Journal of Sound and Vibration (1999) **220**(2), 279–295
Article No. jsvi.1998.1929, available online at http://www.idealibrary.com on IDEAL

TRANSPORTATION NOISE ANNOYANCE—A SIMULATED-ENVIRONMENT STUDY FOR ROAD, RAILWAY AND AIRCRAFT NOISES, PART 2: ACTIVITY DISTURBANCE AND COMBINED RESULTS

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(*Received* 24 *May* 1995, *and in final form* 11 *August* 1998)

Part 2 of two companion papers is a continuation of the discussion presented in Part 1, and is concerned with the effects of the noise level and type of noise source on activity disturbance as obtained by a simulated-environment study. The design of the experiment, with account taken of the factors which are important in simulation of noise, environment and community, have been explained in detail in Part 1. Tests each lasting 30 min consisted of two consecutive parts under continuous and similar noise conditions, enabling the subjects to perform two different activities, namely, reading and listening without being interrupted. The indoor levels of the road, railway and aircraft noise samples (only side flights were considered) varied in the range of 30–55 dB(A) in L_{eq} (30 min) with increments of 5 dB(A). 64 subjects participated and each subject attended three different tests. The statistical results indicated that the correlation coefficients between the activity disturbance and noise level were high ($r = 0{\cdot}951$ and $0{\cdot}970$) for the GROUP DATA, and the comparison of the dose and annoyance relationships obtained for reading and listening situations, revealed a shift at 45 dB(A) after which the listening annoyance suddenly increased with the noise level. The source–type effect was found to be significant for the listening annoyance and for Summindex ($P < 0{\cdot}05$). The reading annoyance did not significantly depend on the source type, probably because of the deeper concentration of the subjects. This implies that the source type may not be a very important factor in daily life activities when transportation noises intrude from the façade. The comparison of

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the results with some of the previously published studies has indicated that the regression lines between noise and annoyance obtained in this study are steeper and the correlation coefficients are higher than those of previous results.

1. INTRODUCTION

Annoyance by transportation noise sources have been investigated through field studies and some simulated-environment experiments in the laboratory. However in real life (as widely accepted), overall annoyance is composed of different feelings and combined reactions of the respondents during daily activities. In the field studies aiming to search for noise and annoyance relationships, the respondents are frequently asked several questions about their annoyance degrees while performing different activities at home, such as reading, speech communication, concentration on mental work, sleeping etc. in closed and open window conditions, in addition to general annoyance by noise [1–3]. However in these studies, it is rather difficult to determine precisely the exact indoor noise levels, since these activities might be performed in different rooms located in different parts of the building exposed to the noise source. Therefore, the response to these questions might have a potential importance in verification and support of the respondent's overall judgment of annoyance which would be carefully analyzed after the survey. It has been observed that generally the annoyance degrees declared by the respondents increase about one degree, after they were asked questions to investigate the annoyance in a broader sense.

On the other hand, the simulated-environment laboratory technique provides more reliable and comparable data on the activity disturbance, as well as on overall annoyance, in controlled laboratory conditions, if appropriate simulation of noise, environment and annoyance is fulfilled (see Part 1).

This Part 2 of the two papers is focused on the comparison of annoyance from the sources of transportation noise by emphasizing the differences particularly between reading and listening. It was a psycho-acoustical experiment in which the annoyance reactions were investigated simultaneously for the three types of source, in identical living environments, with identical techniques and subjects performing similar activities at the same time.

2. BRIEF REVIEW OF THE INVESTIGATIONS ON ACTIVITY DISTURBANCE BY TRANSPORTATION NOISES

Effects of noise on activity performances have been studied so far in respect to either the task performance or annoyance during daily activities. It has been evidenced by a number of investigations that mental and psychomotor tasks are influenced in different ways by various noise conditions and it has been suggested that noise masks the auditory signals concerned in the performance of the above mentioned tasks [5]. The complexity and difficulty of the mental task depending on its verbal and visual characteristics, the physical nature, the meaning of the noise and the exposure time have been found to be factors affecting both accuracy and speed, in completion of the task.

The experiments of Hellbrück and Kuwano revealed that a steady noise (e.g., babble noise) and a fluctuating noise (e.g., traffic noise) both on an average of 75 dB(A), had a stimulating effect on the subjects up to one hour, by increasing the accuracy and the speed respectively [6]. However, interference with the mental process can be observed afterwards. It has also been confirmed that a single voice signal can interrupt the short term memory process, more than a broad-band noise which does not attract the attention so much. Interference effects of noise on the mental process require further investigation in order to correlate the results with those obtained from the annoyance studies. A study by Bronzaft and McCarthy based on a survey in schools, revealed that elevated train noise had many adverse effects, in different ways, on reading ability [7].

Hall and Taylor suggested that the subjects were interrupted generally not only by an average noise level, but mostly by specific noisy events occurring at the same time [8]. In respect to speech interference, it was indicated that particularly intermittent noises could be noticeable at 50 dB(A) at the listener's ear during a low-level conversation. As the maximum noise level increases, the probability of error in intelligibility rises and the percentage of correctly identified syllables decreases. According to their model, max. indoor level of 58 dB(A) is the level at which 50% of people report speech interference. However, 45 dB(A) was suggested as the level at which 50% of the people reported speech interference. The maximum indoor level for 100% sentence intelligibility for relaxed conversation was proposed as 45 dB(A).

Generally speaking, field studies confirmed that disturbance of speech communication from road traffic is less than sleep disturbance, but the reverse is true for aircraft noise. However, speech interference due to the masking effect (signal to noise ratio) is a phenomenon to be evaluated differently from annoyance judgment although they are strongly related to each other.

The reactions in terms of "acceptability" while listening, was found to be dependent on the sound energy given as peak levels of noise, the speech level, the duration of noisy event and the number of noise-events, through Langdon's investigations [9]. He declared that doubling of energy due to increased intensity, duration and rate have similar effects on acceptability: i.e., a 10 dB increase in intensity corresponds to a doubling of dissatisfaction while TV viewing under aircraft noise exposure. In terms of the peak level of noise, Williams *et al*. found that for 75–85 dB(A) peak levels, 15–30 flights/hour and peak durations of 2–16 s, the acceptability was in the "region of barely acceptable" and 65–75 dB(A) was in the "acceptable region", during listening with aircraft noise. This implied that a 10 dBA increase in level could produce a 2 unit change in acceptability ratings during listening [10]. Langdon found a steeper line than that of Williams *et al*.

Rice in his earlier experiment carried out in an anechoic room [11], deliberately chose a speech environment and aimed to investigate "the interference with the ability to relax and to enjoy listening to the spoken word" under road traffic noise exposure. He suggested that an acceptable indoor noise level for listening to speech, would be in the order of 45 dB(A) in L_{10} level while the speech signals were at $L_{10} = 54$ dB(A) in his experiment. Results showed that the subjects became less tolerant as the experiment proceeded. He also added that the units based on the peak levels, the low frequency components of the noise and the indoor noise levels had a better relationship with annoyance.

In the simulated environment laboratory experiments dealing with an annoyance problem for specific noises, subjects are asked to perform some easy tasks, such as reading magazines, listening to tape-recordings, marking some cards or playing cards. Rice in another study chose playing bridge because of the high level of motivation of this task [12]. Consequently, playing cards was influenced after 55 dB(A) L_{eq} (indoor), corresponding to about 75 dB(A) (outdoor) for both aircraft and road traffic noises. On the other hand, by comparing the results obtained for a relaxed activity (like reading), Rice found that if the subjects were deeply concentrated under the aircraft noise exposure, the annoyance reduced to the equivalency of 10 dB(A) L_{eq}. Therefore, he concluded that "a relaxation activity involving concentration should not unduly interfere with subjective responses".

The above review of the investigations revealed some uncertainties in the following issues, due to the lack of comparable data. (1) How does annoyance on a 7-point scale change with the noise level regardless of source type, during reading and listening? (2) Is there an effect of source type on disturbance while reading and listening? (3) What is the difference between disturbances during reading and listening under identical noise conditions? The objectives of the experimental study which will be explained in what follows are concerned with the possible answers to the above issues.

3. DESIGN OF EXPERIMENT

The simulation of the noise, environment and community in this study have been carried out in view of the considerations mentioned in Part 1 in which the laboratory conditions, surveying technique, questionnaire form, annoyance scale used in the evaluations, etc., were explained in detail.

3.1. ACTIVITY PERFORMED BY THE SUBJECTS

In this study, it was planned to focus neither on speech interference nor on short-term memory performance deliberately, but to determine the annoyance in terms of interference with daily life activities requiring a certain degree of concentration. For this purpose, the task chosen for the subjects should not be a difficult one requiring the deep attention that may reduce the annoyance by causing an activation within 30 min, as explained above. Thus, two tasks were selected: a visual one; reading an article from a magazine, and an aural one; listening to a given speech from a tape-recorder whose results enabled comparisons between the degrees of two activity disturbances. These activities were performed by the subjects within the 30 min test duration in the two consecutive sessions under the prevailing similar and continuous noise conditions. Since the peak levels have been evidenced to be rather effective on annoyance predictions in the previous studies, while a task was performed, both L_{eq} and L_{peak} levels were used in the evaluation of the data.

For the reading task, comprising the first part of the tests, some Japanese magazines were provided in the room and the subjects were asked to read an article which they would select before the tests started. In order to secure their attention to the task, they were also informed beforehand that they would be required to write a resumé of what they would be reading and listening during the tests when they were over.

For the listening activity to investigate the performance of speech-communication in terms of intelligibility and enjoyment of speech, some listening tapes were specially prepared. The contents of the tapes were considered to be relatively attractive for most of the subjects, therefore a novel reading of 15 min that was recorded from a radio broadcast was selected first. However, during the pilot tests performed with five subjects for the three types of source, it was noticed, with surprise, that the speech was too monotonous to get the subject's attention, especially in a masking situation. The subjects said that when interrupted while listening, their interest declined so that it became difficult to re-concentrate, even to the extent of falling asleep while trying to listen. Then the contents of the tapes were changed and drama programs, each passage lasting 15 min, were selected to be used during the experiment. Three different tapes were prepared for the same subject group attending the three consecutive tests. The speech sounds were given to the subjects, as if they were coming from the tape-radio that was placed on a table in a corner of the room. The maximum speech level was kept at 65 dB(A) at the listeners' ears, which is rather satisfactory for the face to face communication at 1·20 m in the room. This level was controlled via a ceiling microphone in the room and by an attenuator, a monitor and a graphic-recorder in the control room. The subjects were given notice about termination of the first and the second half of the test from a lamp placed behind the seats in the room and controlled from the outside without interrupting the continuous noise exposure during the entire session of 30 min.

There were 64 Japanese subjects from different social sections and each subject attending the three different tests was exposed to the three noise sources at different levels. Presentation of the noise samples were designed by the Latin Square Technique as mentioned in Part 1. As a reminder, the noise levels in L_{eq} (indoor) were changed from 30 to 55 dB(A) with 5 dB(A) intervals by keeping equal levels at each of the two sequences of the test. The pass-by number of the railway and the aircraft traffic (N) was given values of 8, 12 and 16 per 30 min and both sequences were divided by half.

4. EVALUATION OF DATA AND RESULTS

The results of the experiment were analyzed in terms of three data categories, such as individual annoyance scores (INDIV DATA), group average scores (GROUP DATA) and the percentage of highly annoyed subjects (HIGHAN DATA), as explained in Part 1.

4.1. COMPARISON OF ANNOYANCE RESPONSES WHILE READING AND LISTENING

Annoyance during the reading and listening activities under the similar noise exposures in the experiment was elaborated in order to investigate the variation of disturbance by the noise level for each source and to make comparisons with respect to source-type. GROUP DATA comprising the average group responses for different source, level and pass-by conditions were mainly used in the below analysis. The number of cases were 30.

Figure 1 gives the comparison of the responses to the reading annoyance question (RAQ) and the listening annoyance question (LAQ) which have been averaged on equal noise levels regardless of source type and number of pass-by (N). In Figure 1(a), the variation of disturbance with respect to noise level reveals an apparent increase of annoyance with noise levels for both activities which is quite similar to each other at below 45 dB(A), at which point the lines coincide. Above this level, the listening annoyance increases more sharply compared with the reading annoyance with maximum difference of 1·6 AAS (average annoyance

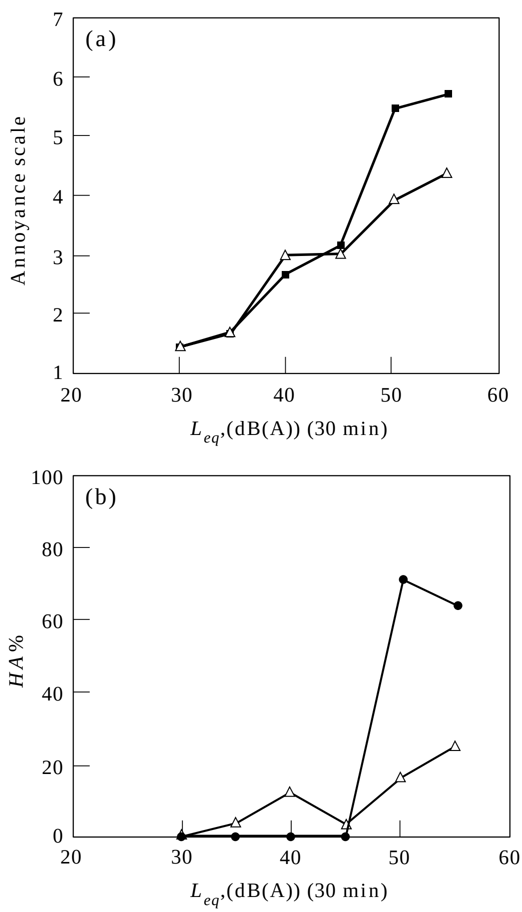

Figure 1. Comparison of two activity disturbances with respect to noise level (n = 30 for each activity). △, Reading; ●, listening. (a) Group average scores (GROUP DATA); (b) percentage of highly annoyed (HIGHAN DATA).

TABLE 1

Correlation coefficients between activity disturbance and noise levels

	Individual scores (INDIV DATA) $n = 192$	Average group scores (GROUP DATA) $n = 30$	Percentage of highly annoyed subjects HA % (HIGHAN DATA) $n = 30$
Reading and listening	0·7582**	0·9298**	0·7667**
Reading and L_{eq} level	0·5838**	0·8716**	0·5817**
Listening and L_{eq} level	0·7536**	0·9033**	0·7456**
Reading and L_{max} level	0·5397**	0·7931**	0·5176**
Listening and L_{max} level	0·7247**	0·8638**	0·6999**

1-tailed signif: *0·01; **0·001.

scores) at 50 dB(A). Similar coincidence level can also be seen in Figure 1(b), when the variation of the percentage of highly annoyed subjects (HA%) with noise level for two activities are considered. The maximum difference is as high as 54% at 50 dB(A).

Correlation coefficients between reading and listening annoyances and between activity disturbances and noise levels are given in Table 1, for the combined data of all the sources and N values. The AAS's give the best correlation amongst the three annoyance descriptors obtained by the different data categories. Correlation with noise levels in L_{eq} seems better than with L_{max} levels for both activities. Table 1 indicates the listening activity is more affected by the changes in the noise level.

When the individual responses (INDIV DATA) for reading and listening were compared in the t-test, the difference between the means and the standard deviations was found 0·36 and 1·3 respectively. The t-value and the significance level indicated that the two distributions were statistically different [see Table 2(a)]. When the same test was applied to the GROUP DATA, the results indicated less difference between the standard deviations, but greater in means. Consequently the activity type was confirmed to be significantly effective ($P < 0{\cdot}05$) in the annoyance responses (see Table 2(b)).

Linear regression analyses between noise level and each activity combined for all sources resulted in the following relationships for the three annoyance descriptors:

$$\text{INDIV DATA} \quad \text{Reading } AS = 0{\cdot}127\, L_{eq} - 2{\cdot}60 \quad (\text{SE} = 1{\cdot}46), \tag{1}$$

$$\text{GROUP DATA} \quad \text{Reading } AS = 0{\cdot}124\, L_{eq} - 2{\cdot}35 \quad (\text{SE} = 0{\cdot}62), \tag{2}$$

$$\text{HIGHAN DATA} \quad \text{Reading } HA\% = 0{\cdot}941\, L_{eq} - 30{\cdot}53 \quad (\text{SE} = 11{\cdot}55), \tag{3}$$

$$\text{INDIV DATA} \quad \text{Listening } AS = 0{\cdot}191\, L_{eq} - 4{\cdot}99 \quad (\text{SE} = 1{\cdot}37), \tag{4}$$

$$\text{GROUP DATA} \quad \text{Listening } AS = 0{\cdot}192\, L_{eq} - 4{\cdot}82 \quad (\text{SE} = 0{\cdot}79), \tag{5}$$

$$\text{HIGHAN DATA} \quad \text{Listening } HA\% = 3{\cdot}03\, L_{eq} - 110{\cdot}10 \quad (\text{SE} = 23{\cdot}8). \tag{6}$$

The second-order polynomial expressions are compared in Figure 2(a) in which the coincidence point seems to shift to 42 dB(A) for the both group average scores and *HA*%. The increase of listening annoyance with noise level diverges from the reading curve and rises abruptly over reading annoyance. For *HA*%, the coincidence point appears at the same level and the maximum difference of percentage of highly annoyed subjects listening to radio is 55% more than those reading at 55 dB(A), as can be seen in Figure 2(b).

TABLE 2

t-test results for grouped data according to activity type; *RAQ*, *annoyance while reading*; *LAQ*, *annoyance while listening*

(*a*) *INDIV DATA*: *Individual responses* ($n = 192$)

One-sample statistics

	n	Mean	SD	SEM
RAQ	192	2·8906	1·7940	0·1295
LAQ	192	3·2552	2·0877	0·1507

One-sample test

	Test value = 0					
	t	d.f.	Sig. (2-tailed)	Mean difference	95% confidence interval of the difference: Lower	Upper
RAQ	22·327	191	0·000	2·8906	2·6353	3·1460
LAQ	21·605	191	0·000	3·2552	2·9580	3·5524

(*b*) *GROUP DATA*: *Group average scores* ($n = 30$)

One-sample statistics

	n	Mean	SD	SEM
RAQ	30	2·9597	1·2492	0·2281
LAQ	30	3·4377	1·8248	0·3332

One-sample test

	Test value = 0					
	t	d.f.	Sig. (2-tailed)	Mean difference	95% confidence interval of the difference: Lower	Upper
RAQ	12·977	29	0·000	2·9597	2·4932	3·4261
LAQ	10·319	29	0·000	3·4377	2·7563	4·1190

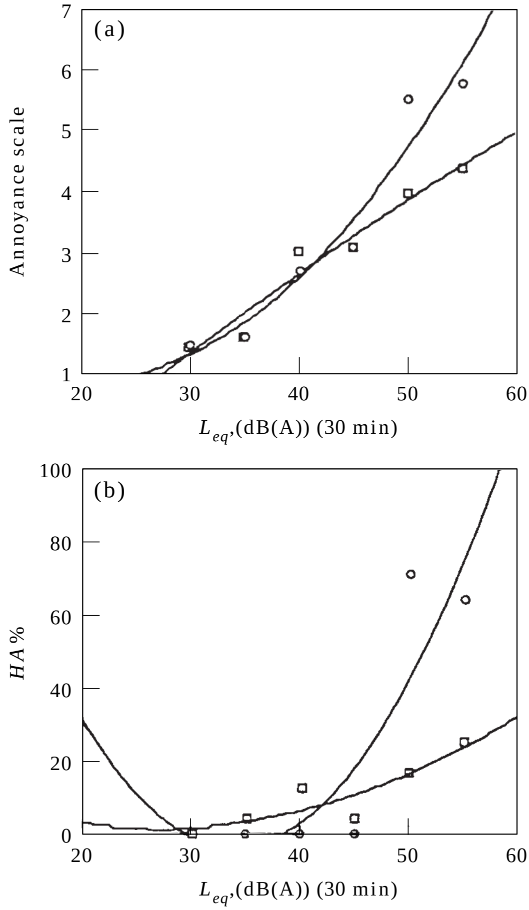

Figure 2. Comparison of polynomial regression curves of readng and listening annoyances ($n = 30$ for each activity). ○, Listening; □, reading. (a) Group average scores (GROUP DATA); for LAQ, $y = 2{\cdot}7606 - 0{\cdot}18001x + 0{\cdot}00438x^2$, $r^2 = 0{\cdot}940$; for RAQ, $y = -3{\cdot}098 + 0{\cdot}16031x - 0{\cdot}00043x^2$, $r^2 = 0{\cdot}951$; (b) percentage of highly annoyed (HIGHAN DATA); for LAQ, $y = 203{\cdot}09 - 12{\cdot}162x + 0{\cdot}17898x^2$, $r^2 = 0{\cdot}789$; for RAQ, $y = 22{\cdot}622 - 1{\cdot}5707x + 0{\cdot}02892x^2$, $r^2 = 0{\cdot}795$.

4.2. COMPARISON OF SOURCE-SPECIFIC ANNOYANCES

(1) Source-specific line charts (noise level and response graphs) for road, railway and aircraft noises are given in Figure 3 for two activity situations. It can be observed that there was a crosspoint of all the source-lines at 45 dB(A) for reading and listening situations and below this level, railway noise caused higher annoyance than the road and aircraft noises. Apparently the railway noise tends to be the more prominent transportation noise at almost all levels, contrary to some previous studies carried out either in the field or in the laboratory. However, this suggestion has also been confirmed by Berry, Ahrlin and by some Japanese investigations [13–15].

(2) The linear regression lines obtained by using the *AAS* from GROUP DATA ($n = 18$) for three sources are compared in Figures 4(a) and (b). The distributions of response data vary by a maximum of 1·47 dB(A) (standard deviation) for

different questions and the slopes and the intercepts are given in Table 3 in which the group-average scores are evidenced as the best correlated annoyance descriptor. Regression equations for each source and specific activity disturbance are as follows:

$$\text{Reading annoyance: for road traffic noise} = 0{\cdot}130\ L - 2{\cdot}539,\quad r^2 = 0{\cdot}906, \tag{7}$$

$$\text{for railway noise} = 0{\cdot}105\ L - 1{\cdot}403,\quad r^2 = 0{\cdot}718, \tag{8}$$

$$\text{for aircraft noise} = 0{\cdot}136\ L - 3{\cdot}046,\quad r^2 = 0{\cdot}942, \tag{9}$$

$$\text{Listening annoyance: for road traffic noise} = 0{\cdot}205\ L - 5{\cdot}417,\quad r^2 = 0{\cdot}832, \tag{10}$$

$$\text{for railway noise} = 0{\cdot}188\ L - 4{\cdot}337,\quad r^2 = 0{\cdot}804, \tag{11}$$

$$\text{for aircraft noise} = 0{\cdot}176\ L - 4{\cdot}523,\quad r^2 = 0{\cdot}941. \tag{12}$$

The intersection point between the source-specific regression lines in Figure 4 is not as clear as in the line charts, although road and railway noises tend to coincide at 45 dB(A) while aircraft and road do at 53 dB(A) for the reading situation. The lines for railway and aircraft noise are quite parallel to each other

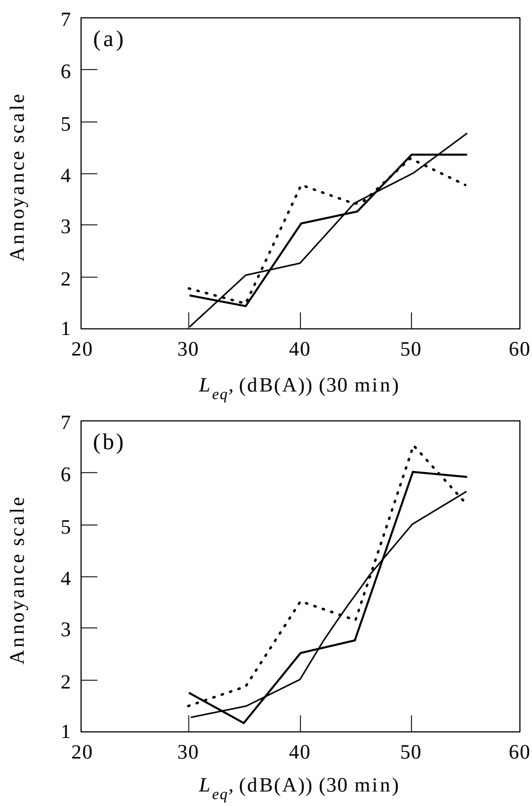

Figure 3. Effect of source type on activity disturbance with respect to noise level (GROUP DATA, $n = 18$). ——, Road; ——, aircraft; ·····, train. (a) Reading annoyance (RAQ); (b) listening annoyance (LAQ).

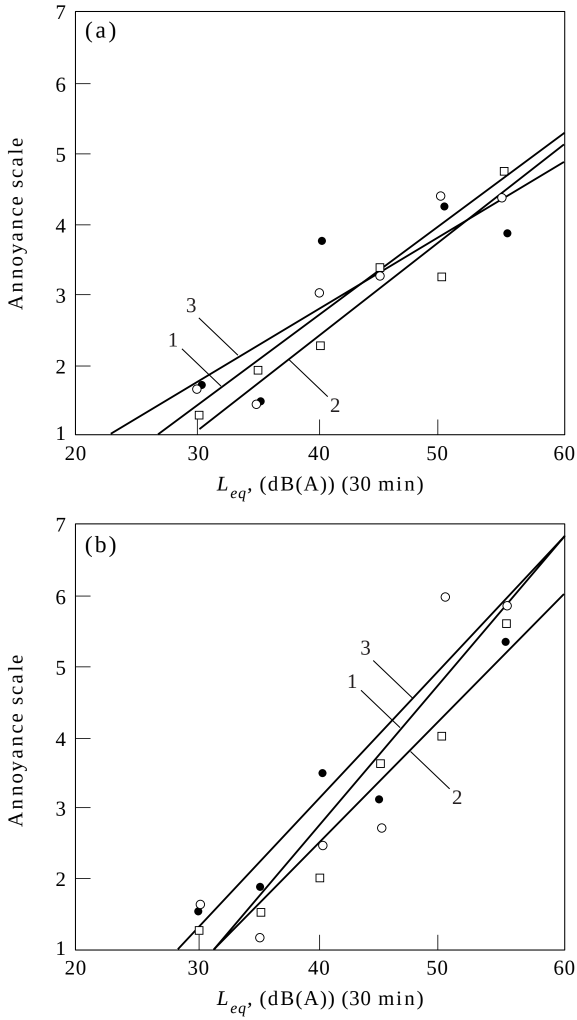

Figure 4. Comparison of regressions obtained between group-average annoyance scores and noise level for three sources (GROUP DATA, $n = 18$). ○, Road traffic noise, 1; □, Aircraft noise, 2; ●, Railway noise, 3. (a) RAQ (reading); for road, $0{\cdot}130x - 2{\cdot}539$, $r^2 = 0{\cdot}906$; for railway, $0{\cdot}105x - 1{\cdot}403$, $r^2 = 0{\cdot}718$; for aircraft, $0{\cdot}136x - 3{\cdot}046$, $r^2 = 0{\cdot}942$. (b) LAQ (listening); for road, $0{\cdot}205x - 5{\cdot}417$, $r^2 = 0{\cdot}832$; for railway, $0{\cdot}188x - 4{\cdot}337$, $r^2 = 0{\cdot}804$; for aircraft, $0{\cdot}176x - 4{\cdot}523$, $r^2 = 0{\cdot}941$.

for the listening situation where the difference is 3·5 dB(A) on average at the same annoyance degree and less than this for road traffic noise and the other two.

(3) The results of the variance analysis performed by taking into account of both level and source type for each activity, are given in Tables 4 and 5 calculated both for GROUP DATA and INDIV DATA. As can be seen, level is always significant at 0·000 level, while source type is significant at 0·081 and 0·054 levels for reading and listening respectively in case of $n = 30$ taken in the GROUP DATA. When the individual data and $HA\%$ data are introduced into the analysis, the significance is not much different. However, $HA\%$ seems to be the worst descriptor of activity annoyance with respect to noise source, contrary to the field

TABLE 3

Results of linear regression analysis for source-specific annoyance responses (GROUP DATA) (parameters: average group scores and indoor noise levels in L_{eq} per 30 min) $n = 18$ cases for each question type

	RAQ			LAQ			SUMMIN		
Question type	Road	Aircraft	Railway	Road	Aircraft	Railway	Road	Aircraft	Railway
Correlation coeff.	0·951	0·970	0·847	0·912	0·970	0·896	0·957	0·990	0·920
Intercept	−2·539	−3·046	−1·403	−5·417	−4·523	−4·337	−3·078	−3·149	−2·472
Slope	0·130	0·136	0·105	0·205	0·176	0·187	0·158	0·151	0·148
SE	0·440	0·353	0·692	0·964	0·463	0·968	0·502	0·220	0·654
F value	38·414	65·352	10·164	19·872	63·784	16·455	43·447	207·151	22·280
Significance	0·0034	0·0013	0·0333	0·0112	0·0013	0·0154	0·0027	0·0001	0·0092

RAQ, annoyance during reading; LAQ, annoyance during listening; SUMMIN, average responses of the four question types including overall annoyance and home-projected annoyance given in Part 1.

TABLE 4

Summary of variance analysis to determine the main effects of level and source type on activity disturbance (GROUP DATA; $n = 30$ for each question) ($P < 0.05$); RAQ, reading annoyance; LAQ, listening annoyance; SUMMIN, average-responses of four annoyance questions including overall and home projected annoyance given in Part 1

	Unique method				
Source of variation	Sum of squares	d.f.	Mean square	F	Signif. of F
RAQ by LEVEL and SOURCE					
Main effects					
(Combined)	33·534	7	4·791	10·003	0·000
LEVEL	30·592	5	6·118	12·775	0·000
SOURCE	2·988	2	1·494	3·120	0·081
2-way interactions					
LEVEL AND SOURCE	1·057	10	0·106	0·221	0·989
Model	39·508	17	2·324	4·853	0·004
Residual	5·747	12	0·479		
Total	45·255	29	1·561		
LAQ by LEVEL and SOURCE					
Main effects					
(Combined)	78·249	7	11·178	22·106	0·000
LEVEL	74·428	5	14·886	29·438	0·000
SOURCE	3·787	2	1·893	3·744	0·054
2-way interactions					
LEVEL AND SOURCE	3·512	10	0·351	0·694	0·714
Model	90·494	17	5·323	10·527	0·000
Residual	6·068	12	0·506		
Total	96·562	29	3·330		
SUMMIN by LEVEL and SOURCE					
Main effects					
(Combined)	48·649	7	6·950	27·145	0·000
LEVEL	46·228	5	9·246	36·112	0·000
SOURCE	2·448	2	1·224	4·782	0·030
2-way interactions					
LEVEL AND SOURCE	1·165	10	0·117	0·455	0·889
Model	56·551	17	3·327	12·993	0·000
Residual	3·072	12	0·256		
Total	59·623	29	2·056		

studies. By using the individual responses ($n = 192$), the significance levels for the source-type are obtained as 0·116 and 0·011 for reading and listening disturbances respectively. From the both analyses, the dependence of annoyance on level which appears to be greater in the listening situation, has been always found to be very strong with the F values given in Table 4 and 5, implying that all the significance levels are <0.001.

TABLE 5

Summary of variance analysis to determine the main effects of level and source type on activity disturbance (*INDIV DATA*; $n = 192$ *for each question*) ($P < 0{\cdot}05$); *RAQ, reading annoyance*; *LAQ, listening annoyance*; *SUMMIN, average-responses of four annoyance questions including overall and home projected annoyance given in Part* 1

Source of variation	Unique method				
	Sum of squares	d.f.	Mean square	F	Signif. of F
RAQ by LEVEL and SOURCE					
Main effects					
(Combined)	212·162	7	30·309	13·839	0·000
LEVEL	203·245	5	40·649	18·561	0·000
SOURCE	9·546	2	4·773	2·179	0·116
2-way interactions					
LEVEL AND SOURCE	8·606	10	0·861	0·393	0·948
Model	233·636	17	13·743	6·275	0·000
Residual	381·067	174	2·190		
Total	614·703	191	3·218		
LAQ by LEVEL and SOURCE					
Main effects					
(Combined)	500·434	7	71·491	44·165	0·000
LEVEL	484·726	5	96·945	59·891	0·000
SOURCE	15·032	2	7·516	4·643	0·011
2-way interactions					
LEVEL AND SOURCE	18·984	10	1·898	1·173	0·312
Model	550·841	17	32·402	20·018	0·000
Residual	281·654	174	1·619		
Total	832·495	191	4·359		
SUMMIN by LEVEL and SOURCE					
Main effects					
(Combined)	2975138	7	425019·7	31·855	0·000
LEVEL	2886366	5	577273·2	43·267	0·000
SOURCE	90975·723	2	45487·861	3·409	0·035
2-way interactions					
LEVEL AND SOURCE	79826·916	10	7982·692	0·598	0·814
Model	3254471	17	191439·5	14·348	0·000
Residual	2321542	174	13342·193		
Total	5576012	191	29193·782		

5. COMBINED RESULTS OF THE STUDY (PARTS 1 AND 2): VARIATION OF ANNOYANCE WITH DIFFERENT ANNOYANCE QUESTIONS

Source-specific annoyance responses obtained by using the GROUP DATA separately for different questions are given in the line charts in Figures 5(a–c). Comparison of the answers according to the question type reveals that the home-projected question (HAQ) always gives the highest scores, i.e., maximum 1·5 *AAS* higher than the scores for overall annoyance (OAQ). For road and aircraft

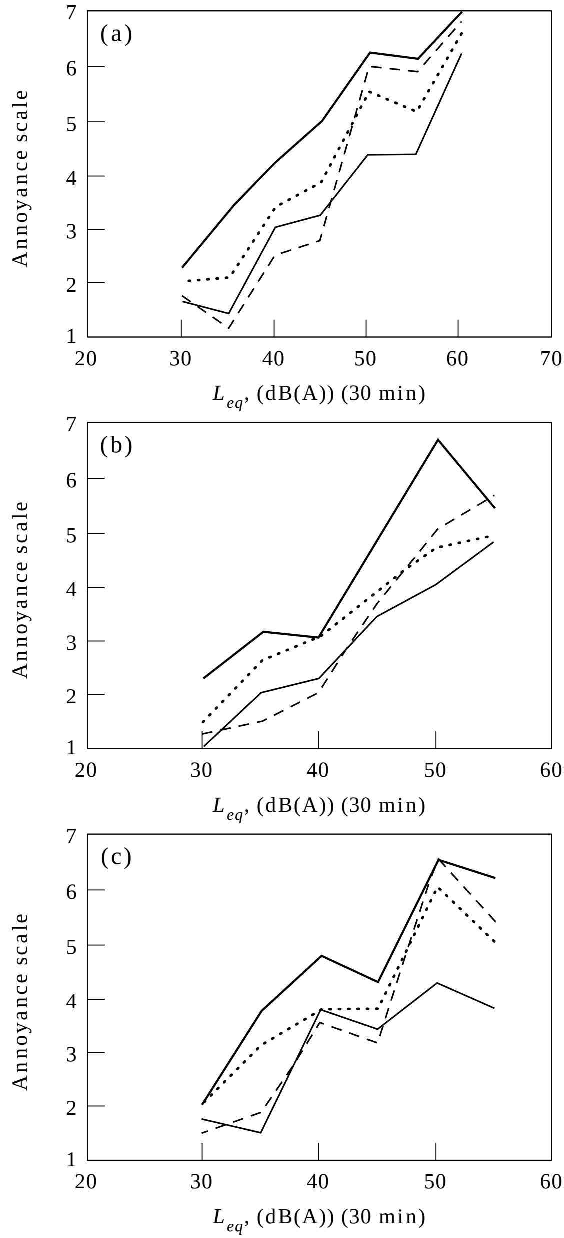

Figure 5. Group-average responses given to four annoyance questions in the experiment (RAQ, annoyance while reading; LAQ, annoyance while listening; OAQ, overall annoyance; HAQ, home-projected annoyance) GROUP DATA, $n = 18$. ——, RAQ; –––, LAQ; · · · · , OAQ; ——, HAQ. (a) Road traffic noise; (b) aircraft noise, $N = 12$; (c) railway noise, $N = 12$.

noise, the annoyance lines for RAQ and LAQ seem to be almost parallel to each other, while both increase with the noise level. Generally speaking, the listening annoyance highly contributes to the formation of the HAQ at high noise levels by remaining above RAQ and LAQ, particularly after $L_{eq} = 45$ dB(A).

6. CONCLUSION

In Part 2 of the laboratory study on community response to noise, the type-of-activity-based annoyance by transportation noises was investigated; also studied was whether or not the type of noise source influenced the annoyance while performing reading and listening. The results are as follows.

(1) In general, transportation noises cause annoyance of increasing degrees based on the noise level on both types of activity (reading and listening). However, there is a different pattern of annoyance and noise for the reading and listening tasks. For reading, a 10 dB(A) increase in the indoor noise corresponds to a constant increase (linear) of group average scores (1·24 degrees *AAS* on the 1–7 scale) in annoyance. For listening, this increase, which is exponential, is although the same below 45 dB(A), it goes up to 2·4 *AAS* at higher levels of noise supporting Langdon's earlier suggestions [10]. The difference of annoyances between the two tasks is due to the difference of characteristics between the reading activity (verbal task), which requires short-term memory and has verbal characteristics, and the listening activity with aural characteristics for which intelligibility is important. The variance analysis that was made has shown that the type of activity has a significant effect on the annoyance caused by any of the transportation noise (at 0·000 level). When analyzed by the level of noise, this significance was apparent especially with 40–50 and 55 dB(A).

(2) Investigation on whether or not the annoyance during both activities is source-dependent, resulted in the levels of significance of 0·011 and 0·054 ($P < 0{\cdot}05$) for the listening annoyance for the individual and group-data respectively. Not finding a satisfactory significance level for reading activity is likely because the higher concentration of the subjects during reading, disregarding the number of noise events and the source type, except the level of the noise. This suggestion is parallel to Rice's earlier findings [12]. On the other hand, the intermittent noises such as railway and aircraft noise, have some similarities regarding the slopes and intercepts for the listening case and railway noise indicates a dB-equivalent annoyance of 3–4·8 dB(A) higher than of aircraft noise. However, annoyance from road traffic noise has a steeper increase with the noise level in the same range.

(3) When all of the four different questions inquiring about the subjects' annoyance degrees are compared, the answers given to the HAQ which comes latest in the questionnaire, yield the highest scores implying the subject's overreaction, e.g., 1·5 *AAS* on average higher than the annoyance revealed by the OAQ.

ACKNOWLEDGMENTS

This experiment was conducted in Kobe University, Japan, between September 1991–June 1992, supported financially by a fellowship awarded to the first author by the Japan Society for Promotion of Science and the data was statistically analyzed and evaluated in Istanbul Technical University. We would like to thank especially Dr Sakagami, Mr Tanaka from Ken-On Co. and Mr Nakao and his team from Sekisui Housing Laboratories, for their great assistance during the experiment. We would also like to express our gratitude to Dr Vallet (France), Dr Izumi and Dr Kuwano (Japan) and N. Tamer (Turkey), for their kind contributions at different phases of the study.

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