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ESTIMATES OF ANNOYANCE OF SOUNDS OF DIFFERENT CHARACTER

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SUMMARY

The character of a sound is defined as the weighted combination of all acoustic factors, not contained in L_A, *contributing to its annoyance.*

From this definition it follows that differences in annoyance due to sounds with equal L_A *are differences in sound character. For the concept of sound character to have real significance it is necessary that listeners agree on the annoyance due to sounds with equal* L_A.

This paper describes a listening experiment with a variety of sounds of equal L_A. *The annoyance due to the sounds was rated by twelve subjects. Their individual ratings show significant agreement. Moreover, their average rating correlates well* (0·90) *with the ratings obtained by Terhardt and Stoll*[4] *in a similar experiment.*

INTRODUCTION

In the field of noise abatement the A-weighted equivalent sound level, L_A, is gaining increasingly wide application. There are at least two reasons for this. One is that L_A correlates almost as well with certain indicators of annoyance as do sophisticated measures of sound (Botsford[1]). Another is the urgent need for a simple, universally accepted measure of sound that can be understood by politicians, policemen and the public (Bolt[2]).

There is, however, still room for doubt as to the adequacy of L_A as a measure of the annoyance due to sound, especially when its level is not very high. Some results on the annoyance due to the sounds of a refrigerator have illustrated this (Cardozo and van der Veen[3]). In that paper, the notion of sound character was introduced as the combination of all acoustic factors, *other than* L_A, contributing to annoyance.

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This definition of sound character leaves the universal role of L_A intact. It merely aims at a correction that takes account of certain features of the sound—for example, variations in amplitude or in frequency, the fact that the sound may have a penetrating pitch (which is not the same as a clearly recognisable pure tone in its spectrum), etc. The features making up the character of a sound may be even more complex.

The present paper deals with an experiment devised to obtain more information on sound character. We took fourteen sounds giving a fair representation of an 'acoustic day of the average Dutchman'; however, *we made the A-weighted levels equal within narrow bounds.*

EXPERIMENT

The sounds were all given a fixed duration of 3·8 s, including a fading in of 150 ms and a fading out of the same duration. A stimulus tape was prepared in which each of the fourteen sounds was recorded fourteen times. The tape was made to satisfy the condition that every sound was preceded by every other sound at least once, so as to balance possible interaction between consecutive stimuli. The sounds are listed in Table 1.

TABLE 1
MEASURED SOUND LEVELS AND SUBJECTIVE ANNOYANCE

	Sound	L_A *dB(A)* *input* *I*	L_{max} *dB(A)* *art. ear* *II*	L_A *dB(A)* *art. ear* *III*	a *IV*
1	Refrigerator	0·2	66·3	59·0	1·02 ± 0·4
2	Pink noise	0·2	63·3	61·5	0·55 ± 0·7
3	Coffee mill	0·2	63·3	60·4	0·49 ± 0·5
4	Electric shaver	−0·1	64·3	61·5	0·45 ± 0·4
5	Cooker hood	−0·3	64·3	59·6	0·37 ± 0·4
6	Braking car	0·1	65·0	59·0	0·36 ± 0·6
7	Jet plane	0·2	63·3	59·1	0·41 ± 0·4
8	Vacuum cleaner	−0·1	65·0	59·1	0·26 ± 0·5
9	Typewriter	−0·1	65·3	60·1	0·15 ± 0·4
10	Baby's cry	0·1	63·8	59·9	−0·03 ± 1·0
11	Ship's horn	0·1	65·5	58·7	−0·31 ± 0·5
12	Church bell	−0·1	63·9	57·0	−0·54 ± 1·0
13	Bird song	−0·1	67·0	60·1	−0·78 ± 0·8
14	Fragment of music	−0·3	63·8	58·0	−2·26 ± 0·4

I. 'L input' represents the sound volume in equivalent dB(A) measured at the input of the Sennheiser HD424 headphone, with an arbitrary voltage as reference.
II. L_{max} is the maximum A-weighted level, measured with the hold circuit of a B & K 4426 with an artificial ear (B & K 4156) coupled to the HD 424 headphone.
III. L_A is the equivalent, A-weighted level, also with the artificial ear, B & K 4156.
IV. In the fourth column a stands for the normalised annoyance, averaged over twelve subjects. The standard deviation is given in the same column.

In order to make the experiment expedient, the sounds had to be made short. Because they were also deprived of their context, it was not obvious beforehand that listeners would recognise the sound sources. A pilot experiment convinced us that they did, however. In the main experiment, twelve subjects listened to the 196 taped stimuli by means of a Sennheiser headphone HD424 in a sound-proofed booth. They did so under the following instruction.

INSTRUCTION

'You will be presented with a set of widely different sounds that all have exactly the same duration and the same sound energy. As a result, some sounds will be unnaturally loud. Your task is to give a rating number (1 to 10) for the annoyance caused by every sound as it is presented. The highest number is for the most annoying sound. The sounds are delivered with 5 s silent intervals during which you can write down your annoyance rating. The entire test is divided into two parts, consisting of seven blocks of fourteen sounds, separated by bleeps.

Suggestion: as for "annoyance", think that you are in an easy chair at home. Suddenly, you hear the stimulus sound.'

There was a semantic problem in this instruction, since music or bird song were considered euphonious rather than annoying by the subjects. However, they managed to attach annoyance values to each of the stimuli presented.

RESULTS

In Table 2 each annoyance is the average of fourteen ratings given by the subject to one type of sound stimulus. As a first test of the feasibility of the experiment, the coefficient of concordance, W, among subjects was computed. We found that $W = 0{\cdot}46$, which is a very significant ($p < 10^{-5}$) deviation from random responses ($W = 0$).

It is obvious from an inspection of Table 2 that subjects made rather different uses of the rating scale, 1, 2, ... 10. For instance, subject 1 used all values from 2 to 9, whereas subject 2 restricted himself to the numbers 5 to 9. These differences do not affect W, which is based on ranking, but they do produce some scatter which has to do with our rating system rather than with the sounds presented. This scatter is eliminated by normalising each subject's rating values. Every column in Table 2 can, of course, be transformed linearly so that the new column has a mean value 0 and a standard deviation 1. These normalised annoyance values, a, averaged over twelve subjects, are given in Table 1, last column. The added $\pm$ values give the standard deviation of the set of twelve a's. The standard deviation gives an indication of the spread among subjects in the annoyance values for the particular sound. It is seen

TABLE 2

ANNOYANCE RATINGS OF FOURTEEN SOUNDS BY TWELVE SUBJECTS ON A RATING SCALE OF 1–10. EACH FIGURE IN THE MATRIX IS THE AVERAGE OF FOURTEEN RATINGS.

	Sound	Subject 1	2	3	4	5	6	7	8	9	10	11	12	Average
1	Refrigerator	8·0	8·6	9·7	8·3	9·5	7·5	8·0	8·6	10·0	6·7	8·9	9·8	8·6 ± 1·0
2	Pink noise	5·6	8·9	7·3	8·1	9·7	4·2	6·7	7·4	7·9	6·1	8·4	9·9	7·5 ± 1·6
3	Coffee mill	6·7	7·6	8·6	8·0	7·8	5·1	8·4	6·2	7·6	7·0	9·0	8·1	7·5 ± 1·1
4	Electric shaver	7·0	7·5	9·2	7·5	8·3	6·8	7·7	6·3	7·1	6·4	8·9	7·4	7·5 ± 0·9
5	Cooker hood	6·6	8·3	6·1	7·7	8·0	5·2	7·1	8·5	7·9	6·6	7·8	8·0	7·3 ± 1·0
6	Braking car	8·0	7·3	7·1	6·5	6·1	6·5	9·9	9·3	7·7	6·4	7·6	7·0	7·5 ± 1·1
7	Jet plane	7·4	7·2	7·3	6·8	7·5	7·2	8·3	9·8	7·9	6·6	7·9	6·9	7·4 ± 0·5
8	Vacuum cleaner	6·9	8·0	7·7	7·8	7·6	3·9	7·2	8·0	6·9	6·5	7·8	7·4	7·1 ± 1·1
9	Typewriter	7·0	7·4	6·6	6·8	9·1	5·4	6·5	6·6	7·0	7·0	7·3	6·7	7·0 ± 0·8
10	Baby's cry	8·8	7·1	4·1	6·3	6·5	9·9	8·7	2·7	7·8	5·3	5·6	6·9	6·6 ± 2·0
11	Ship's horn	6·0	5·5	3·4	6·4	6·6	5·4	7·4	7·0	6·0	6·3	7·3	5·8	6·1 ± 1·0
12	Church bell	3·3	5·3	2·4	5·9	6·4	9·3	8·0	5·3	4·4	7·1	6·0	3·1	5·5 ± 2·0
13	Bird song	4·4	7·6	1·6	5·7	6·4	5·7	7·3	2·3	3·5	2·1	7·3	6·3	5·0 ± 2·1
14	Fragment of music	2·0	5·4	1·0	4·2	2·9	0·0	2·4	1·0	1·4	2·0	4·6	1·0	2·3 ± 1·6
Average		6·3 ± 1·8	7·3 ± 1·1	5·9 ± 2·8	6·9 ± 1·1	7·3 ± 1·7	5·9 ± 2·3	7·4 ± 1·6	6·4 ± 2·6	6·7 ± 2·1	5·9 ± 1·6	7·5 ± 1·2	6·7 ± 2·3	6·7

that the baby's cry and the church bells elicited relatively large differences in opinion whereas, for instance, the music and the jet plane noise obtained rather uniform normalised annoyance values.

DISCUSSION

It is claimed that the annoyance values in the last column of Table 1 reflect the sound character. There might be some effect of the sound level since the sound samples are not exactly equal in L_A *as measured with the artificial ear.*

In Fig. 1, the fourteen sounds have been plotted against L_A horizontally and against the annoyance, a, vertically. There is some tendency for low annoyance to go with low L_A, and vice versa. The regression line would allow a 'sound level correction' to be made to the annoyance values. However, the correlation coefficient $r = 0{\cdot}33$ is not significantly different from $r = 0$ even at the 10 per cent probability level.

Also, the validity of the artificial ear measurement for the particular headphone used is not beyond doubt. We therefore accept the values of a in Table 1 as a fair estimate of the relative annoyances due to the characters of the sounds.

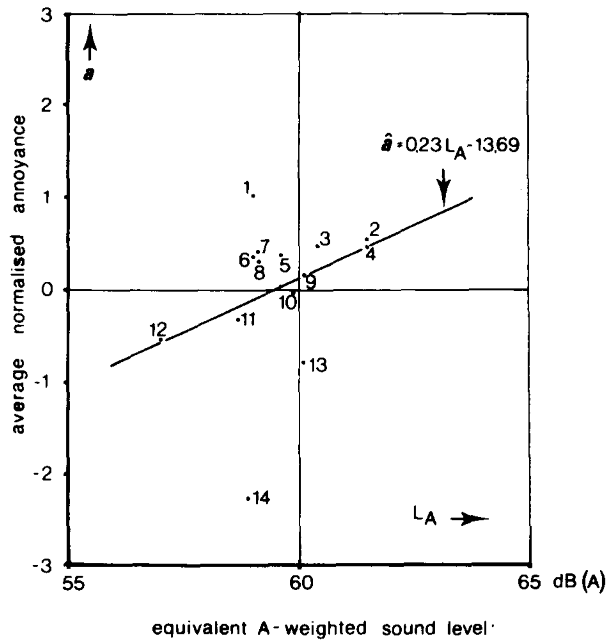

Fig. 1. Sounds 1 to 14 as points in an L_A–a diagram. L_A is the equivalent A-weighted sound level as measured with the artificial ear (see Table 1). The sloping line satisfies the regression equation $\hat{a} = 0{\cdot}23L_A - 13{\cdot}69$.

It is interesting to compare our result with those of Terhardt and Stoll[4] who performed a similar experiment. They presented seventeen everyday life sounds to sixteen subjects. The sounds were presented by earphone (Beyer DT 48) at a level of 78 Zwicker phon. Eight of their sounds are more or less the same as eight of our sounds, as shown in Table 3.

TABLE 3
COMPARISON OF TWO SUBJECTIVE EVALUATIONS OF SOUNDS

Terhardt experiment 2 *Inverted euphonia rank number*		*Our experiment* *Annoyance rank number*	
Coffee mill	1	Coffee mill	2
White noise	2	Pink noise	1
Aeroplane	3	Jet plane	3
Typewriter (ball-type)	4	Electric typewriter (separate types)	6
Car (starting)	5	Car (braking audibly)	4
Vacuum cleaner	6	Vacuum cleaner	5
Church bells	7	Church bells	7
Musical chord	8	Fragment of music	8

The rank correlation between both sets, $R = 0{\cdot}90$, is high. In view of the many differences, this is striking. In the first place, the sound pairs were far from identical. Moreover, they formed subsets of larger sets that were different.

The equalisation was in Zwicker phon in Terhardt and Stoll's experiment and in equivalent A-weighted decibels in ours. The scaling methods were different and so were the instructions to the subjects. In particular, Terhardt and Stoll's listeners had to evaluate euphonia and not annoyance. Therefore, it is tempting to draw the conclusion that listeners agree to a considerable extent in the appreciation of what we have termed sound character.

SUMMARY AND CONCLUSIONS

Since the equivalent A-weighted sound level, L_A, is becoming widely accepted in noise abatement and for legal purposes, there seems to be a need for an additional quantity—that is, sound character—to take account of the differences in annoyance caused by different sounds that have the same L_A. A set of fourteen sounds, sampled from everyday life, were presented at virtually equal L_A to twelve members of our laboratory staff and students. There was a very significant agreement of opinion on the annoyance of these sounds. It seems unlikely that this was brought about by possible slight differences in the experienced loudness. Moreover, it transpired that eight sound samples were ranked in almost the same way as eight similar sounds in an experiment by Terhardt and Stoll, notwithstanding differences in the experiments. This seems to present some confirmation of the usefulness and reality of the concept of sound character.

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