What Describes the Airborne Sound Insulation in Technical and Subjective Regard?

Reinhard O. Neubauer
University of Sheffield UK, R.Neubauer@sheffield.ac.uk

Jian Kang
University of Sheffield UK, j.kang@sheffield.ac.uk

Summary

The airborne sound insulation is an important quality factor for a building. While a primary concern in sound insulation is to protect people's well-being and health, mentally and physically, in the currently used descriptors, there is a lack of consideration based on research in this regard, and also, there is a lack of coherent requirement in different countries. The technically derived values to fulfil the aim of protecting people from disturbing neighbourhood noise are generally not directly based on subjectively evaluated or on medically justified values. In this research, some indices commonly used to describe airborne sound insulation are discussed and consequently, comparisons with subjectively judged values of airborne sound insulation are made. The comparisons have been carried out using three broadband noise signals, namely pink, white and grey noise; and using two typical music samples, namely classic and rap music. Some psychoacoustic predictors have also been considered. In the presentation some preliminary results will be presented on this on-going study.

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1. Introduction

Current standards and regulations relating to sound insulation are in general based on the difference in sound levels from one side of a partition (e.g. a wall) to the other, indicating the sound transmitted through the partition. Acoustic tests relate sound loss through a partition at various frequencies then average the results to provide a single absolute value number. Basically, there are two different approaches for a single number rating. The first is a comparison with a reference curve what is used in most European countries following the procedure of ISO 717 [1] yielding the quantities: R_w, R'_w, $D_{n,w}$, and $D_{nT,w}$. The second is the A-weighted level difference R_A, D_{nAT}. The prediction models in the European countries are somewhat different in both the requirements to be met by the constructions and the calculation method [2, 3]. Also, the quantity used for rating the sound insulation of the constructions is different. On the other hand, the calculations in all European countries are based on single number ratings, but none takes into account the subjective estimation of such single number ratings. This might be the reason that despite the enforcement of sound insulation standards, many countries still observe increasing complains about sound insulation. Clearly what we hear and what we judge is a sound level intruding our ear and thus, it is important to examine this sound level. In this study, therefore, the transmitted sound level, i.e. the sound signal, has been analysed using software ArtemiS of HEAD acoustics V10.

2. Signal description

In this research three broadband noise signals, namely pink, white and grey noise, and two typical music samples, namely classic and rap music, were chosen for comparison. The chosen classical music was Beethoven: Symphony Nr. 9: Poco Allegro, Stringendo Il Tempo, Sempre Piu Allegro - Prestissimo, and the rap music was: "Eminem" with the song: "Loose Yourself". The signals are shown and analysed in Fig. 1 to Fig. 6.

The sound signal Beethoven used in this research had a time interval of 90 s and an overall sound pressure level (SPL) of 85 dB. The calculated loudness N was 50 sone and the fluctuation strength Fls was 0,106 vacil.

The sound signal Eminem had a time interval of 90 s and an overall SPL of 85 dB. The calculated loudness *N* was 38.5 sone and the fluctuation strength *Fls* was 0,356 vacil.

Figure 1. Time signal of Beethoven Symphony Nr. 9, with SPL of 85 dB, and duration of 90 s.

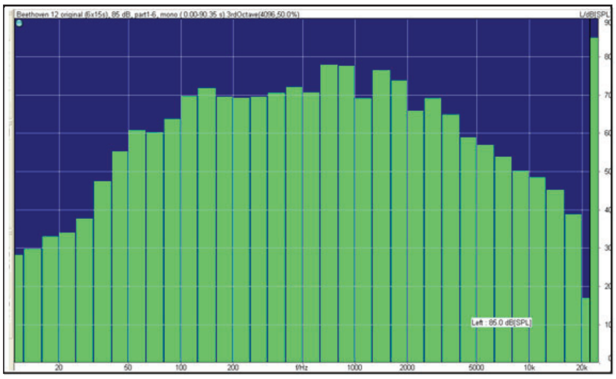

Figure 2. Beethoven, signal shown in 3rd octave bands over a frequency range up to 20 kHz.

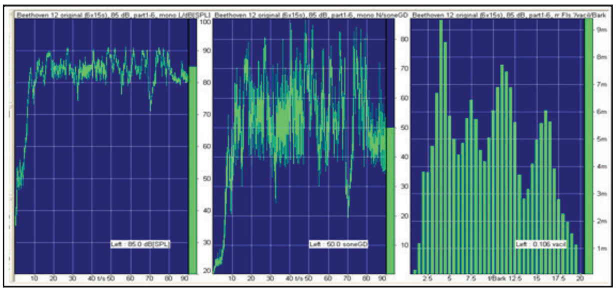

Figure 3. Beethoven Symphony Nr. 9, duration 90 s. Left to right: SPL in dB, loudness in sone and fluctuation strength in vacil.

In Fig. 7 the power spectral density over frequency is shown for the used random signals, i.e. the pink, white and grey noise. Pink noise, also known as 1/f-noise, is a signal with a frequency spectrum such that the power spectral density is proportional to the reciprocal of the frequency. There is equal energy in all octaves. In terms of power at a constant bandwidth, 1/*f*-noise falls off at 3 dB per octave. Pink noise is usually used to measure the sound insulation. White noise is a random signal with a flat power spectral density. The signal contains equal power within a fixed bandwidth at any centre frequency. Grey noise is a random pink noise corresponding to a psycho-acoustic equal loudness curve (such as an inverted A-weighting curve) over a given range of frequencies. It is supposed that grey noise provides a listener the perception that it is equally loud at all frequencies. This is in contrast to standard pink noise, which has equal strength over a logarithmic scale of frequencies but is not perceived as being equally loud due to biases in the human equal-loudness contour.

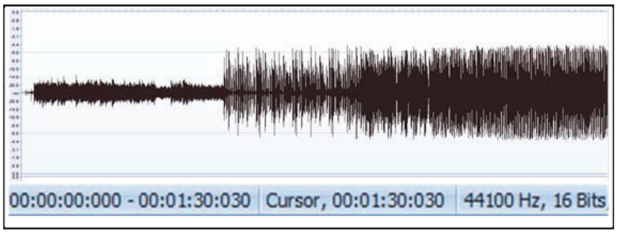

Figure 4. Time signal of Eminem - Lose yourself, 85 dB SPL, 90 s.

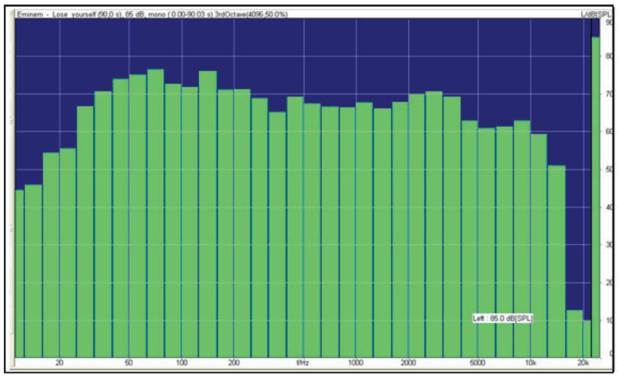

Figure 5. Eminem, signal shown in 3rd octave bands over a frequency range up to 20 kHz.

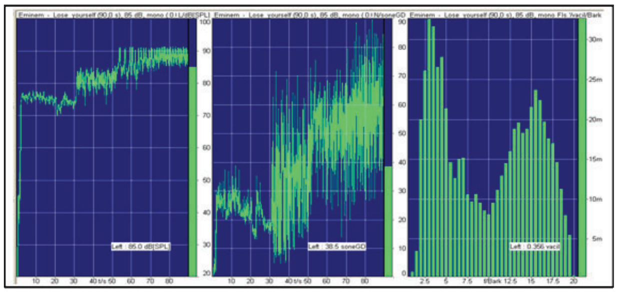

Figure 6. Eminem, duration 90 s. Left to right: SPL in dB, loudness in sone and fluctuation strength in vacil.

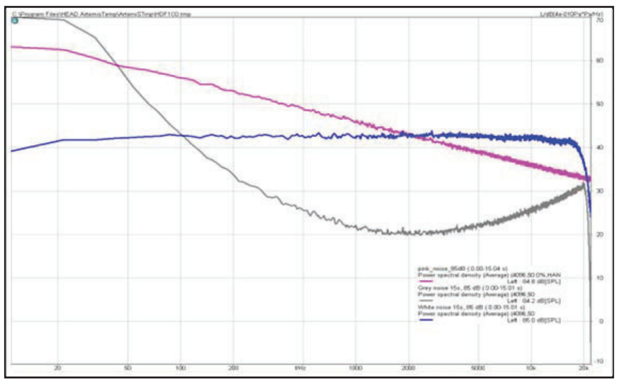

Figure 7. Power spectral density (PSD) of pink, white and grey noise as a function of frequency in the range of 20 to 20k Hz.

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This is in contrast to standard pink noise, which has equal strength over a logarithmic scale of frequencies but is not perceived as being equally loud due to biases in the human equal-loudness contour.

3. The Sound Level after Transmission

In this study a partition is regarded as a signal filter to the unprocessed sound signal. The filters, i.e. the coefficients of the built transfer function, are generalised damping coefficients in the frequency range 50 to 5k Hz characterising the frequency dependent R-values. No dips in the filter function are introduced in this investigation, i.e. the R-values are continuously rising with increasing frequency. The R-values are varied from 10 to 60 dB in step of 10 dB, which are shown in Fig. 8. It can be seen that grey noise gives highest receiving SPL whereas the lowest level is obtained using white noise. It is also interesting to note that using Eminem as a source signal leads to higher receiving SPL than Beethoven.

4. Loudness and Sound Pressure Level

The sensation that corresponds most closely to the sound intensity of the stimulus is loudness.
The loudness *N* of the above signals are presented in Fig. 9. Corresponding to Fig. 8, the loudness using pink noise gives higher values in sone as using Beethoven followed by white noise, Eminem and grey noise. It is observed that grey noise and Eminem yield highest level in SPL whereas in terms of loudness they yield lowest values. This may be interpreted as that, SPL and loudness do not well correlate in this study.

Roughness is often used for the subjective judgment of sound impression and for sound design. With increasing roughness, noise emissions are perceived as increasingly noticeable and usually as increasingly annoying. Fluctuation strength is also often used but the modulation frequency is around 4 Hz instead of 70 Hz as for the roughness. Since speech is related to a modulation frequency of about 4 Hz a sufficiently high modulation depth is necessary. In Fig. 10 the calculated roughness *R* and in Fig. 11 the specific fluctuation strength *Fls* for different source signals filtered with three different filter functions are shown. In Fig. 10 it can be seen that pink noise and white noise have highest roughness followed by Eminem, Beethoven and grey noise. In Fig. 11 Eminem is rather high compared to the other sound samples. There is no much difference between the three types of noise.
In Table I the calculated results are shown.

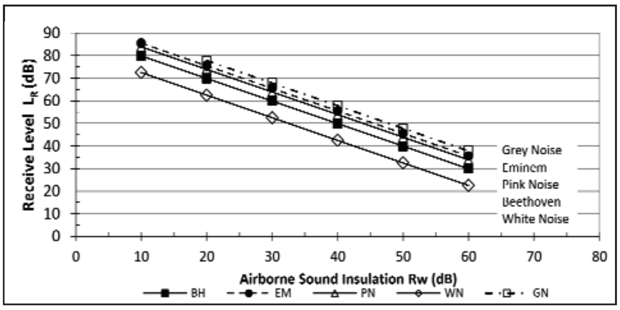

Figure 8. Different source signal in terms of SPL, filtered with filter functions of 10 to 60 dB in steps of 10 dB, with source signal of 85 dB.

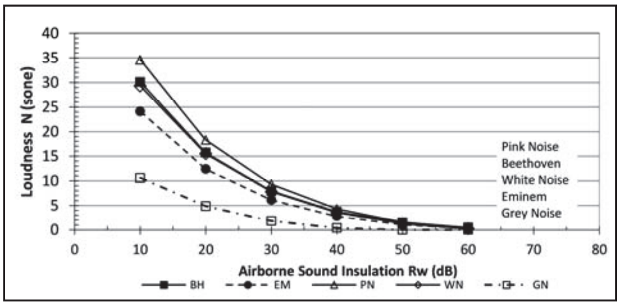

Figure 9. Different source signals in terms of loudness, filtered with filter functions of 10 to 60 dB in steps of 10 dB, with source signal of 85 dB.

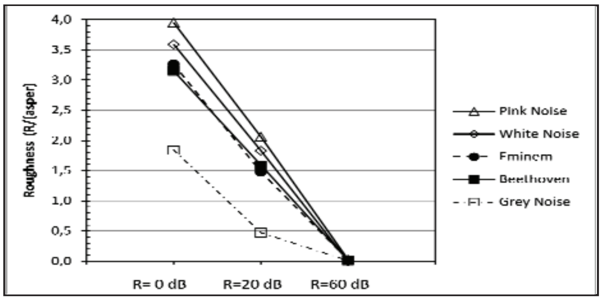

Figure 10. Comparison of roughness of different source signals filtered with filter functions of 0 dB, 20 dB and 60 dB.

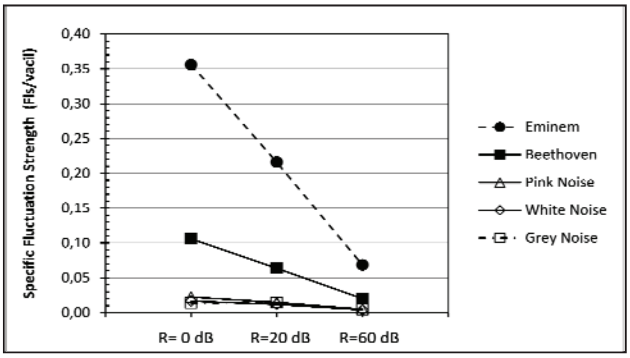

Figure 11. Comparison of specific fluctuation of different source signals filtered with filter functions of 0 dB, 20 dB and 60 dB.

Table I. Comparison of calculated results, receiving level *L2*, loudness *N*, spec. fluctuation strength *Fls*, and roughness *R*, respectively.

Filter Rw (dB)	0	10	20	30	40	50	60	
Pink Noise L2 =	85,0	82,1	72,1	62,1	52,1	42,1	32,1	dB SPL
N =	60,5	34,70	18,20	9,24	4,27	1,59	0,323	sone GD
Fls=	0,0223	0,0194	0,0146	0,0109	0,00819	0,00614	0,00461	vacil
R=	3,94	2,91	2,06	1,45	0,816	0,138	0,0185	asper
White Noise L2 =	85,0	72,3	62,3	52,3	42,3	32,3	22,3	dB SPL
N =	57,6	29,30	15,50	7,79	3,54	1,25	0,205	sone GD
Fls=	0,0166	0,0160	0,0120	0,00903	0,00677	0,00508	0,00381	vacil
R=	3,59	2,59	1,83	1,29	0,614	0,0	0,0	asper
Grey Noise L2 =	85,0	(85,3)	75,3	65,3	55,3	45,3	35,3	dB SPL
N =	19,2	10,20	4,72	1,75	0,33	0,00128	0,00	sone GD
Fls=	0,0137	0,0181	0,0136	0,0102	0,00763	0,00572	0,00429	vacil
R=	1,84	1,35	0,472	0,105	0,0446	0,0154	0,00901	asper
Beethoven L2=	85,0	79,5	69,9	59,9	49,5	39,5	29,5	dB SPL
N=	50,0	30,00	15,70	7,90	3,72	1,53	0,452	sone GD
Fls=	0,106	0,0853	0,0640	0,0480	0,0360	0,0270	0,0202	vacil
R=	3,15	2,30	1,59	1,06	0,589	0,193	0,0105	asper
Eminem L2=	85,0	83,8	73,8	63,8	53,8	43,8	33,8	dB SPL
N=	38,5	23,80	12,30	6,07	2,74	1,01	0,238	sone GD
Fls=	0,356	0,290	0,217	0,163	0,122	0,0917	0,0688	vacil
R=	3,26	2,24	1,49	0,897	0,349	0,0850	0,0202	asper

5. Subjective Estimation of Intrusive Sound

In order to test subjectively sound insulation, in this initial experiment a small number of nine persons, five women and four men, were ask to listen to some sound samples via headphone (Sennheiser HD 280 pro) and judge the sound by answering pre-coded questions. The median of age was 34. The subjects were asked to select one of the following answers: 0 - *I do not hear a sound*; 1 - *I can hear a weak sound*; 2 - *I hardly hear a sound*; 3 - *Yes I can hear a sound but not easily*; 4 - *Yes I can hear a sound when concentrate on it*; 5 - *Yes I can hear a sound*; 6 - *Yes I can clearly hear a sound*.

The sound sample offered in this initial listening test started with a reference signal with a SPL as a first unfiltered sound sample. The R-values were then varied from 20 to 50 dB in steps of 10 dB, and also with a maximum damping having 56 dB. The source signals as mentioned above were used. The results of the listening tests are shown in Tables II to V, where both means and standard deviations (sd) are shown.

It is seen that although all the sound samples used started with the same SPL of 85 dB, the filtered sound signal was differently judged by the test subjects.

In order to quote "*I hear a weak sound*" a damping of 50 dB was needed for all sound signals and in the case of "*I do not hear a sound*" the subjects scored this using pink noise and music for a damping of 56 dB.

In the case of white noise and grey noise the subjects still did quote, even for a damping of 56 dB. Eminem was judged "louder" (Tab.III: 5,4 ± 0,7) than Beethoven (Tab.III: 5,3 ± 0,7).

The music group was judged as: "*can hear / can clearly hear*", while the noise group was judged as: "*can hear when concentrate on it / can hear*". The two groups differe in judgment by one chategory, which means noise samples are judged not as loud as music sound samples.

It is surprising that overall the response was: "*can hear"* (Tab.V: 5,0 ± 0,7). This indicates, that even a sound insulation of 56 dB does not mean sound is not heard at all. The judgement is therefore depending on the characteristics of the sound itself.

Relating the subjective tests results with psychoacoustic parameters it is clear that even the loudness of Beethoven is higher than Eminem the subjective test states the opposite.

It might be concluded from this preliminary result, that loudness is not a reasonable descriptor for sound insulation. On the other hand, fluctuation strength *Fls* relates to the subjective tests better.

Table II. Mean and standard deviation of response distribution for data samples of white, pink, grey noise, respectively.

Signal	White Noise						Pink Noise						Grey Noise					
Filter (dB)	20	30	40	50	56		20	30	40	50	56		20	30	40	50	56	
Mean	6,0	5,67	5,11	4,44	3,89	**5,02**	6,0	5,67	5,56	4,56	4,33	**5,22**	6,0	5,56	4,56	2,89	1,67	**4,13**
sd	0,0	0,50	1,62	1,74	1,83	**1,08**	0,0	0,50	0,53	1,51	1,50	**0,70**	0,0	0,53	1,81	1,76	1,73	**1,03**

Table III. Mean and standard deviation of response distribution for data samples of Eminem and Beethoven.

Signal	Eminem						Beethoven					
Filter (dB)	20	30	40	50	56		20	30	40	50	56	
Mean	6,0	5,78	5,67	4,89	4,67	**5,40**	5,89	5,78	5,56	5,00	4,33	**5,31**
sd	0,0	0,44	0,50	1,36	1,66	**0,71**	0,33	0,44	0,53	1,12	1,50	**0,72**

Table IV. Mean and standard deviation of the grouped response distribution for the grouped data samples of noise and music.

Signal	Noise						Music					
Filter (dB)	20	30	40	50	56		20	30	40	50	56	
Mean	6,0	5,63	5,07	3,96	3,30	**4,79**	5,94	5,78	5,61	4,90	4,50	**5,30**
sd	0,0	0,31	1,2	1,48	1,29	**0,81**	0,17	0,26	0,42	1,20	1,52	**0,68**

Table V. Mean and standard deviation of of the overall grouped response distribution.

Signal	**All 20**	**All 30**	**All 40**	**All 50**	**All 56**	
Mean	5,980	5,690	5,290	4,360	3,780	**5,02**
sd	0,067	0,267	0,819	1,276	1,309	**0,72**

6. Conclusions

The results of this on-going study imply that it is highly depending what kind of excitation is used to be heard after being transmitted through a filter which is supposed to be a dividing partition. This result implies, that using pink noise as a test signal in order to measure the sound insulation does not relate well with heard sound.

It also turned out in this research, that using loudness as a measure to describe the intrusive sound does not describe the subjectiv estimated impression properly. The time structure of the signal seems to play a massive part in the subjectively judged sound. This was seen by comparison of fluctuation strength. It seems that the subjects required higher insulation using music as a source signal.

References

[1] ISO 717: Acoustics – Rating of sound insulation in buildings and of building elements. (1996).

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