Decibel-loving drivers are not just risking their hearing, they're also risking their safety, says British drivers' rights organisation the RAC Foundation. It backed UK MP Dr Tony Wright's call for antisocial in-car stereos to be run off the road. Wright told the House of Commons "Research carried out by the RAC Foundation found that drivers who were listening to loud music with a fast beat were twice as likely to go through a red light, and that they have twice as many accidents. Cocooned in their sound bubble, they are oblivious to other road users and to their general environment." Research showed that, while improvements in technology mean car engines were 50 percent quieter than ten years earlier, factory-fitted car stereos had become more powerful and aftermarket units more affordable. Environment minister Ben Bradshaw said: "I wonder how many people have been distracted by the sudden 'Boom" Boom! Boom!' coming from one of those cars, wondering what on earth was happening as the ground shook to the heavy thud of some violent bass beat?" He compared the volume of a top-of-the-range sound system with a jet aircraft taking off and reminded drivers that anyone exposed to that level of sound in their workplace would have to wear ear protection. The RAC Foundation's noise research shows:

* Noisy cars are the second most irritating neighbourhood noise in the UK.
* Drivers listening to music with a fast beat are twice as likely to go through a red light and have twice as many accidents.
* A typical car stereo can produce 110 dB; noise levels of more than 85dB for long periods can be expected to cause hearing loss.

**EGYPT**

By the end of this summer's tourism season Egypt is set to face two potential reductions: one, a decrease in noise pollution from the Russian 11-86 airliner; the other, is an expected reduction in tourist flow to the country as a result of the impending ban on the aircraft. The 350-passenger mid-range plane, used widely between Egypt and Russia for charter flights, is already banned in the European Union due to safety concerns and its non-compliance with noise and environmental requirements. It has consequently become the most commonly flown plane from Russia to Egypt and Turkey. A ban on the 11-86 has been pending since 2002. Interest in keeping tourism rates up, however, has delayed any action. Egypt says this is the last time the ban will be postponed. Industry analysts say the ban, if applied, will likely raise flight prices to Egypt and decrease the influx of Russian tourists, currently estimated at about 900,000 per year. When the airplane was banned by the European Union, tourist flow from Russia into Cyprus and Bulgaria decreased by 25 percent.