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LOUDNESS, ANNOYANCE AND UNPLEASANTNESS OF AMPLITUDE MODULATED SOUNDS

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INTRODUCTION

In the evaluation of noise, the term "annoyance" is often used. It is also used in daily life conversation when people talk about the disturbance of noise. Various factors, physical and/or psychological, may have an effect on the impression of annoyance. In our former study of the loudness, noisiness and annoyance using actual and artificially synthesized sounds[1], it was found that there was little difference among loudness, noisiness and annoyance judgments with synthesized sounds. On the other hand, when actual recorded sounds were used, the sources of which could be clearly identified by subjects, significant differences were found among loudness, noisiness and annoyance judgments and between German and Japanese subjects. Aesthetic and/or cognitive aspects of sounds may influence the judgments when the sound sources are identified[2],[3].

It was also suggested in our former experiments with helicopter noise[4] that even though the impression of annoyance and unpleasantness showed fairly high correlation with L_{Aeq} and loudness level, other factors seemed to be effective on the impression of annoyance and unpleasantness. Similar result was reported by Kahn et al.[5] in the experiments with diesel engine noise.

Recently, the software for calculating various measures for the evaluation of sound quality has become available such as sharpness[6], roughness[7], fluctuation strength[8], tonality[3] and unbiased annoyance[3]. In this study, it will be examined the factors which contribute to the impression of loudness, annoyance and unpleasantness using synthesized and recorded sounds. The applicability of other psychophysical measures will also be discussed.

EXPERIMENT 1 (synthesized sounds)

Stimulus. Pink noise was used as carrier and three kinds of modulation frequency for amplitude-modulation and five kinds of filter were added as shown in Table 1. Their levels were set at 50, 65 and 80 dBA in L_{AE}. The duration of these sounds was 5 sec with 2.5 sec rise- and fall-time.

Procedure. In Exp.1-1 the impression of loudness, unpleasantness, sharpness, roughness and fluctuation strength of the sounds were judged using magnitude estimation and in Exp.1-2 the impression of loudness and annoyance were judged. Subjects were asked to judge by assigning any positive number which reflects their impression and put the number into a computer with a computer key board. Two trials were conducted for each judgment after training.

Apparatus. The stimuli were reproduced with a DAT recorder and presented to subject's ears through a free-field equalyzer and headphones (Beyer DT48) in a sound proof room.

Subjects. Six female and four male subjects aged between 22 and 38 with normal hearing ability participated in Exp.1-1, and four female and seven male subjects aged between 20 and 34 in Exp.1-2.

Physical and Psychophysical measures. Loudness level[9], sharpness[6] and roughness[7] of every 100 msec and fluctuation strength[8] of every 1 sec were measured with Psychoanalyzer (Cortex CF90). The maximum values are abbreviated as LLmax, Smax, Rmax, Fmax, respectively. The energy based average of loudness level of every 100 msec is abbreviated as LLp, and the arithmetic means of sharpness, roughness and fluctuation strength are abbreviated as Smean, Rmean and Fmean, respectively.

Results and discussion. The coefficient of correlation between two trials was calculated for each subject. Since statistically significant correlation was found in all the cases, the geometric means of the judgments of all the subjects were calculated.

The coefficients of correlation between judgments are shown in Table 2. High correlation was found among loudness, pleasantness and annoyance judgments. They showed good correlation with loudness level as shown in Table 3. The relations between loudness and annoyance judgments and between loudness and LLp are shown in Figs.1 and 2, respectively. In this experiment, synthesized AM noise was used and the impressions of pleasantness and annoyance of these sounds seem to be mainly determined by

Table 1 Stimulus conditions

modulation frequency (Hz)	filter
0	pink noise
0	-6dB/oct
0	band pass (20-1000Hz)
0	band pass (1500-2500Hz)
0	band pass (7500-8500Hz)
4	pink noise
4	-6dB/oct
4	band pass (20-1000Hz)
4	band pass (1500-2500Hz)
4	band pass (7500-8500Hz)
70	pink noise
70	-6dB/oct
70	band pass (20-1000Hz)
70	band pass (1500-2500Hz)
70	band pass (7500-8500Hz)

Table 2 Coefficient of correlation between judgments

	P	S	R	F	L2	A
loudness (L1)	.950	.531	.913	.804	.978	.965
pleasantness (P)	-	.568	.896	.781	.952	.953
sharpness (S)		-	.357	.532	.491	.482
roughness (R)			-	.825	.931	.944
fluctuation strength (F)				-	.812	.816
loudness (L2)					-	.989
annoyance (A)						-

Table 3 Coefficient of correlation between measures and judgments

	L1	P	S	R	F	L2	A
LAE	.872	.852	.710	.718	.736	.860	.848
LLmax	.962	.934	.410	.939	.803	.978	.980
LLp	.963	.937	.429	.920	.779	.977	.977
Smax	-.221	-.131	.600	-.365	-.157	-.246	-.267
Smean	-.000	.082	.723	-.200	.017	-.031	-.064
Rmax	.240	.259	-.291	.421	.105	.290	.318
Rmean	.380	.372	-.252	.577	.310	.417	.460
Fmax	.599	.600	.386	.665	.801	.631	.638
Fmean	.499	.506	.372	.558	.734	.533	.540

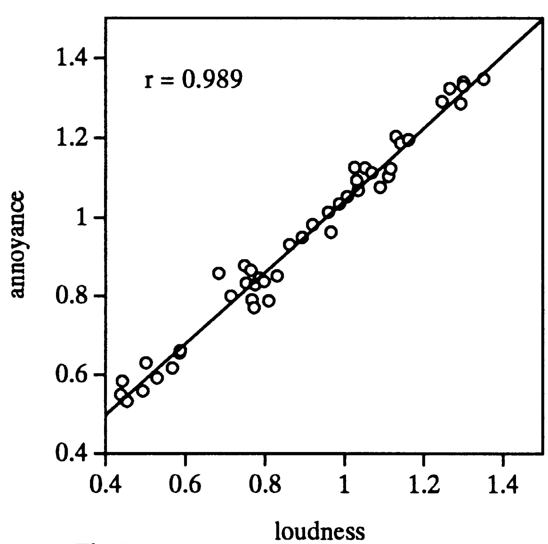

Fig.1

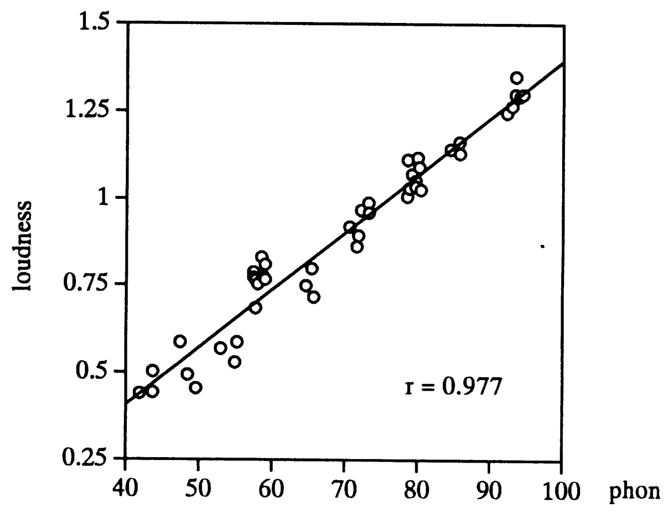

Fig.2

loudness, especially when they are judged in a laboratory.

The judgments of sharpness, fluctuation strength and roughness showed some correlation with calculated sharpness, fluctuation strength, and roughness, respectively, as shown in Table 3. Good correlation cannot always be seen between them. Except for loudness level which is standardized in ISO 532B[9], there is no standardized algorithm for calculating each measure. It would be necessary to examine carefully when these measures are applied to non-steady state sounds. Also it is important to confirm on what aspects of the sounds subjects judged these impressions.

EXPERIMENT 2 (actual sounds)

Stimulus. In experiment 2, twenty-five kinds of recorded road traffic noise of various operating conditions was used as stimuli, which were used in the former study[3]. They are listed in Table 4. The duration was about 15 sec.

Procedure. The loudness and annoyance of the stimuli were judged using magnitude estimation. Subjects judged each stimulus four times in random order.

Apparatus. The same apparatus was used as in Experiment 1.

Subjects. Five female and four male subjects aged between 22 and 50 with normal hearing ability participated in Experiment 2.

Physical and Psychophysical measures. The sound exposure level, loudness level, sharpness, roughness and fluctuation strength were measured as in Experiment 1.

Results and discussion. Since statistically significant correlations were found among four judgments of each subject, the 36 judgments by nine subjects were averaged. The coefficients of correlation between judgments and physical and psychophysical measures are shown in Table 5. LLp showed the good correlation with loudness and annoyance. Their relations are shown in Figs.3 and 4. Though loudness showed good correlation with LLp, the idling sounds (Nos.4 and 20), for example, were judged a little louder than the other sounds with the same values of LLp. The correlation was not so much improved

Table 4

sound	motor	speed (km/h)	gear	distance (m)
1	Diesel	60	3	7.5
2	Otto	30	1	7.5
3	Diesel	70	2	7.5
4	Otto	0	idle	0.9
5	Otto	80	3	7.5
6	Otto	80	3	15.0
7	Diesel	35	1	7.5
8	Diesel	70	4	7.5
9	Otto	50	2	7.5
10	Diesel	110	4	7.5
11	Diesel	acceleration	1	7.5
12	Diesel	racing start	1	7.5
13	Otto	60	3	7.5
14	Diesel	30	1	7.5
15	Otto	50	2	3.5
16	-	60	coast	7.5
17	Diesel	0	idle	7.5
18	Diesel	60	4	7.5
19	Otto	ISO 362	2	7.5
20	Diesel	0	idle	7.5
21	Diesel	80	3	3.75
22	Diesel	50	2	3.75
23	Diesel	80	3	3.75
24	Diesel	90	4	7.5
25	Otto	80	3	3.75

even if the multiple regression coefficient was calculated including sharpness, roughness and fluctuation strength. The stimuli used were recorded actual sounds and other subjective factors may have an effect even on loudness judgment[2]. The data were more scattered in the annoyance judgment than in the loudness judgment as shown in Fig.4. The coefficient of correlation increased a little (r=.791) when multiple regression coefficient was calculated including sharpness, roughness and fluctuation strength, which confirms the results reported by Kahn et al.[5]. However, when annoyance of actual recorded sounds were judged, other subjective factors than physical properties of sounds seem to have an effect.

When sound levels were varying with time, maximum levels did not show good correlation with subjective judgments as shown in Table 5. When loudness level is applied to time varying sounds, energy based average would be appropriate.

Table 5

	loudness	annoyance
LAE	.871	.695
LLmax	.691	.395
LLp	.906	.742
PA	.900	.763
Smax	-.015	-.172
Smean	.481	.467
Rmax	-.063	-.111
Rmean	.130	.034
Fmax	.552	.417
Fmean	.568	.479

It was reported that "Psychoacoustic Annoyance (PA)" shows good correlation with judgments by German subjects[3]. PA is an index which includes loudness, sharpness, roughness and fluctuation strength. When PA is applied to the annoyance judgments in the present experiment, PA showed a little higher coefficient of correlation with annoyance judgment than LLp as shown in Table 5. However, there is no statistically significant difference between PA and LLp in the coefficient of correlation with annoyance. Though the same sounds were used in both experiments with German and Japanese subjects, there was some difference in the correlation with PA. This may be cross-cultural difference as was found in our former study[1].

SUMMARY

It was found that the impressions of loudness, annoyance and unpleasantness of synthesized sounds are similar to each other and mainly determined by loudness level based on ISO 532B when the level fluctuation is averaged on energy basis. On the other hand, in the case of recorded road traffic noise, there was some difference between loudness and annoyance judgments. These results suggest that aesthetic and/or cognitive aspects of the sound may have an important role in the impression of annoyance or unpleasantness.

Some deviations were found between the impressions of sharpness, fluctuation strength and roughness and the values of calculated sharpness, fluctuation strength and roughness, respectively. It would be necessary to examine the applicability of calculated sharpness, roughness and fluctuation strength in detail before applying them to actual situations.

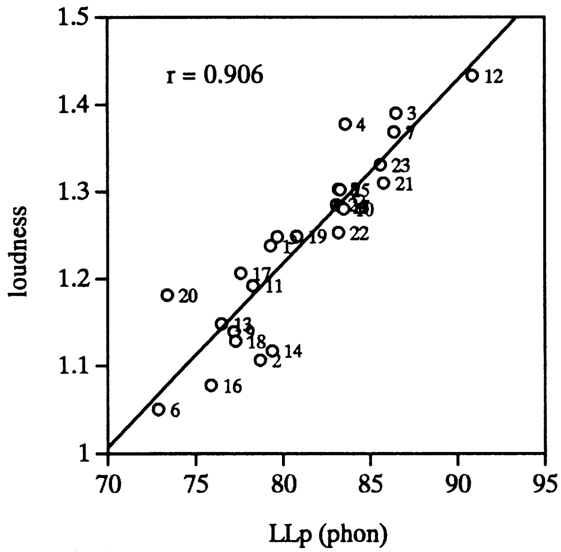

Fig.3

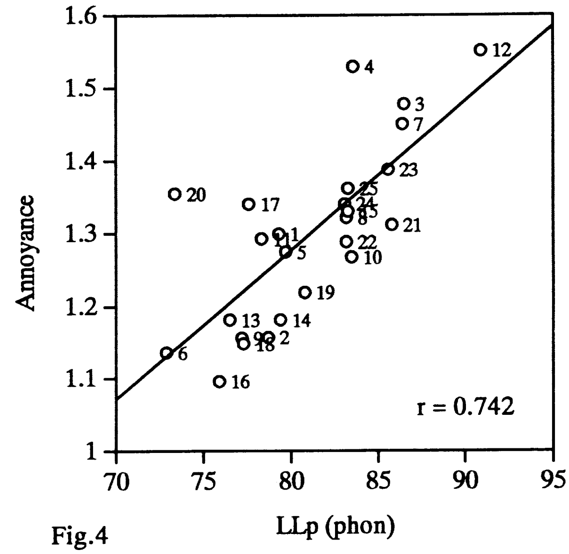

Fig.4

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