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an investigation of twenty-one cases

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Low-frequency-noise complaints: an investigation of twenty-one cases

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Summary

From 203 cases of low-frequency complaints a random selection of twenty-one cases were investigated. The main aim of the investigation was to answer the question whether the annoyance is caused by an external physical sound or by a physically non-existing sound, i.e. low-frequency tinnitus. Noise recordings were made in the homes of the complainants, and the complainants were exposed to these in blind test listening experiments. Furthermore, the low-frequency hearing function of the complainants was investigated, and characteristics of the annoying sound was matched. The results showed that some of the complainants are annoyed by a physical sound (20-180 Hz), while others suffer from low-frequency tinnitus (perceived frequency 40-100 Hz). Physical sound at frequencies below 20 Hz (infrasound) is not responsible for the annoyance – or at all audible – in any of the investigated cases, and none of the complainants has extraordinary hearing sensitivity at low frequencies. For comparable cases of low-frequency noise complaints in general, it is anticipated that physical sound is responsible in a substantial part of the cases, while low-frequency tinnitus is responsible in another substantial part of the cases.

1. Introduction

Many cases of noise annoyance deal with noise that has a significant content of low frequencies and the complainants typically describe the noise as "rumbling". The cases are often solved, either by use of traditional noise limits and measurement methods, or by use of special low-frequency procedures as introduced by some countries: Austria (ÖNORM S 5007 1996) , Denmark (Miljøstyrelsen 1997) (explained in (Jakobsen 2001)), Germany (DIN 45680 1997) , Poland (Mirowska 1998) (explained in (Mirowska 2001)), The Netherlands (Nederlandse Stichting

Geluidhinder 1999) , Japan (Ministry of the Environment 2004) (explained in (Kamigawara *et al.* 2004)), Sweden (Socialstyrelsen 2005) (criteria) and (Simmons 1996) (measurement procedure, translated and explained in (Socialstyrelsen 1996)).

However, there is a group of cases where persons claim to be annoyed by rumbling noise, but where they are not helped in a way that they find satisfactory. This often leads to repeated complaints, anger at authorities, feeling of helplessness, and reports in the daily press. To a certain extent, these cases have some common characteristics. There is often no obvious noise source, and often only one or a few persons are annoyed. Many of the cases are in areas that are generally quiet, and, if measurements are made, they often show low values.

From 203 cases of low-frequency-noise complaints a random selection of twenty-one cases were investigated. The main aim of the investigation was to answer the question whether the annoyance is caused by an external physical sound or by a physically non-existing sound, i.e. low-frequency tinnitus.

This paper contains only a brief overview of the investigation. For more details see the published article (Pedersen *et al.* 2008) .

2. Experimental design

Noise recordings were carefully made in the homes of the 21 complainants, taking into account the possible problems caused by standing waves. The complainants were exposed to these recordings from their own home in blind test listening experiments carried out in a special low-frequency test facility (Santillan *et al.* 2007) . Furthermore, the low-frequency hearing function of the complainants was investigated, and characteristics of the annoying sound was matched. Based on the outcomes of these tests, complainants can be divided into the following three categories:

1. The complainant could hear the recorded sound and reported that it resembled the annoying sound.
2. The complainant could hear the recorded sound but reported that it did not resemble the annoying sound.
3. The complainant could not hear the recorded sound.

For the first and last categories, natural conclusions are that the annoyance felt at home is caused, respectively not caused, by a physical sound. For complainants who fall into the second category, there is no obvious and straightforward conclusion, and it may not be possible to make a final conclusion.

For the sounds that were heard, blind tests and recognition tests were made for the sounds divided into four frequency sub-bands in order to reveal, which frequencies are audible and possibly responsible for the annoyance.

3. Results

From the results of the blind test listening experiments with the recordings from the subjects homes it was possible to categorize the subjects as seen in Table 1. Seven subjects could hear the sound recorded in the home and recognize it as the annoying sound, which shows that these subjects are annoyed from a physical sound. Five subjects could not hear the sound recorded in their home, which means that they are not annoyed by a physical sound, but rather a type of tinnitus. The remaining subjects could hear the sound, but did not think that it resembles the annoying sound, which makes it difficult to conclude on these subjects. The focus in this section will be on the cases with annoyance from physical sound. For more results see the published article (Pedersen *et al.* 2008) .

Category	Description	Subjects
1	**Heard. Resembles annoying sound**	B, E, H, I, P, Q, R
2	**Heard. Does not resemble annoying sound**	D, F, G, K, L, M, N, O, S
3	**Not heard**	A, C, J, T, U

Table 1: Division of subjects into categories based on the results from the blind and recognition tests with original recordings x.

A more detailed analysis of the results for the subjects who are annoyed from a physical sound (category 1) can be seen in Figure 1, where third-octave spectra of the sound, individual hearing threshold, equal-loudness and matching results are shown for each subject. It is obvious from these results that the subjects are annoyed by a low-frequency sound with frequencies below 180 Hz.

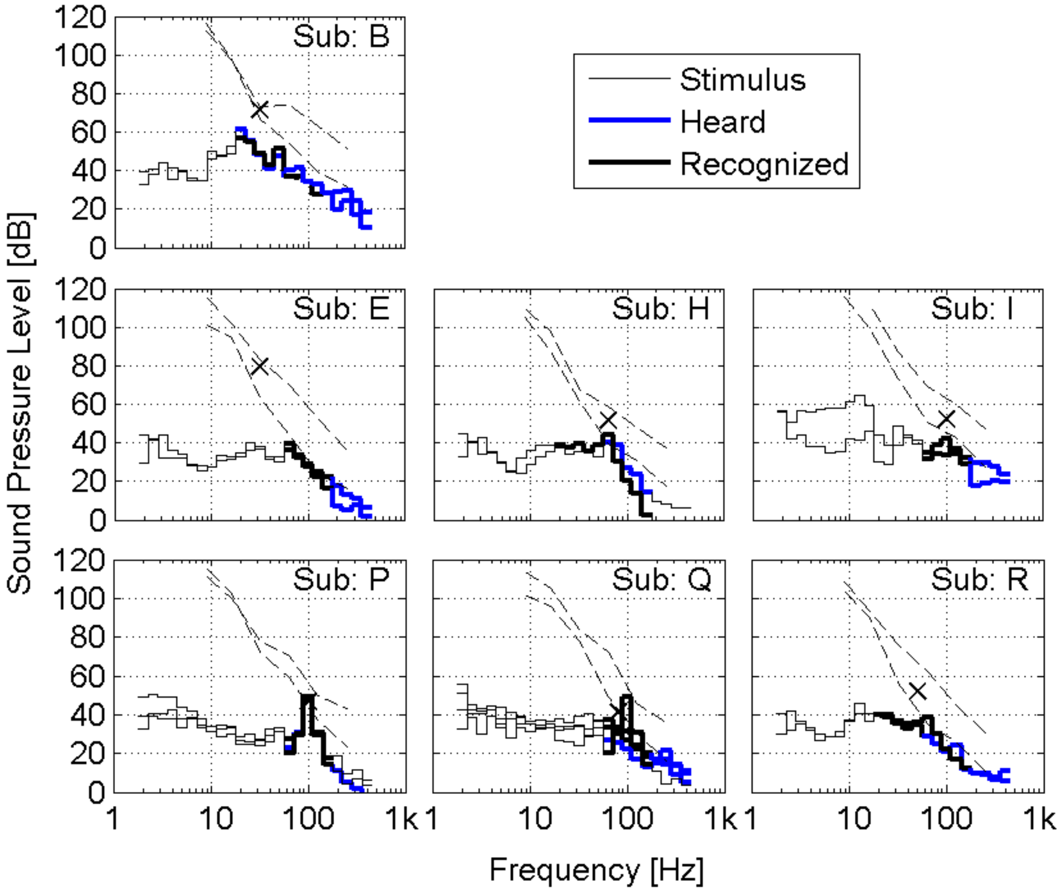

Figure 1: Individual data for seven subjects annoyed by a physical sound: Third-octave analysis of the stimuli, where the thick lines in blue and black represent a frequency range audible to the subject at natural level (from blind tests with filtered sounds) and black is the most resembling frequency range (from recognition tests with filtered sounds). Dashed lines show individual hearing thresholds and equal-loudness contours. Results from the matching experiment are shown as an x.

A narrow band frequency analysis of the sound found in the home of the seven subjects annoyed by a physical low-frequency sound is shown in Figure 2. It was not within the scope of the investigation to find the noise source, however, in general the sound in all seven cases contains combination of low-frequency tones. This indicates that the source(s) in each case has rotationary parts or pistons running at fixed (revolution) frequencies (e.g. pumps/compressors, engines, fans and ventilation systems).

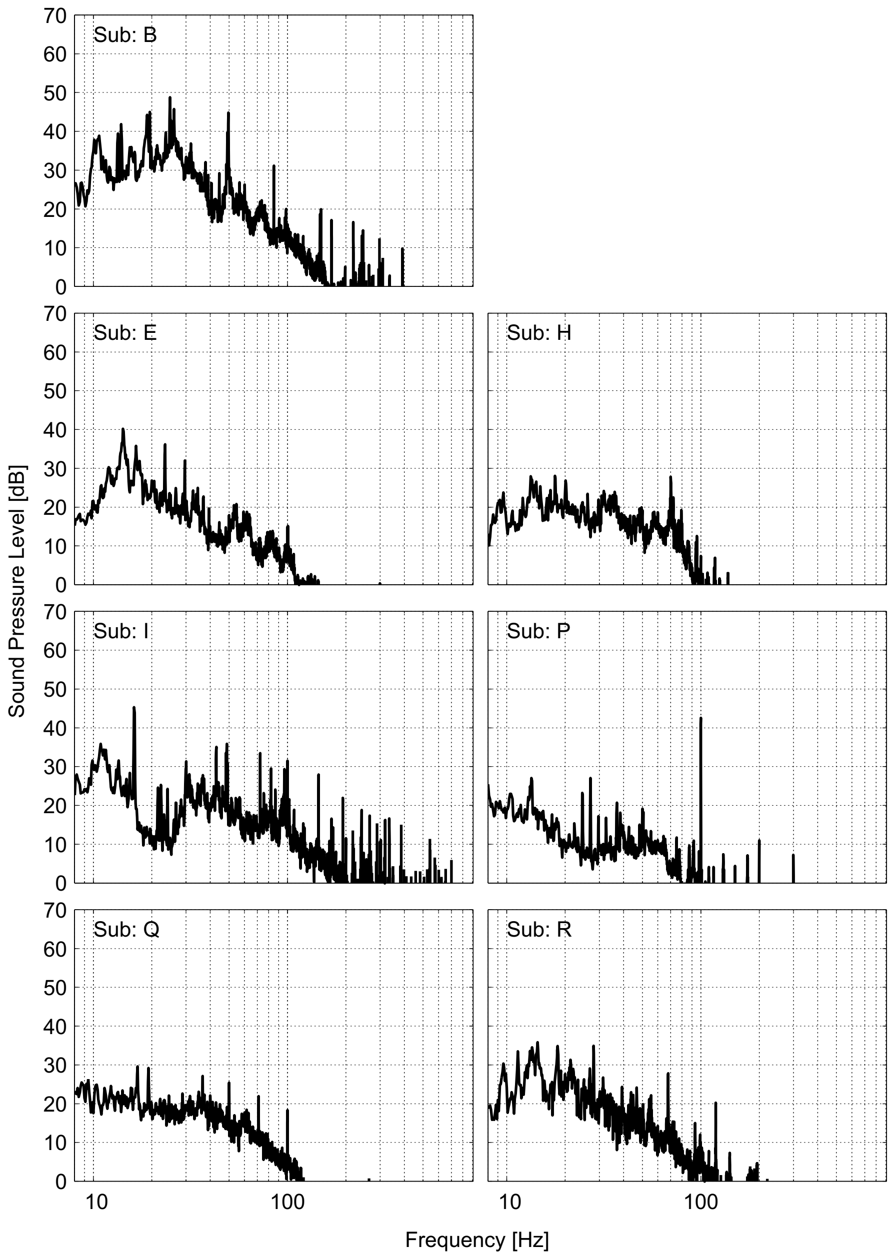

Figure 2: Power-average of FFT spectra with 0.1 Hz frequency resolution (50% overlap Hanning window) from the eight corner positions for each of the clear low-frequency noise cases.

4. Evaluation of cases by Danish and Swedish low-frequency noise guidelines

The seven cases in category 1, where the annoyance is explained by a specific physical sound, are evaluated using the Danish and Swedish guidelines. Figure 3 shows results of the two methods as well as the power average of the eight 3D-corners for the longest possible undisturbed periods. With the measurement positions used, three different outcomes exist of the Swedish method and 24 of the Danish method. For all measurement methods, third-octave levels are given as well as G-weighted levels (L_{pG}) and A-weighted levels for the 10-160 Hz frequency range ($L_{pA,LF}$ as defined by the Danish guidelines). The figure also shows the limits for third-octave levels given by the Swedish guidelines and the limit for dwellings given by the

Danish guidelines to $L_{pA,LF}$ (25 dB at daytime, 20 dB evening and night). The Danish limit of 85 dB for L_{pG} is above the scale in the figure.

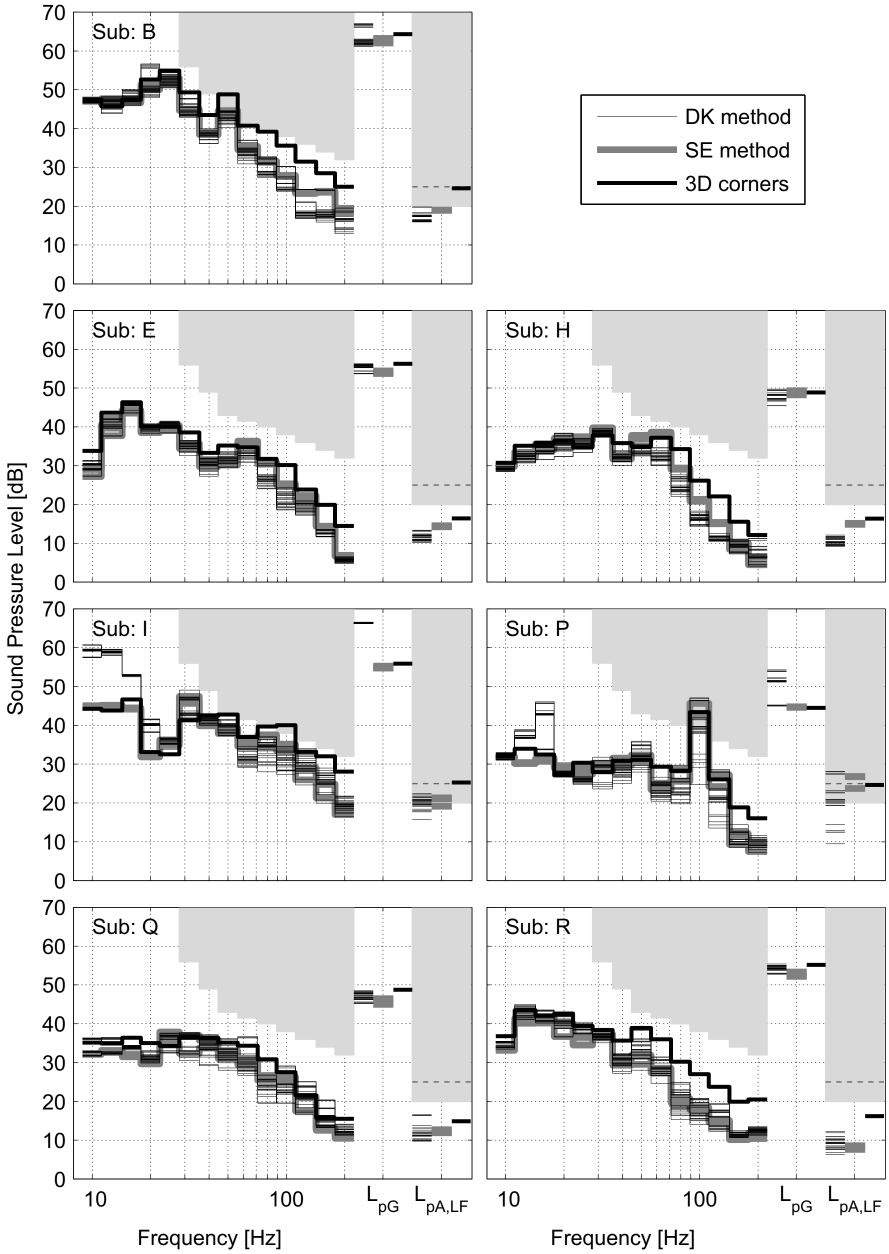

Figure 3: Comparison of all possible outcomes of the measurement methods compared to the Danish and Swedish limits. The grey areas represent the limits in Denmark (for $L_{pA,LF}$) and Sweden (for third-octave levels). The Danish L_{pG} limit of 85 dB is above the scale and not shown. For the L_{pG} and $L_{pA,LF}$ the lines are plotted in the order: DK method, SE method, and 3D corners.

5.1 Measurement methods

It is not within the scope of the present investigation to evaluate measurement methods, but a few comments are appropriate. At the lowest frequencies (<25-50 Hz, probably depending on room size), the third-octave levels generally demonstrate a good agreement between methods. This is natural, since at these frequencies, the wavelength is large compared to the room dimensions, and the level varies less within the room than at higher frequencies. Exceptions are seen in the results for subjects I and P, however, these are caused by differences in the sound between measurement periods rather than spatial variation. (The deviating spectra are from the same recording period). The agreement between methods at the lowest frequencies (and disagreement for subjects I and P) is reflected in the results for L_{pG}.

At higher frequencies, i.e. above 25-50 Hz, third-octave levels agree less well. There is even significant variation between different outcomes of the Danish method. The highest levels are usually obtained by the power average of 3D corners and the lowest by the Danish method. The variations above 25-50 Hz are also reflected in the results for $L_{pA,LF}$. The largest variation is seen for subject P, where levels obtained with the Danish method span a range of nearly 20 dB. In this case, the sound is dominated by a single third-octave band (actually a 100 Hz tone, see Figure 2).

The findings are in line with the results by (Pedersen *et al.* 2007) who proposed the level that is exceeded in 10% of a room as a target for measurements of low-frequency noise in rooms. This level is close to the highest levels in the room, however avoiding levels being present in only small parts of the room. Thus, it serves as a good estimate of the level that people will normally be exposed to in the room. They showed that, particularly the Danish measurement method has large uncertainty and high risk of giving results below the target.

5.2 Comparisons with limits

Of the seven cases, two (subjects B and P) have levels that exceed the Swedish limit (using the Swedish measurement method), and two (subjects I and P) have levels that exceed the Danish limits (using the Danish measurement method). For the latter, though, only some of the outcomes of the Danish method exceed the limits. However, the power average of 3D corners is above both the Swedish and Danish limits for all three cases.

The large uncertainty in measurement results of particularly the Danish method is a major problem in the assessment of such cases. The extremely large variation in the case of subject P has already been mentioned, but also the case of subject B is an unfortunate example. Values of $L_{pA,LF}$ above the 20 dB limit were actually seen in several of the original measurements (range 16.6-23.2 dB), but the selection procedure for positions in the Danish measurement method made the result end up in the range 16.9-19.8 dB. These are all below the limit of 20 dB, even when there is no doubt that the 20 dB limit is exceeded at many places in the room.

It is not within the scope of the present investigation to evaluate the national limits of Denmark and Sweden. However, it is worth noting that, even when using the best available measurement method (power average of 3D corners), and even when none of the complainants had unusual hearing sensitivity, the limits only indicate low-frequency problems in three out of the seven low-frequency noise cases. There are evidences in the literature that noise below the Danish limits can be annoying even for people who do not complain from low-frequency noise (e.g. (Poulsen 2003), (Inukai *et al.* 2004), (Inukai *et al.* 2006)).

6. Conclusions

The results showed that some of the complainants are annoyed by a physical sound (20-180 Hz), while others suffer from low-frequency tinnitus (perceived frequency 40-100 Hz). Physical sound at frequencies below 20 Hz (infrasound) is not responsible for the annoyance – or at all audible – in any of the investigated cases. None of the complainants has extraordinary hearing sensitivity at low frequencies. For comparable cases of low-frequency-noise complaints in general, it is anticipated that physical sound is responsible in a substantial part of the cases, while low-frequency tinnitus is responsible in another substantial part of the cases.

Microphone positions are critical in indoor low-frequency noise measurements. This problem is insufficiently addressed in the Danish guidelines for low-frequency noise measurements, and results obtained with these may be encumbered with significant uncertainty. When appropriate measurement methods are used, the Danish limits are exceeded in three out of the seven cases caused by physical low-frequency noise.

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