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THE SUITABILITY OF A-WEIGHTED SOUND POWER FOR LABELLING DOMESTIC APPLIANCES

J R BROOKS, K ATTENBOROUGH

DEPT. OF ENGINEERING MECHANICS, THE OPEN UNIVERSITY, WALTON HALL, MILTON KEYNES, MK7 6AA

INTRODUCTION

The use of domestic appliances in modern society is widespread. The noise levels that these appliances emit, and the effect they have on the domestic noise environment are accepted as an inevitable consequence of labour saving. Even though an appliance may be disliked because of its noise emission level, the labour saving value often outweighs all other feelings towards the appliance. Considering the extent to which domestic appliances feature in every day life, little is known about domestic appliance *noise*, other than a number of small studies investigating appliance noise levels *in situ* [1,2,3]. Unlike railway, aircraft and road traffic noise, even less is known about the subjective reaction to domestic appliance noise [4,5]. The research discussed in this paper aims to identify the noise index which best correlates with subjective reactions to domestic appliance noise by examining the relationship between subjective judgements of domestic appliance noise and a variety of noise indices - $L_{WA}, L_{Aeq}, L_{AX}, L_{Amax}, L_p, L_{pA}, L_{pD}$, PNL and TPNL. EEC directive No 86/594/EEC recommends the labelling of appliances with their A-weighted sound power level [6].

DETERMINING THE OBJECTIVE QUANTITIES OF DOMESTIC APPLIANCE NOISE

In order to investigate the relationship between the objective measures of domestic appliance noise and subjective reactions, it was necessary to obtain relevant measurements. Measurements were made on 30 appliances - 11 hair dryers, 8 vacuum cleaners, 4 food mixers, 4 liquidisers and 3 food processors. Measurements of L_{WA} were made according the ISO 3741 - Acoustics - Determination of Sound Power Levels of Noise Sources - Precision methods for broadband sources in reverberation rooms [7]. The comparison method was adopted, using a Bruel and Kjaer Reference Sound Source Type 4240, and an array of three fixed microphones. Sound power levels were calculated from the data obtained.

Measurements of $L_{Aeq}, L_{AX}, L_{Amax}, L_{pA}, L_{pD}$, and L_p were made in the lounge and kitchen of a small detached house on the campus of the Open University. It was considered preferable to use such venues, rather than laboratory versions of these rooms so that the subjective ratings given were indicative of responses in natural surroundings. Appliances were used, rather than their recordings, again so that the reactions of the subjects were as natural as possible.

Measurements of L_{Aeq}, L_{AX} and L_{Amax} were made during the subjective experiments, by means of a noise level analyser (Bruel and Kjaer Type 4427), to which was connected a half inch microphone (Bruel and Kjaer Type 4165), situated at the subject's ear level. The analyser was programmed

A	B	D	C
B	C	A	D
C	D	B	A
D	A	C	B

Figure 1: Balanced Latin square design for four stimuli

to monitor single events, and to commence analysis of each event as a pre-defined noise level was exceeded. Measurements of L_p, L_{pA}, L_{pD}, PNL and TPNL were determined from analysis of an *in situ* tape recording of the noise of each appliance. The tape recordings were made using a Nagra IV-SJ tape recorder (with A-weighted filter and slow averaging time). A second half inch microphone (Bruel and Kjaer type 4165) was also located at the subject's ear level. The tape recorder was connected to the noise level analyser, which triggered the start and finish of each recording when the sound level was greater than or less than a pre-defined sound level. By replaying the calibrated appliance noise recordings into an FFT analyser (Ono Sokki 910) and making 128 averages, it was possible to obtain time-averaged A-weighted sound pressure levels for each one-third octave centre frequency from 100 Hz to 10 kHz. Converting the A-weighted one-third octave centre frequency values to linear values gave one-third octave unweighted sound pressure levels, and to these were added D-weightings to obtain D-weighted one-third octave centre frequencies. Overall time-averaged sound pressure levels (unweighted, A and D weighted) were then obtained using the following formula:

$$10 \; log_{10} \sum 10^{\frac{Li}{10}} \qquad (1)$$

where Li refers to the sound pressure level at each one-third octave centre frequency.

Also, using the unweighted one-third octave centre frequency values, it was possible to calculate Perceived Noise Level (PNL) for each appliance, using the standard method [8]. Tone corrections were also made to the Perceived Noise Levels using the method described in BS5727 - Method for describing aircraft noise heard on the ground [9].

Having obtained the objective measures of domestic appliance noise, the next step was to obtain subjective reactions to the same appliance noise levels, and then to correlate these with the various measurements.

DETERMINING THE SUBJECTIVE REACTIONS TO DOMESTIC APPLIANCE NOISE.

Twenty four subjects, all with normal hearing (according to ISO 389 - 1975 [10]) and aged between 22 and 55 were required to complete the chosen experimental design. It was decided that the randomization of presentation of appliance noises should follow a balanced Latin square design, whereby each stimulus occurs once in each row and once in each column, and every stimulus follows every other stimulus an equal number of times - see Figure 1. Such a design has been used successfully by researchers in other subjective experiments [4,5,11].

Subjects were asked to rate the noisiness of each appliance using a rating scale. In deciding upon the length of rating scale to be used during the subjective experiments, consideration was made of the following points:

- Using too short a scale could result in coarse ratings.
- Using too long a scale could exceed the discriminating powers available to the subject.

After studying the literature it was quite clear that the choice of scale (both length [12] and labels [13]) was very random with no obvious rules for selection. So it was decided that subjects should be asked to rate noisiness according to a 7 point scale, where the extremes of the scale were labelled 'Very Quiet' (1) to 'Extremely Noisy' (7).

The experimental procedure involved presenting the appliances (in groups of six) to subjects, in an order determined by the balanced Latin square design. Subjects were asked to rate the noisiness of each appliance immediately after its presentation. The procedure was then repeated, in a reversed order of presentation. Instruction sheets were provided for guidance, and they were carefully worded to avoid subject bias. There were no oral instructions.

ANALYSIS OF THE RESULTS

The ratings generated by the subjective experiments were analysed to determine the strength of the relationship between the subjective ratings and the various objective measures of the domestic appliance noise. A variety of statistical techniques were adopted. One analysis was aimed specifically at investigating whether subject's noisiness ratings varied in a way that was highly correlated to A-weighted sound power level (L_{WA}). If this relationship appeared, one might expect that subjects would give identical noisiness ratings to appliances with identical A-weighted sound power levels. Also, noisiness ratings would reflect increasing magnitudes of A-weighted sound power level. By ordering appliances according to the magnitude of sound power level, ordering mean noisiness ratings according to magnitude, and by using the statistical test known as Least Significant Difference to evaluate which mean was significantly different from any other, it was possible to investigate the validity of L_{WA} as an index for domestic appliance noise. The results are shown in Table 1. Bracketed

Table 1: Comparison of order of magnitude of L_{WA} and mean noisiness ratings

Group of Appliances	Order of Magnitude of L_{WA}	Order of Magnitude of Mean Noisiness Ratings
GROUP I	(1 2)3 4(5 6)	1 3 5 4 6 2
GROUP II	3(2 4)(1 6)5	2 6 1 3 5 4
GROUP III	(1 3)(2 4 5 6)	1 3 5 4 2 6
GROUP IV	(4 6)(2 3 5)1	6 4 2 5 3 1
GROUP V	3(1 6)4 5 2	6 1 3 2 4 5

numbers identify appliances having the same L_{WA}. Underlined numbers indicate ratings which were not significantly different from each other.

From Table 1 it can be seen that:

- mean noisiness ratings vary significantly even when A-weighted sound power levels are identical.
- the rank order of noisiness ratings is not the same as that of A-weighted sound power levels.

It was concluded that ratings of noisiness did not appear to vary in a way that was comparable with the magnitude of A-weighted sound power levels.

To determine which of the noise indices - L_{WA}, L_{Aeq}, L_{AX}, L_{Amax}, L_p, L_{pA}, L_{pD}, PNL - correlates the best with subjective noisiness ratings, Pearson Product Moment Correlation was carried out on the data. The results of this are presented in Table 2.

Table 2: Correlation coefficients for mean noisiness ratings and various noise indices.

Index	Correlation Coefficient	Significance Level
L_{WA}	0.687	.001
L_{pAav}	0.815	.001
$L_{Aeq,30sec}$	0.882	.001
L_{Amax}	0.874	.001
L_{AX}	0.877	.001
PNL	0.821	.001
L_{pav}	0.762	.001
L_{pDav}	0.808	.001

It can be concluded from Table 2 that all of the noise indices correlate significantly with subjective ratings. Further analysis was necessary in order to identify whether some indices correlated better than others. When mean noisiness ratings were plotted against the various noise indices, it was apparent that the relationship between them was not linear. Therefore polynomial regression was carried out. Table 3 presents the results of this.

Table 3: Regression analysis for mean noisiness ratings against noise indices assuming a polynomial model.

Index (x)	Correlation Coeff.	Signif. Level	Intercept Coeff.	x	x^2	F Value	%variance accounted for
L_{WA}	0.727	.001	26.4	-0.65	0.005	15.18	52.9
L_{pAav}	0.824	.001	13.6	-0.35	0.003	28.62	67.9
$L_{Aeq,30sec}$	0.891	.001	10.6	-0.28	0.003	52.18	79.4
L_{Amax}	0.885	.001	11.5	-0.30	0.003	48.94	78.4
L_{AX}	0.888	.001	16.3	-0.39	0.003	50.54	78.9
PNL	0.845	.001	34.7	-0.80	0.005	44.67	71.4
L_{pav}	0.765	.001	03.6	-0.06	0.001	19.03	58.5
L_{pDav}	0.819	.001	17.8	-0.43	0.003	27.01	67.0

Again, the correlation coefficients are highly significant for all indices. However the percentage of variance accounted for by the regression curve varied for the different indices. The final analysis involved determining statistically which index (or indices) performed the best. The statistical test, known as 'Bootstrapping' allows an investigation of whether the correlation coefficients (r_1 and r_2) of two indices are significantly different by investigating how significantly different from zero is the value of:

$$r_1^2 - r_2^2. \tag{2}$$

If the indices are both equally good, then the result should be close to zero. The results of this test may be represented as follows where the indices are ordered from worst to best:

$$L_{WA} \quad \underline{L_{pav} \quad L_{pDav} \quad L_{pAav} \quad PNL} \quad L_{Amax} \quad L_{AX} \quad L_{Aeq,30sec}$$

$$\text{(second underline: } L_{pAav} \quad PNL \quad L_{Amax} \quad L_{AX} \quad L_{Aeq,30sec}\text{)}$$

Indices are underlined when there is no significant difference between them. This result indicates that the A-weighted sound power level index performed worse than the other indices in rating domestic appliance noise. It was not possible to distinguish between the performance of Perceived Noise Level and sound pressure level (linear, D and A-weighted). L_{AX}, L_{Amax} and $L_{Aeq,30sec}$ performed in a statistically different way from the remaining indices (except L_{pAav} and PNL) but equally among themselves, and the percentage of variance explained by the regression curve was greatest for these indices. It can be concluded that these indices correlate more successfully with subjective noisiness ratings than L_{WA}.

Another important finding was that subjects' ratings of noisiness varied according to the family of appliances under investigation. However, the strength of this relationship was dependent on the noise index with which the noisiness ratings were correlated, such that noisiness ratings for kitchen appliances as a group were generally higher than noisiness ratings for hair dryers and vacuum cleaners, even when they produced similar L_{WA}. This finding suggests that an A-weighted sound power level label will be misleading to consumers whose choice is noise-dependent, and a separate labelling scheme for different families of appliances would be an advantage. However since the dependence on appliance family was weaker when noisiness ratings were correlated with L_{Aeq} and L_{pAav}, use of either of these indices would enable a single labelling scheme for all appliance types.

CONCLUSION

1. Mean noisiness ratings of domestic appliances do not vary systematically with the magnitude of A-weighted sound power levels.

2. On the other hand, subjects' ratings of noisiness of domestic appliances correlate highly with several noise indices - in particular L_{Aeq}, L_{AX} and L_{Amax}.

3. When subjects' noisiness ratings were correlated with L_{WA} in terms of the family of appliances, it was found that noisiness ratings were generally higher for kitchen appliances than for hair dryers and vacuum cleaners of similar L_{WA}. Therefore labelling appliances with L_{WA} would be very misleading to consumers whose choice is noise-dependent.

4. A noise labelling scheme that used values of both L_{WA} and L_{Aeq} would relate well to subjective response.

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