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Analysis of the suitability of using the A-weighting filter for evaluating road traffic noise exposure

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Summary
A-weighted sound pressure level is the most widely used descriptor for evaluating noise annoyance. However, strong criticism is associated with the dB(A) scale because it overcompensates for the hearing system's reduced sensitivity at low frequencies. Thus, many authors claim against the using of A-weighted sound pressure level for assessing noise annoyance when the low frequency content is highly dominant since dB(A) units do not give a true picture of the annoyance potential for low frequency noises. For this reason, a listening test has been conducted with the goal of: (i) analyzing the convenience of using the A-weighted scale for evaluating sound environments characterized by the physical dominance of low frequency noise; and (ii) analyzing and quantifying the difference in audibility and perceived annoyance among broad-band low frequency (LF), medium frequency (MF) and high frequency (HF) noises. The obtained results suggest that the A-weighting filter properly describes the difference in perceived annoyance between LF and MF noises, but some improvements have to be undertaken in order to address a better description of the differences in perceived annoyance between both MF and LF noises and HF noises.

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1. Introduction

Under the typical circulation dynamics in urban environments, because of the prevailing contribution of engine noise, low frequency content has been found as (at least to some extent) physically dominant [1-2].
Although the A-weighted sound level is the main indicator for quantifying the annoyance of road-traffic noise, the dB(A) scale has been strongly criticized since it overcompensates for the hearing system's reduced sensitivity at low frequencies [3-4]. Thus, it is claimed that when the low frequency content is highly dominant the dB(A) unit does not give a true picture of the annoyance potential for low frequency noise [5]. However, in Alayrac et al. [6] the A-weighted sound level was proved to be adequate for assessing perceived annoyance evoked by low-frequency noises.

The disparity of results found in the literature regarding the contribution of low frequency content to the perceived annoyance or the relative importance of each frequency range (low, mid and high frequencies) on the prediction of noise annoyance leads to the lack of consensus as for the use of A-weighting for assessing road traffic noise. Thus, some studies suggest that sounds with similar A-weighted sound pressure levels are perceived as louder and more annoying the greater their low frequency content is [4,7]. Nevertheless, Versfeld et al. [8] found that the difference in level between the high frequency content and the low frequency content as a highly influential factor in explaining perceived annoyance, so that sounds containing relatively much high frequency content were judged as being more annoying than those having relatively much low frequency content. Also, Torija and Flindell [9] demonstrated that the physical dominance of low frequency in urban road traffic noise does not lead to subjective predominance (perceived annoyance).

For these reasons, this work is aimed at analyzing the performance of the A-weighting for assessing the road traffic noise annoyance under indoor conditions, where the low frequency content is physically dominant. Also, the audibility threshold and the annoyance evoked by wide-band low- (LF), mid- (MF) and high-frequency (HF) noises is quantified.

2. Methods

2.1. Experiment 1: Indoor conditions

A 12.5 s master recording of continuous urban main road traffic noise (L_{Aeq} = 69 dBA) was chosen as the basis for all the stimuli used in this experiment. The recorded master sound were carefully selected to avoid any extraneous noise sources other than continuous steady road traffic background noise with up to 5 individual vehicles being identifiable from time to time within the overall 12.5 second duration, but not prominent in the overall sound level time history. A filter for simulating the sound transmission through a window was applied. This filter was built using the values reported by Quirt [10] for a double 3-mm thick glazing, with an interpane spacing of 3 mm. After that, another filter was applied to simulate the reverberation effect (reverberation time = 0.5) of a typical medium-sized room. This filter was applied by using the software Sound Forge Pro 10.0.

The test sounds for this experiment were produced by boosting or cutting the LF (20-250 Hz), MF (315-2000 Hz) and HF (3150-20000 Hz) ranges. A low pass shelf filter and a high pass shelf filter were applied with – 9dB, -3 dB, + 3dB and +9 dB relative gain setting to synthesize the 8 filtered sound used in this test. The low pass shelf filter cut-off frequency was 315 Hz with a 0.1 octave transition. The high pass shelf filter cut-off frequency was 250 Hz with a 0.1 octave transition. The amplifier gain in the listening room was set so that the reference sound would play back at its corresponding sound level (L_{Aeq} = 50 dBA), and all the test sounds were then reproduced without changing the overall gain setting.

Before starting the listening experiment, the aims and procedures were carefully explained to the listeners. The relative magnitude estimation (RME) method was used for evaluating the test sounds. For each test and condition, the participants were required to record their subjective impressions by comparing the target stimuli to the reference sound, as to two subjective attributes: perceived loudness and perceived annoyance. It should be noted that a value of 100 was given to the reference sound as to both perceived loudness and annoyance. For each stimulus, the evaluation required 12.5 seconds for the reference sound and 12.5 seconds for the target sound with a 1 second gap between the two sounds and an allowance of 10 seconds for questionnaire completion. The order of presentation of the target sound was fully randomized.

2.2. Experiment 2: Audibility and perceived annoyance

In this experiment an 8 s master recording of the passing-by of an urban bus (L_{Aeq} = 68 dBA) was chosen as the basis for all the test sounds. This sound was selected because of its important content in LF (engine noise), MF (rolling noise) and HF (gas exhaust noise). This master sound was filtered into three components: (i) LF sound, where a high pass shelf filter (cut-off frequency = 250 Hz) was applied for subtracting MF and HF components; (ii) MF sound, where a low pass shelf filter (cut-off frequency = 315 Hz) and a high pass shelf filter (cut-off frequency = 2000 Hz) was applied for subtracting the LF and HF components; (iii) HF sound, where a low pass shelf filter (cut-off frequency = 2500 Hz) was applied for subtracting the LF and MF components. These three test sounds were normalized at 70 dB.

In the audibility threshold task, for each frequency range, the test sounds were reproduced simultaneously along with a 70 dB pink noise (L_{Aeq} = 67 dBA). Thus, the test sounds were varied in level from 50 dB (-20 dB ref to pink noise) to 74 dB (+4 dB ref to pink noise) in steps of 2 dB. At varying the level of the test sounds, the listener was asked to indicate when he/she was able to detect the road traffic sound.

In the perceived annoyance task, for each frequency range, the test sounds were reproduced along with a reference sound (70 dB pink noise), with their sound level ranging from 55 (-15 dB ref to pink noise) dB to 95 dB (+25 dB ref to pink noise) in steps of 5 dB. In this case, the listeners heard the reference sound and after a 2 s gap they heard an test sound. Once heard both sounds, the listeners were asked to indicate whether the road traffic test sound was perceived as less, equally or more annoying than the reference sound. This process was repeated, randomly varying the level of the test sound until the listener reported the test sound as equally annoying than the reference sound.

2.3. Participants

Sixteen adult listeners took part in this listening trial. All listeners were required to confirm normal hearing ability. The participants were paid a thank you gift as inducement to take part.

2.4. Equipment

The listening trials were conducted in a soundproofed room at the University of Southampton. All audio signals (.wav files) were generated via a mainstream laptop with a good quality sound card, and then sent to the loudspeakers via a small high quality audio mixing console. The test sounds were reproduced via 2 high-quality loudspeakers (Behringer Truth model B2031A). The reproduced sound levels were calibrated immediately before each trial using a class 1 sound level meter (Norsonic Environmental Analyser type 121, with a Norsonic free-field microphone type 1225) with the microphone placed at the positions which would be occupied by the listener's head. The amplifier gain was checked before each trial using a reference 80 dBA pink noise .wav file signal reproduced through the same system.

3. Results

3.1. Experiment 1: Indoor conditions

In Figure 1 is shown the relationship between perceived annoyance and the filter setting for the LF and the MHF regions. It is found that despite of the greater relative difference (compared to the reference sound) in perceived annoyance with increases in filter setting for LF region (especially in – 9 dB and + 9 dB) than with the same increases in filter setting for MHF region, a similar tendency is observed for both frequency regions. These findings seems to indicate that under these conditions, high physical dominance of the LF content, the variations in the LF content are marginally dominant in explaining differences in perceived annoyance, but also that the MHF content should be still taken into account.

Figure 2 shows the linear relationship (R^2-value) between the A-, C- and D-weighted sound levels and the perceived annoyance. Because of the overestimation of the subjective importance of the LF content, the C- and D-weighting scales are not able to properly describe the variation in perceived annoyance with increases in filter setting for MHF regions. Meanwhile, with the use of the A-weighting scale the variation in perceived annoyance with increases in filter setting for both LF and MHF regions is appropriately described.

Thus, despite of the great physical dominance of the LF content under indoor conditions, the MHF content is found as a factor to be considered for explaining the differences in perceived annoyance.

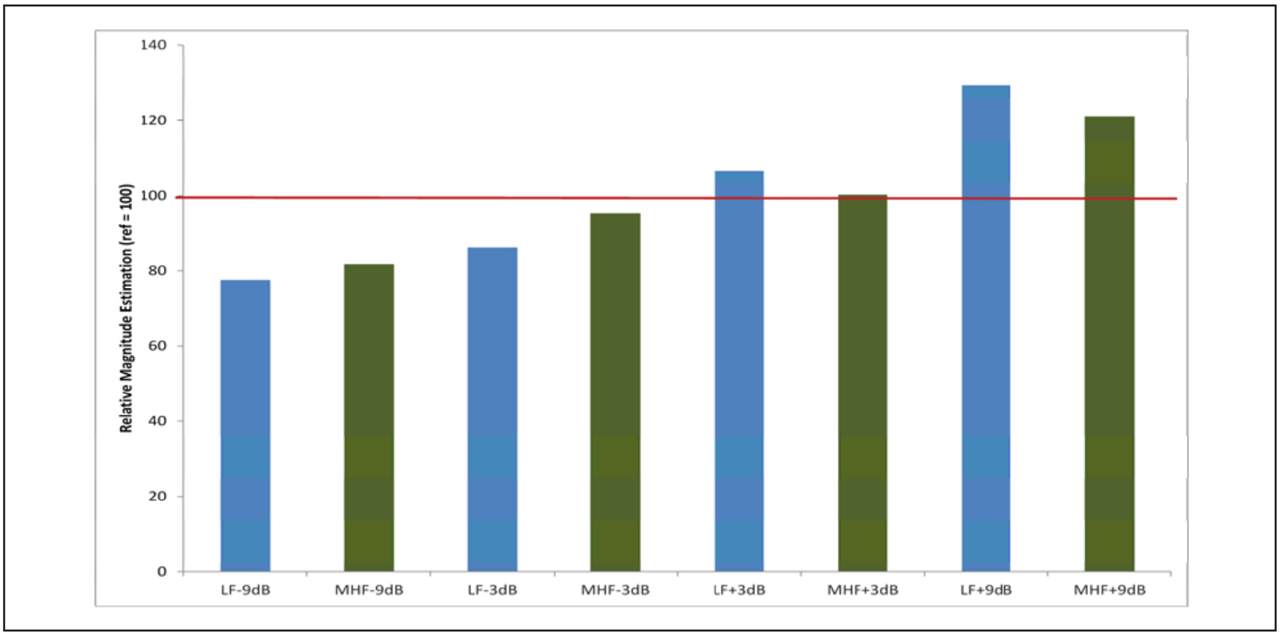

Figure 1. Perceived annoyance for each stimulus.

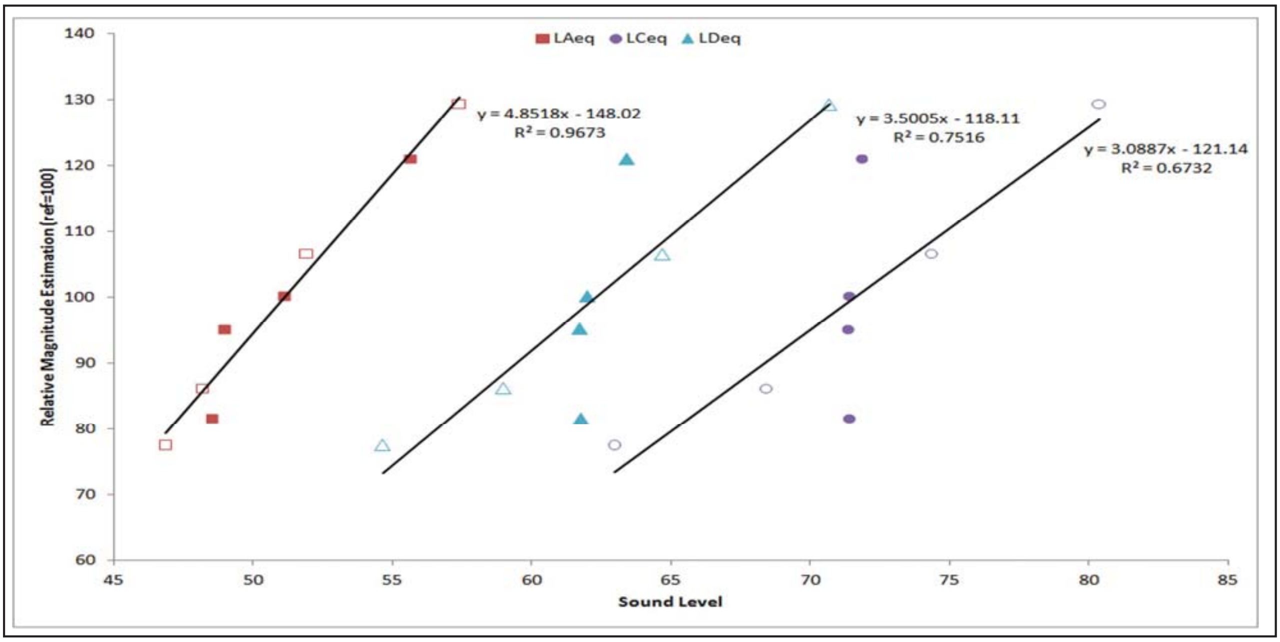

Figure 2. Linear relationships for each frequency weighting evaluated. Filled symbols correspond to MHF filter gain and unfilled symbols to LF filter gain.

Because of its characteristics, the A-weighting scale is able to describe in a more appropriate way the differences as to the subjective importance between the LF and the MHF content.

3.2. Experiment 2: Audibility and perceived annoyance

As showed by the Table I, the differences in audibility threshold among the three frequency regions, as referred to 70 dB pink noise, ranges between ~ 2 dB (LF-MF) and ~ 3.5 dB (LF-HF). As for the perceived annoyance, the differences among frequency regions notably increase, so that an average increment of ~ 11 dB (LF-MF) and ~ 16 dB (LF-HF) is observed. These data suggest that the audibility threshold, which is rather similar, is not an influential factor for explaining the observed differences as to perceived annoyance. Based on these findings, an equal-sensation level relationship among LF, MF and HF regions is suggested. It should be noted that the sensation level corresponds to the perceived annoyance as referred to the audibility threshold.

Table I. Audibility threshold, perceived annoyance and sensation level for each frequency region.

	Audibility Threshold	*Perceived Annoyance*	*Sensation Level*
LF	-9.38	16.25	25.63
MF	-11.63	5.31	16.94
HF	-12.75	0.31	13.06

In Table II, the differences in sound level reported by the listeners for perceiving the LF, MF and HF filtered test sounds as equally-annoying is expressed using the A-, C- and D-weighting. As observed in Table II, the difference as to perceived annoyance between LF and MF is better described by the A-weighting than by the C and D weightings. However, among the evaluated frequency weightings, the best filter for describing the difference in perceived annoyance between MF-HF and LF-HF is the D-weighting.
Based on the results of this experiment could be suggested that, a frequency filter derived from the A- and D-weighting could enable a more precise description of the relationship as to perceived annoyance among wide-band LF, MF and HF sounds.

Table II. Differences in sound level among equally-annoying perceived frequency filtered sounds for each frequency weighting evaluated.

Differences between frequency ranges	*A-weighting*	*C-weighting*	*D-weighting*
LF-MF	**-0.95**	10.53	3.06
MF-HF	3.51	5.91	**-1.49**
LF-HF	2.56	16.44	**1.57**

4. Conclusions

This work presents the results of two listening experiments which are aimed at analyzing the performance of the A-weighting for describing road traffic noise annoyance. In light of the obtained results can be concluded that: (i) at low sound levels (around 50 dBA) and with LF content physically dominant (indoor conditions) the A-weighting outperforms C and D weightings in explaining the variance of the annoyance as perceived by the listeners, since C and D filters overestimate the contribution of LF; (ii) at higher sound levels (around 68 dBA) the A-weighting properly describes the differences in perceived annoyance between LF and MF, but underestimates the contribution of the HF content. In this case, the D-weighting is the filter that gives the best description of the differences in perceived annoyance between both LF-HF and MF-HF. For this reason, a new frequency filter built from the A and D weightings could be proposed in order to enable a better description of the differences in perceived annoyance among wide-band LF, MF and HF road traffic sounds.

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