Journal of Sound and Vibration (1999) **220**(2), 251–278
Article No. jsvi.1998.1928, available online at http://www.idealibrary.com on IDEAL

TRANSPORTATION NOISE ANNOYANCE—A SIMULATED-ENVIRONMENT STUDY FOR ROAD, RAILWAY AND AIRCRAFT NOISES, PART 1: OVERALL ANNOYANCE

S. KURRA

Faculty of Architecture, Division of Physical Environment, Istanbul Technical University, Istanbul, Turkey

M. MORIMOTO

Faculty of Engineering, Environmental Acoustics Laboratory, Kobe University, Kobe, Japan

AND

Z. I. MAEKAWA

Environmental Acoustics Laboratory, Oyoda Naka 4-3-11, Osaka 531, Japan

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

This paper presents a simulated-environment study to determine the effects of noise level and source type on annoyance responses to different transportation noises. Noise sources used in the study were; road, railway and aircraft traffic whose noise levels varied between 30–55 dB(A) in L_{eq} (indoor). Pass-by number for railway and aircraft traffic had values of 8, 12 and 16 per 30 min, while road traffic was continuous during this period. 64 subjects attending three different sessions of 30 min each, filled in a special questionnaire during the experiments. At each session, the subjects performed two different activities (reading and listening) and thus in addition to the overall annoyance, the activity disturbance was investigated. The total of 192 answers were analyzed as individual values, group average scores and highly annoyed subjects (HA%). The overall annoyance in both group average scores (giving the best correlation with noise level) and individual scores, are presented in this first of the two companion papers. The noise and annoyance relationships determined for each source revealed very strong dependence on noise levels and the regression lines displayed a steeper increase in comparison with the previous results. The significance of the source-type effect on annoyance was found at the levels of 0·03 and 0·02 for the overall annoyance question ($P < 0{\cdot}05$). However since this effect was significant only for half of the different questions asked, it can be said that the source type is not a highly deterministic factor while the respondents are concentrating on daily work at home. Railway noise appeared to be the most prominent noise source in the overall annoyance, especially at moderate and low noise levels. The results supported the view that $L_{eq} = 45$ dB(A) is an indoor noise limit indicating a crossover between the source-specific annoyance lines. The activity disturbance will be elaborated in Part 2.

0022–460X/99/070251 + 28 $30.00/0

1. INTRODUCTION

Scientific investigations on community reaction to transportation noises have been going on for years and the various aspects of the issue are still being debated at the international level [1]. As is well known, annoyance is a subjective judgment more complicated than loudness and noisiness due to non-auditory factors influencing both the long and short-term responses of people. When transportation noises are concerned, in addition to the noise-related factors which affect annoyance (e.g., noise levels, frequency content and irregularity of spectra, number of noise events, temporal variations, background noise levels, etc.) and the environmental factors (e.g., topography, reflective surfaces, barriers, ground type, meteorological conditions, etc.), the individual characteristics, such as social and economic status, education, age, visual influence, meaning of noise, activity type, noise sensitivity, adaptation to noise, etc., should be taken into consideration in evaluating the noise impacts on a community and in development of the noise control strategies.

Annoyance studies have generally dealt with a particular noise source or mixed sources either in the field or in the laboratory. However, some investigations mostly based on the field surveys have enabled comparisons to be made of annoyance degrees obtained for different transportation noise types [2–4]. This subject has been of interest for the purpose of deriving a decibel-equivalent source-type effect which may give a unified index in measuring the annoyance from various sources.

On the other hand, comparison of the reactions to different types of noises based on field and laboratory studies lead to conflicting results requiring further investigations. The simulated-environment method is a useful technique for studying the effects of specific parameters on annoyance and for obtaining comparable results.

An experimental study has been carried out in Kobe University in Japan, supported financially by a grant provided to the first author by the Japan Society for Promotion of Science. Significant contributions to the study were made by Japanese experts, aiming to compare the source-specific annoyance responses for three types of transportation noise [5]. Some of these results are presented in this paper. The comparative approach used in the study is to compare the "noise-dose and response relationships" to be obtained by using the same methodology and techniques on similar subjects exposed to the three types of noise for a sufficient time, while performing similar activities in the same living environment. In the study, the annoyance responses were investigated in terms of both overall annoyance and activity-specific disturbance which are given in Parts 1 and 2.

2. BRIEF REVIEW OF LITERATURE REGARDING ANNOYANCE COMPARISONS

Field studies have confirmed the distinct effect of the source type on annoyance responses and that the dose and response relationships form different patterns according to the source type. Some comparisons regarding the source-specific annoyances that have been made in previous investigations and given in detail in reference [1] are summarized as follows.

2.1. PREVIOUS STUDIES AND DISCUSSIONS

Ollerhead [4], reviewing different surveys, indicated that traffic noise with a steeper increase in the regression lines, caused more annoyance than railway noise and that the difference between the noise levels at equal annoyance degrees were greater at high noise levels given in L_{eq} (24 h). Knall and Scheumer [2], comparing the survey results on railway and road traffic noise, found 4·4 dB(A) in L_{eq} of traffic noise was needed to reach the same amount of annoyance as that from railway noise at high noise levels. For the lower noise levels, this difference was reduced to 1·8 dB(A) on the average. The road and rail difference was confirmed to be greater in urban environments than in rural areas [3]. Berry [6] compared three U.K. surveys including railway and road traffic noises and suggested that the railway noise was not always less annoying than road traffic noise. On the other hand, the regression lines for aircraft and road traffic noise seem to be almost parallel to each other with a 10 dB(A) constant difference for the same annoyance degree, implying higher annoyance from aircraft noise. Cooper *et al*. [7], in their Heathrow Airport study, compared the source-specific annoyances expressed on a four-point scale and showed that aircraft noise caused relatively higher annoyance at L_{eq} (outdoor) = 60 dB(A), whilst below this level, road traffic noise caused higher disturbance.

Fields and Walker [8, 9], presented two different charts to compare source-specific reactions and suggested that railway traffic was less annoying than road and aircrafts at high noise levels (between 55–80 dB(A) L_{eq} and 35–60 *NNI*), and that the railway annoyance increased less rapidly with the increasing noise level. In the case that the percentage of highly annoyed respondents was considered in the comparisons, Kryter [10] showed that the aircraft noise annoyance was greater than the road traffic noise at all levels in the range of L_{dn} (L_{eq}) = 50–80 dB(A), e.g., at 70 dBA, *HA*% for aircraft noise is 12% more than that of road traffic noise with a wider gap between the regression lines at higher noise levels. According to Hall *et al*., this difference emerged as 35% at the same level [11]. Kryter, considering the results of various field surveys, suggested a decibel correction of 6–12 dB(A) to be applied to the noise levels of road vehicles in order to induce annoyance equal to that of aircraft noise.

However, before these studies, Rice carried out some experiments dealing with a wide variety of conditions for aircraft and road traffic noises and found a constant 5 dB(A) in L_{eq} (indoor) and 3 dBA L_{eq} (outdoor) difference between the regression lines and suggested that the traffic noise was significantly more difficult to live with than aircraft noise, contrary to later suggestions [12]. Öhström, Björkman and Rylander have also found similar results by using truck noise [13], and Izumi in Japan supported this finding. However, he also found that the difference between aircraft and road traffic noise annoyances was declining at high noise levels, contrary to the above mentioned investigations [14]. Miedama and Fidell *et al*. found that the annoyance reactions from aircraft noise were slightly stronger than those of other transportation noises [15, 16]. Finegold *et al*., comparing the data obtained from a number of national community response surveys, revealed that the source-specific lines were very close to each other below $L_{dn} = 60$ dB(A) and the railway noise annoyance increased over road traffic noise after $L_{dn} = 70$ dB(A), whilst the aircraft noise was most annoying at all noise levels [17].

2.2. STUDY OBJECTIVES

There were a number of discussions about the methodological problems and possible errors arising during the comparisons of the annoyances obtained by different field surveys carried out in different communities and under different environmental conditions by using different techniques [3, 8, 10, 18]. Similar considerations have emerged while comparing the field and laboratory data [19], especially on conversion from outdoor levels to indoor levels and the calibration values. Due to the lack of information about the exact indoor conditions, the social level of the community concerned, and due to the differences in the annoyance scales used, the comparable data for this purpose are rather difficult to obtain and combine meaningfully. Therefore some comparisons may yield conflicting results, indicated above. Consequently, it can be said that the decisions about the variation of annoyance from the transportation noises are somewhat contradictory and inadequate, requiring further simultaneous studies on this subject. Although there are prediction methods yielding conflicting results on the change of annoyance according to the noise levels from various sources, as far as known there is yet no model for investigating the change of annoyance according to the types of source. It seems that an acceptable model for the annoyance predictions, as a function depending on source type and noise level in L_{eq}, has not yet received much attention. In developing such a model, the simulated-environment method has appeared to be rather appropriate, particularly in enabling the comparison of source-specific annoyances, if the simulation of noise and living environment, sampling of the community and projection of the subjects into real life could be achieved satisfactorily.

This experiment was designed to serve the following objectives: (1) determination of annoyance reactions against three types of transportation noise sources in a simulated-home environment; (2) comparison of these reactions to investigate whether the type of source is significant or not; and (3) comparison of the annoyance reactions while performing different activities.

The simulated environment method that was used in this study has been widely implemented and discussed in the literature, as mentioned above [12]. Its validation for measuring annoyance reactions has been confirmed by many authors. It is generally accepted that this method has some advantages in dealing with the specific aspects of the annoyance problem; e.g., it gives one the possibility to control the stimuli better than in field studies. The success of the study depends upon the efficient simulation of the noise sources and the living environment in the laboratory by taking into account the numbers of physical and psychological parameters affecting the annoyance reactions of the people exposed to noise. Since the types and operational characteristics of transportation noise sources influence the noise generation as well as the annoyance, the acoustical simulation is of importance in this kind of experiment. Satisfying the required criteria of reproducibility and universality, the characteristics of this method have been enumerated as relative judgement, accurate noise parameter, fixed reverie task, normal hearing subjects, low cost, etc. The disadvantage of the short-term exposure has been investigated as has the effect of duration on annoyance and it has been concluded that 30 min is a rather sufficient duration for such experiments [14]. The problem of the order of the presentation of samples, which has a significant effect on the annoyance responses, has been solved by designing the tests in a perfectly randomized and balanced order.

Consequently the relative annoyance reactions which are the primary objective of this study could be determined through a simulated environment study.

3. DESIGN OF THE EXPERIMENT

The technical aspects of the method applied in this study are briefly summarized below.

3.1. SIMULATION OF NOISE

In this study, the noise samples for road, aircraft and railway noises were prepared from the field recordings, and appropriately processed subsequently for use in the laboratory simulations of a home environment. Field measurements were taken in the Kobe and Osaka areas at selected sites satisfying the requirements in the ISO standards. Two microphone positions were selected at each site representing each source type. The distances from the receivers to the noise sources were taken as 30 and 100 m, so that the target noise levels would be $L_{eq} = 50$ and 70 dB(A) within 30 min, preserving natural fluctuations and spectrum changes in the sound signals at near and far distances. During the measurements made simultaneously at the two points of each site, the source movements were also recorded by two video-cameras to provide the visual simulation during the experiment. Master-tapes including the raw signals were then processed in the laboratory, first to obtain the outdoor (facade) noise samples that would be controlled according to the selected pass-by numbers, and second to obtain the indoor noises. In this process, the natural background noise levels were kept 12–25 dBA lower than the peak levels (see Figure 1).

The pass-by number that was formerly found to have caused an effect on annoyance, had to be normalized while comparing the intermittent and continuous noises [9, 20–24]. A review of this subject is given in reference [5]. Due to the contradictory findings, it was planned to conduct a supplementary test (in the first nine sessions) during the experiment to check the effect of the number of events N, within a limited range, on annoyance degrees and to be able to decide about the normalization value. The N values of 8, 12 and 16 per 30 min, were selected among those at which noise annoyance had been confirmed to be almost stable in some of the previous experiments [23, 25]. In selecting this range, the existing situation in Japan was also taken into consideration, i.e., $N = 8$ means a 3·75 min interval between two consecutive peaks of the trains, which is rather common in the cities, and $N = 16$ corresponds to 1·8 min which is the minimum interval for railway and aircraft operations in the busiest traffic conditions.

The noise samples consisting of different types of vehicles were assumed to be randomly distributed within the 30-min test period with varying peak levels and different pass-by durations as in actual situations. However, the pass-by frequencies of the railway and aircraft noises were balanced within the first and the second halves of the test period and the L_{eq} values were kept equal to L_{eq} (30 min). The reason for this was to be able to examine two different activity performances under similar noise conditions during the experiment. 14 different noise samples were prepared as follows:

Noise samples	Source	Noise level L_{eq}
R1	Traffic noise (near)	70 dB(A)
R2	Traffic noise (distant)	50 dB(A)
T1-1 ($N = 8$) T1-2 ($N = 12$) T1-3 ($N = 16$)	Railway noise (near)	70 dB(A)
T2-1 ($N = 8$) T2-2 ($N = 12$) T2-3 ($N = 16$)	Railway noise (distant)	50 dB(A)
A1-1 ($N = 8$) A1-2 ($N = 12$) A1-3 ($N = 16$)	Aircraft noise (near)	70 dB(A)
A2-1 ($N = 8$) A2-2 ($N = 12$) A2-3 ($N = 16$)	Aircraft noise (distant)	50 dB(A)

Simulation of the indoor noise in the laboratory environment, furnished as a living room, required further modifications of the prepared signals, which were important in the audio frequency range. The effective factors were the transmission losses of the facade, acoustical properties of the room and the characteristics of the loudspeakers to be used in simulation of noise. Considering that the noise

Fig. 1(a).

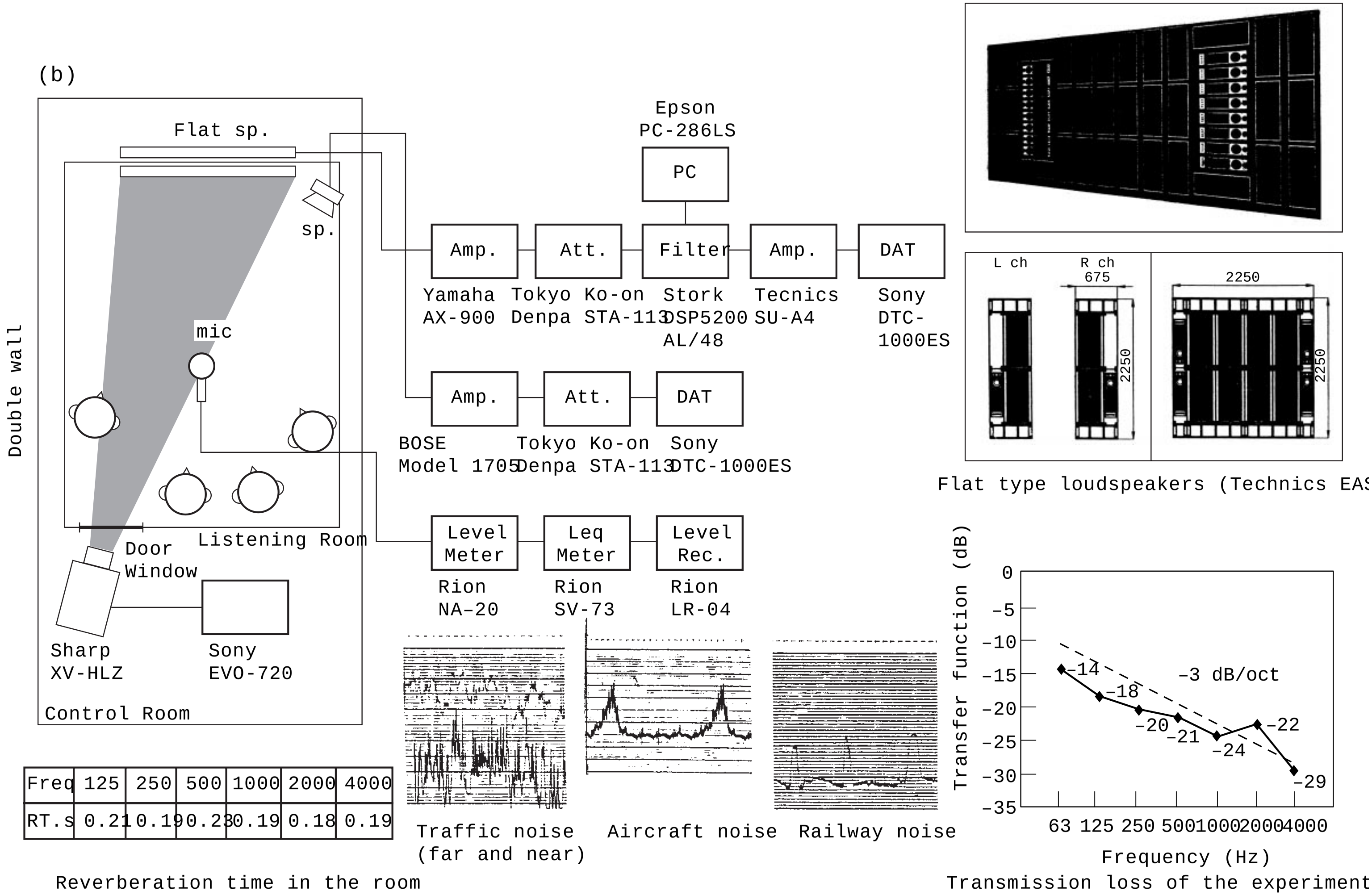

Figure 1. Simulated environment laboratory and equipment set-up (a). Starting the experiment in the laboratory; (b) characteristics of the test room and equipment set-up.

reduction of a wall, expressed in dB(A) difference, is not similar for different source types having different spectrum shapes, even though the facade levels are the same, typical frequency-dependent transmission loss values were applied to the spectra of the signals before they were reproduced by the loudspeakers as noises in the room. The transmission of the experimental wall was a calculated value for a typical insulated wooden construction of a Japanese house, including a window (40% of the wall area) with normal glazing. The room characteristics were also determined through a total transfer function obtained by the indoor measurements by using pink noise. The results given in the octave bands were applied to the signals via a computer controlled filter system within a bandwidth of 63–4000 Hz at the time sequence of 0·5 s and then the signals were synthesized electronically. The overall indoor noise levels at the subjects' ears were set as 35, 40, 45, 50 and 55 dB(A), in L_{eq} (30 min), through an attenuator after the calibration measurements within the room. During the experiment, indoor noises were monitored by a ceiling microphone, graphic recorder and L_{eq} meter.

The simulated-environment laboratory and experimental set-up are shown in Figures 1(a, b). The signals were played back via flat-type loudspeakers that were placed in such a way as to expose the room facade to noise sources.

3.2. SIMULATION OF INDOOR ENVIRONMENT

The laboratory which was constructed apart from the main building was of about 25 m^2 floor area and connected to a control room. It was furnished as a normal modern style living room which is nowadays rather common in Japan [see Figure 1(a)]. A false window was provided in front of the loudspeakers and the video-screen was covered by loose drapery. The measured reverberation time is given in Figure 1(b). Insofar as possible, daylight conditions were reproduced artificially in the room. Visual effects of the noise sources were obtained by means of a video-projector on the screen through a window from the control room.

The video-tapes that were recorded at two distances during the field measurements for each noise source were synchronized according to the source movements, and were played back during the experiment.

3.3. SIMULATION OF COMMUNITY

As a general criterion, psycho-acoustical studies carried out in simulated-environment laboratories should be designed to provide a conformity to those performed in the field. Community reactions in real life vary with the various individuals concerned, and also have to be considered in the experimental studies. The major individual factors such as age, sex, occupation, education level, social and economical status, health, daily noise-dose of the subjects living in noisy or quiet environments, previous experience with noise, adaptation and sensitivity to noise, have been extensively considered in previous field studies and their influence on annoyance degrees has been discussed in the literature [18, 26–29]. Therefore in this experiment, it was planned to select the subjects randomly from different sections of the community without applying a stratified sampling technique. Subjects were considered to come from various occupational, educational and income groups, to be of different ages and sexes, and an appropriate equivalence was desired to be provided within these groups. However, since they were all unpaid voluntary subjects from the nearby communities, it was practically impossible to provide an exact balance in groups of subjects within the restricted time of the study. The major requirement for each subject was to have normal hearing in the audible frequency range and this was checked through the audiometry tests just before attending the experiment.

Sensitivity to noise is a factor that has been given a great deal of consideration in annoyance problems and has been explained by different models [18]. The main effect of the differences of noise sensitivity can be seen in the noise and annoyance relationships, revealing a greater dispersion of annoyance scores at all noise levels. Because of this factor, analyses when using the individual subjective scores in the field studies have not yielded a satisfactory correlation, while group or average annoyance scores have better correlation coefficients. It was generally accepted that the sensitivity problem has been reduced in the laboratory experiments due to almost equal concentration of the subjects. In this study, subjects' sensitivity to noise was checked through two types of questions in the questionnaire form: general sensitivity to the subject's environment and sensitivity to noise problems. However, the effects of this factor—as well as other individual factors—on the responses, will not be presented in this paper.

Adaptation to noise was another factor emerging in two ways during the experiment: the subject's previous experience of noise and his/her adaptation to the noise during these exposures [19, 29]. In this study, the first type of adaptation was checked through some questions about the noisiness of their living and working environment and the second adaptation was eliminated by the design of the tests in which the order of presentation of the noise samples were completely at random. Besides, there were sufficient breaks between the two consecutive sessions to provide their relaxation.

Subjects' attitudes toward the experiment was also important, since it is not easy to make the subjects' projection into real life. This can be done by means of different questions worded cautiously to be able to compare the individual responses. Besides, the annoyance while performing some common daily activities could also be checked in order to support the general or overall annoyance during the entire experiment.

3.4. SURVEY TECHNIQUE

Questionnaire form

The technique to be employed in such a laboratory psycho-acoustical study is also important in order to get results comparable to those of field studies. The questionnaire form should have special instructions for the subjects describing the test procedure and helping them to feel themselves to be in real life. In general, these details should be considered in preparing the questionnaire to provide an identity to other surveys: construction of annoyance scale, construction of activity interference scale (to be explained in Part 2), order of questions, filtering questions and control questions.

Based on the previous experiences obtained in the field studies, the questionnaire form for this experiment, was prepared in English, then translated into Japanese with special care on the wording of the text, particularly on the annoyance expressions which have been investigated as being different for different nationalities [30, 31]. The questions have been categorized as follows: (a) questions for individual characteristics, such as, age, sex, social status, etc.; (b) questions about their previous experience with noise; (c) questions about their sensitivity to noise; (d) questions about their annoyance degrees while reading; (e) questions about the annoyance degrees while listening ; (f) questions about the overall annoyance and home projected annoyance; and (g) comparison of their annoyances from three different noise sources at the end of the all three sessions.

The draft questionnaire-form was tested through a pilot study and the revised copy consisting of 19 pages in the Japanese version was selected according to the three sessions which would be attended by the subjects.

Annoyance scale

Annoyance responses can be quantified by using special scaling techniques in annoyance studies [3, 10, 32]. A rating scale can be in either verbal or numerical form, but it is necessary to use the verbal statements with numerical values for evaluations by means of statistical techniques. Categories consisting of series of numbers at equal intervals have been tried by various investigators and 1 to 7 or 1 to 9 point scales have been found satisfactory; because, too few numbers in the scale may not be sufficient to express the feelings and too many may be difficult to discriminate and judge adequately [14]. The smallest number 1 in the scale generally represents "definitely satisfied" or "not annoyed at all" and the biggest number 5, 7 or 9 indicates the "definitely unsatisfied" or "extremely annoyed" situations. A unipolar annoyance scale employed in this study has been selected as a 7-point category scale from "not at all" to "very much annoyed" that was found appropriate by various investigators due to its suitability also to short-term memory.

Test design and data structure

The total duration of the test was 30 min including two sequences in which the two activity disturbances were to be investigated in addition to the overall annoyance response that was evaluated at the end of the tests. The tests were designed so that each noise stimulus was received by at least two groups of four subjects each. Initially only the three levels [35, 45, 55 dB(A)] were planned; later extra sessions were added for the intermediate levels of noise [30, 40, 50 dB(A)].

The total number of Japanese subjects was 64 with a total number of 48 sessions. Each subject took three sessions involving different source types and noise levels. The order of presentation of the noise samples was designed according to the random sequence Latin Square Design Technique [12, 19, 23]. The raw data relative to the annoyance questions were grouped in three categories: (a) individual scores (responses) (INDIV DATA); Number of cases is 192; (b) group average scores (GROUP DATA), number of group cases of different conditions are 30 (for six noise levels, three sources and three pass-by numbers) and 18 (for six noise levels, three sources and one pass-by number of $N = 12$ per 30 min); (c) percentage of highly annoyed subjects by taking the sixth and seventh degrees of annoyance (HIGHAN DATA), number of cases 30. These descriptors were separately evaluated for different annoyance questions; annoyance during reading (RAQ), annoyance during listening (LAQ), overall annoyance (OAQ) and annoyance projected to subjects' home environment (HAQ). Moreover the average of the answers given to the four annoyance questions including the activity disturbances, named as SUMMIN by Fields *et al*. [9], was also investigated. Activity disturbance will be evaluated in Part 2.

4. EVALUATION OF DATA AND RESULTS

Experimental data were statistically analyzed to assure that they met the above mentioned study objectives, through *t*-tests, correlation, regression and variance analysis by using first SPSS/PC+ (ANOVA), then SPSS for windows, both running on an IBM compatible computer and by Cricket running on Apple MacIntosh. Some of the results of the study are summarized below by emphasizing the annoyance variation with source type.

4.1. CHECKING THE EFFECT OF PASS-BY FREQUENCY (IN THE GIVEN RANGE) ON ANNOYANCE

t-tests

In order to normalize the effect of pass-by number, as mentioned in section 3.1, a supplementary test was carried out in the first part of the experiment by taking account of three pass-by frequencies ($N = 8$, 12, 16 per 30 min) and three noise levels [$L_{eq} = 35$, 45, 55 dB(A)] for railway and aircraft noises. It indicated that the correlation coefficients between N and annoyance by using group average scores (GROUP DATA) were rather small and the means and standard deviations of the three grouped data of N obtained for each question type and for each noise level, were quite similar (see Table 1). This result can imply that N was not a significant factor in the range of 8–16 per 30 min. This analysis was repeated for train and aircraft noises both separately and in combination.

Variance analyses performed to investigate the main effects of level and pass-by number on all the annoyance questions and SUMMIN, for the GROUP DATA, showed the significance level was 0·911 for overall annoyance question, 0·171 for home projected annoyance question; and 0·979 for SUMMIN. This result implies a very high acceptance of the hypothesis of equality between the groups, while the noise level is highly significant for all cases ($<0{\cdot}001$).

Regarding the variation of $HA\%$ with the pass-by number, the results presented by Rice and Rylander [23] were compared with this study for about similar aircraft noise conditions obtained in the field. Rice indicated that the annoyance increase

TABLE 1

t-test summary regarding the effect of pass-by number (N) on the annoyance responses

Question number and groups according to pass-by number	No. of cases	Mean	SD	SE	t-values between groups
Overall annoyance (OAQ)					
INDIV DATA					
$N = 1$	24	3·83	3·83	1·880	0·384
$N = 2$	76	3·64	1·663	0·191	0·47
$N = 3$	36	3·47	1·748	0·291	0·50
GROUP DATA					
$N = 1$	6	3·83	1·625	0·664	
$N = 2$	12	3·62	1·287	0·371	0·30
$N = 3$	6	3·68	1·458	0·595	−1·10
HIGHAN DATA					
$N = 1$	6	16·66	20·412	8·333	
$N = 2$	12	19·79	24·690	7·127	−0·27
$N = 3$	6	16·66	29·226	11·932	0·24
Home annoyance (HAQ)					
INDIV DATA					
$N = 1$	24	4·58	2·125	0·434	
$N = 2$	76	4·31	2·041	0·234	0·55
$N = 3$	36	4·94	1·820	0·303	−1·57
GROUP DATA					
$N = 1$	6	4·58	1·625	0·664	
$N = 2$	12	4·35	1·639	0·473	0·28
$N = 3$	6	5·16	1·388	0·567	−1·04
HIGHAN DATA					
$N = 1$	6	50·00	35·355	14·434	
$N = 2$	12	37·15	33·168	9·575	0·76
$N = 3$	6	52·08	40·633	16·588	−0·84
Average annoyance (SUMMIN)					
INDIV DATA					
$N = 1$	24	3·82	1·850	0·378	
$N = 2$	76	3·54	1·722	0·198	0·67
$N = 3$	36	3·54	1·578	0·263	−0·01
GROUP DATA					
$N = 1$	6	3·82	1·618	0·661	
$N = 2$	12	3·55	1·423	0·411	0·36
$N = 3$	6	3·80	1·539	0··628	−0·35
HIGHAN DATA					
$N = 1$	6	24·98	23·380	9·545	
$N = 2$	12	21·75	23·584	6·808	0·27
$N = 3$	6	24·96	29·503	12·044	−0·25

was 8% with the N variation within 16–32 per hour whereas Rylander suggested no difference in the annoyance after four aircraft per hour. The variation of annoyance with pass-by number by using HIGHAN DATA, has been found to be a 3% increase in the similar noise range in this experiment [5]. Based on the above discussion, $N = 12$ has been selected as an intermediate number of noise events to normalize this effect in comparison of continuous and intermittent noise annoyances. However, there is no significant difference found between the results by taking only the $N = 12$ data and the total data combined for all the three pass-by numbers.

4.2. STATISTICAL ANALYSIS FOR THE GROUP DATA AND RESULTS

The group-average scores can be suggested as the best descriptor of annoyance, since they gave the highest correlation coefficients between the noise levels and the annoyance responses for all the question types and for all the data categories (see Table 2). Firstly the GROUP DATA including 18 cases were employed in the further analyses on deriving the source-specific annoyance responses for road, railway and aircraft noises.

Raw data descriptions

Source-specific line charts (noise level and group average scores), are shown in a comparative manner in Figure 2 for overall and home-projected annoyance questions, that are abbreviated by OAQ and HAQ respectively. As can be seen in the total or overall annoyance chart, the railway noise appears to be the dominant transportation noise at almost all levels, contrary to some previous studies performed either in the field or in the laboratory. It seems that there is a crossover-point of all the source-lines at about 45 dB(A) for overall annoyance and below this level, railway noise causes higher annoyance than the road and aircraft noises. This situation is somewhat different for the home projection question in which this intersection seems as shifted to 48 dB(A) and the difference between the source-specific annoyances is relatively small at around 50 dB(A).

Regressions on GROUP DATA

The linear regression lines obtained for each source are compared in the charts in Figures 3(a) and 3(b) and the noise dose and response relationships are given below. The dependent variable in all the equations is the average annoyance score (AAS) in the 7-point scale and the L represents the indoor noise levels as L_{eq} in 30 min [in the range of 30–55 dB(A)]. The number of cases is 18.

Overall annoyance (OAQ),

$$\text{AAS (road traffic noise)} = 0{\cdot}150\ L - 2{\cdot}742 \quad (r = 0{\cdot}953), \tag{1}$$

$$\text{(railway noise)} = 0{\cdot}135\ L - 1{\cdot}804 \quad (r = 0{\cdot}898), \tag{2}$$

$$\text{(aircraft noise)} = 0{\cdot}126\ L - 2{\cdot}035 \quad (r = 0{\cdot}983), \tag{3}$$

TABLE 2

Correlations between indoor noise level and annoyance for the three data categories

		INDIV DATA ($n =$ [a])	GROUP DATA ($n =$ [b])		HIGHAN DATA ($n =$ [b])
Noise source	Question type	Individual scores and L_{eq}	Group average scores and L_{eq}	Group average scores and L_{max}	HA% and L_{eq}
Road traffic	OAQ	0·7128**	0·9537*	0·9505*	0·8549
	HAQ	0·6123**	0·9786**	0·9620*	0·9803*
	SUMMIN	0·7589**	0·9569*	0·9611*	0·6960
Railway	OAQ	0·5997**	0·8991*	0·9261*	0·7606
	HAQ	0·6405**	0·9209*	0·9286*	0·8552
	SUMMIN	0·6840**	0·9208*	0·9244*	0·8133
Aircraft	OAQ	0·6596**	0·9840**	0·9805**	0·7641
	HAQ	0·6395**	0·8910*	0·8908*	0·8613
	SUMMIN	0·7615**	0·9905**	0·9966**	0·9173*

* −0·01; ** −0·001.
[a] $n = 56$ (for road traffic noise); $n = 36$ (for railway noise, only for pass-by no. = 12); $n = 40$ (for aircraft noise, only for pass-by no. = 12).
[b] $n = 18$ cases (6 cases for each row).

Home-projected annoyance (HAQ),

$$\text{AAS (road traffic noise)} = 0{\cdot}165\ L - 2{\cdot}475 \quad (r = 0{\cdot}978), \tag{4}$$

$$\text{(railway noise)} = 0{\cdot}162\ L - 2{\cdot}323 \quad (r = 0{\cdot}920), \tag{5}$$

$$\text{(aircraft noise)} = 0{\cdot}167\ L - 2{\cdot}983 \quad (r = 0{\cdot}891). \tag{6}$$

As can be seen from the charts, the distribution of response data varies with the standard deviation of max 1·47 dB(A) for different questions. The highest

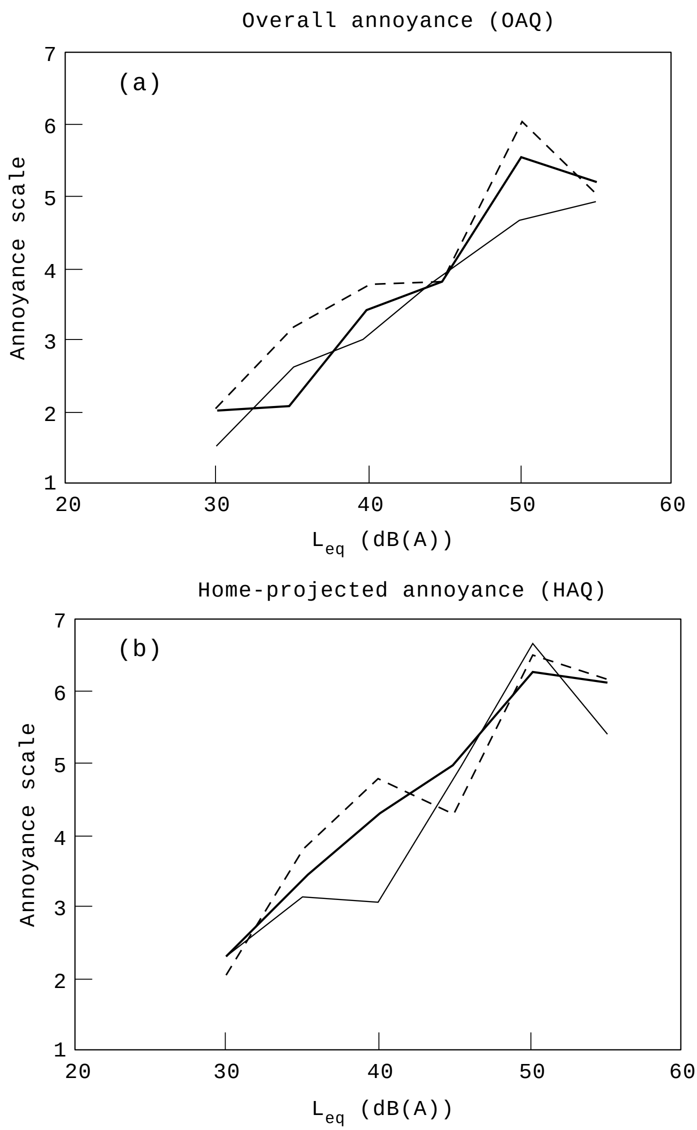

Figure 2. Effect of source type on annoyance responses with respect to noise level (group average scores by using only $N = 12$ data) ($n = 6$ cases for each source) (a) Overall annoyance (OAQ); (b) home-projected annoyance (HAQ). ——, Road; ——, aircraft, $N=12$; – – –, train, $N = 12$.

correlation coefficient was obtained for aircraft noise for both question types (see Table 3). For overall annoyance, the railway noise level is from 3·5–5·5 dB(A) higher than the aircraft noise at equal annoyance degrees. The difference between the railway noise and the road traffic noise is less than this value and changes as a function of noise level, e.g., about 2 dB(A) at the fourth degree of annoyance. However for the home-projection question, the differences between all the sources, particularly for road and railway noise, decrease with the increasing noise level, even merging in 55 dB(A). The result implies that the primary factor in this question is the noise level rather than the source type.

The slopes and the intercepts of the regression lines can be compared in Table 3.

Variance analysis on GROUP DATA

The significance of source-type effect and the noise level on different annoyance responses was examined by variance analyses. Table 4 gives the results for all annoyance questions obtained by the tests. F values for the source type have the greatest value (4·700) with the significance level of 0·031 for the overall annoyance question for $P < 0{\cdot}05$. In case the GROUP DATA with $n = 30$ is taken in the calculations, F becomes 4·936 and sig. of F equals 0·027. SUMMIN comes second with the significance level of 0·040. The response to the home annoyance question was found to be the least dependent on source type (0·221).

From the above analysis, the dependency of annoyance on noise level is always found to be very strong with the F values given in the table. All the significance levels are less than 0·001.

4.3. STATISTICAL ANALYSES FOR THE INDIVIDUAL RESPONSE DATA AND RESULTS

The statistical analysis performed on individual annoyance scores for the overall annoyance question (OAQ) is outlined below: the number of cases is 192 including all the responses for railway and aircraft noises for all pass-by numbers.

Basic tests

(a) The normality tests necessary for the variance analysis (Shapiro–Wilks and Lilliefors histograms) gave the values greater than 0·0000 not rejecting the normality hypotheses.

(b) The boxplots displaying summary statistics for the distribution for each source and noise level are given in Figures 4(a–c).

(c) All the frequencies and the distribution parameters are given in Table 5. As can be seen from Table 5, the source-specific-annoyance scores have different variabilities at 35 dB(A) and railway annoyance responses have the largest spread. At 45 dB(A), road data have relatively less variability while at 55 dB(A), the three source data indicate similar distribution. The comparison of the sizes of the differences in means is very close to zero at 45 and 55 dB(A) and in medians 30 and 45 dB(A) respectively for the overall annoyance question, which can be seen in Figures 5(a,b).

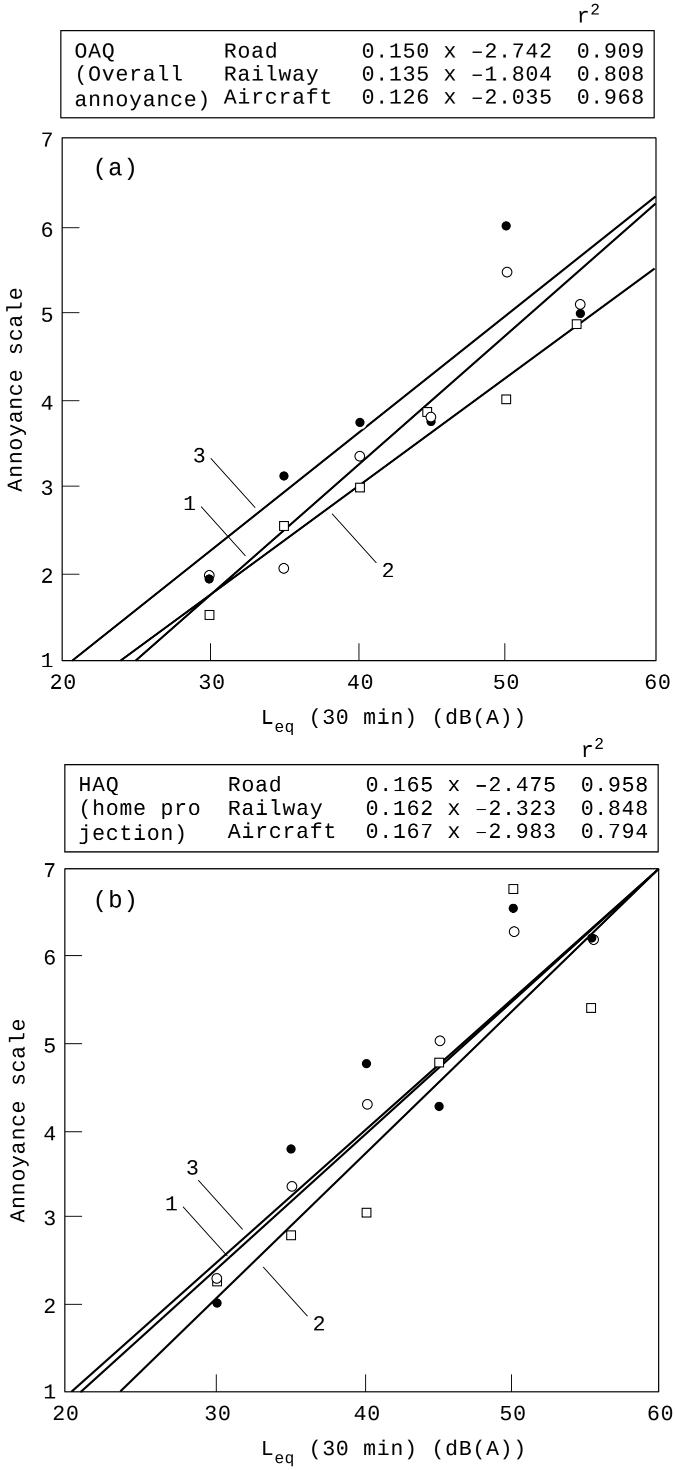

Figure 3. Comparison of regression lines obtained between group-average annoyance scores and noise level for three types of sources ($n = 6$ cases for each source). (a) Overall annoyance (OAQ); (b) home projected annoyance (HAQ). ○, Road traffic noise, 1; □, Aircraft noise, 2; ●, Railway noise, 3. (a) OAQ (Overall annoyance); for road, $0{\cdot}150\ x - 2{\cdot}742$, $r^2 = 0{\cdot}909$; for railway, $0{\cdot}135\ x - 1{\cdot}804$, $r^2 = 0{\cdot}808$; for aircraft, $0{\cdot}126\ x - 2{\cdot}035$, $r^2 = 0{\cdot}968$. (b) HAQ (home-projected annoyance); for road, $0{\cdot}165\ x - 2{\cdot}475$, $r^2 = 0{\cdot}958$; for railway, $0{\cdot}162\ x - 2{\cdot}323$, $r^2 = 0{\cdot}848$; for aircraft, $0{\cdot}167\ x - 2{\cdot}983$, $r^2 = 0{\cdot}794$.

The equality of the means was sought by performing t-tests for paired samples. Since the two-tail significance levels are greater than 0·000, the hypothesis of equality was not rejected, implying that there is no significant difference in means for 95% CI. Only the three level of noise are given below:

	2-tail sig	95% CI	
35 dB(A),			
K1–K2	0·851	−1·040,	0·873
K1–K3	0·030	−2·040,	−0·127
K2–K3	0·019	−1·455,	−0·145;
45 dB(A),			
K1–K2	0·701	−0·766,	1·099
K1–K3	0·795	−0·772,	0·605
K2–K3	0·893	−0·817,	0·717;
55 dB(A),			
K1–K2	1·00	−1·095,	1·095
K1–K3	0·808	−2·146,	1·896
K2–K3	0·440	−1·384,	0·634.

Variance analyses on INDIV DATA

The significance of the source-type effect on the individual annoyance scores at each noise level was also investigated by one-way ANOVA and multiple range tests to find which group means is significantly different. The results are summarized below.

Noise level, dB(A)	F ratio	F prob.	Case no.	Multiple range tests
30	0·3250	0·7282	16	No two groups are significantly different at 0·050 level
35	4·6239	0·0145	52	3rd group (railway noise) indicates difference at 0·050 level
40	0·1716	0·8442	16	No two groups are significantly different at 0·050 level
45	0·2313	0·7994	52	No two groups are significantly different at 0·050 level
50	2·4375	0·1262	16	No two groups are significantly different at 0·050 level
55	0·3292	0·7216	40	No two groups are significantly different at 0·050 level
	Total cases	:	192	

The significance levels obtained from the variance analysis between the noise levels and the source type are given in Table 6. The source type is significantly effective both for the overall annoyance and the listening annoyance as can be seen from Table 6, supporting the results of the GROUP DATA.

TABLE 3

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

	OAQ			HAQ			SUMMIN		
	Road	Aircraft	Railway	Road	Aircraft	Railway	Road	Aircraft	Railway
Correlation coeff.	0·953	0·983	0·899	0·978	0·891	0·920	0·957	0·990	0·920
Intercept	−2·742	−2·035	−1·804	−2·475	−2·982	−2·323	−3·078	−3·149	−2·472
Slope	0·150	0·126	0·135	0·165	0·167	0·162	0·158	0·151	0·148
SE	0·496	0·237	0·687	0·362	0·893	0·717	0·502	0·220	0·654
F value	40·176	121·931	16·880	90·557	15·408	22·323	43·447	207·151	22·280
Significance	0·0032	0·004	0·147	0·0007	0·0172	0·0091	0·0027	0·0001	0·0092

OAQ, overall annoyance; HAQ, home projected annoyance; SUMMIN, average responses of four annoyance question including reading and listening annoyance.

TABLE 4

Summary of variance analysis to determine the main effects of level and source type on average group scores (GROUP DATA n = 30 for each question) (P < 0·05); OAQ, overall annoyance; HAQ, home projected annoyance; SUMMIN, average responses of four annoyance questions including reading and listening annoyance

	Unique method				
Source of variation	Sum of squares	d.f.	Mean square	F	Signif. of F
OAQ by LEVEL and SOURCE					
Main effects					
(Combined)	41·931	7	5·990	19·009	0·000
LEVEL	38·839	5	7·768	24·651	0·000
SOURCE	3·111	2	1·555	4·936	0·027
2-way interactions					
LEVEL AND SOURCE	1·973	10	0·197	0·626	0·767
Model	49·330	17	2·902	9·209	0·000
Residual	3·781	12	0·315		
Total	53·112	29	1·831		
HAQ by LEVEL and SOURCE					
Main effects					
(Combined)	53·458	7	7·637	24·925	0·000
LEVEL	52·661	5	10·532	34·375	0·000
SOURCE	0·793	2	0·396	1·294	0·310
2-way interactions					
LEVEL AND SOURCE	2·713	10	0·271	0·885	0·570
Model	68·823	17	3·754	12·253	0·000
Residual	3·677	12	0·306		
Total	67·500	29	2·328		
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		

4.4. COMPARISON OF THE RESULTS WITH THE PREVIOUS STUDIES

The results of this experiment were compared with the findings of the previous laboratory studies mentioned above and some of the results are discussed below.

(a) Rice's experimental data taking the group average scores of the question "live with" [12], were used to compare with the average responses to the HAQ in Figure 6. The regression lines of this experiment indicate steeper slopes for both sources. However, it is remarkable that the road traffic noise is more annoying compared to aircraft noise, which has been confirmed also by this study.

(b) Izumi's laboratory experiment [14] and Cooper's study [7] which have pointed to the dominance of aircraft noise over traffic noise, are contrary to the results of this experiment as can be seen from Figures 7 and 8. The regression lines obtained for OAQ remain in a similar range but indicate somewhat different slopes.

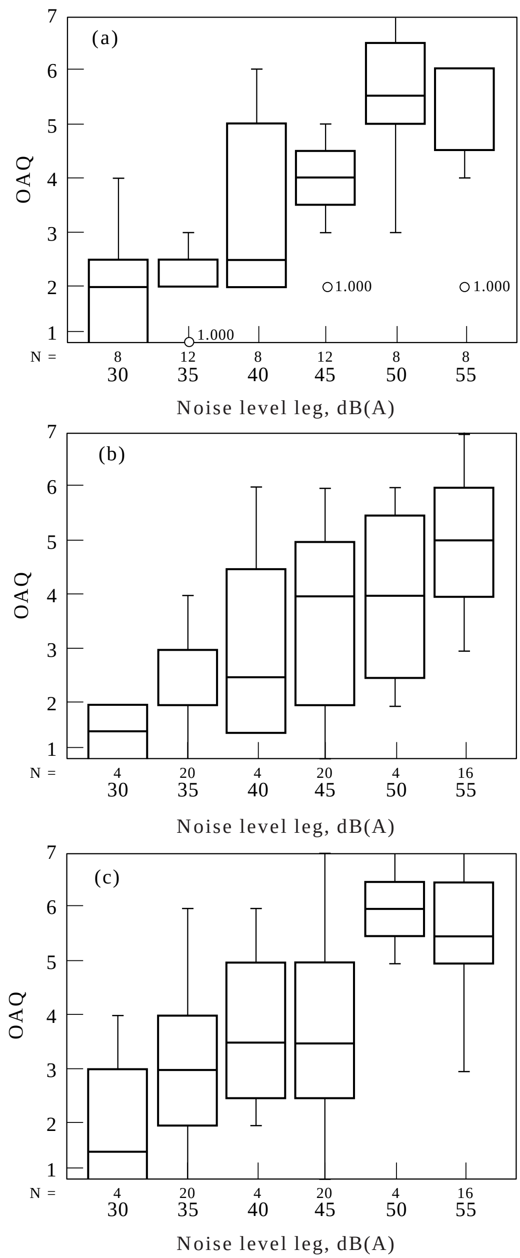

Figure 4. Boxplots of individual data for each source. (a) Road traffic noise ($n = 56$); (b) aircraft noise ($n = 68$); (c) railway noise ($n = 68$).

Table 5

Distribution parameters of the INDIV DATA for overall annoyance question (OAQ)

Level	Source	Mean	Median	Variance	Range	Skewness	Valid case	Mode	25%	50%	75%
30	Road	2·00	2·00	1·1429	3·00	0·935	8	—	—	—	—
	Aircraft	1·50	1·50	0·3333	1·00	0·0000	4	—	—	—	—
	Railway	2·00	1·50	2·0000	3·00	1·4142	4	—	—	—	—
35	Road	2·00	2·00	0·4470	2·00	−0·0862	12	2·00	2	2	2·75
	Aircraft	2·25	2·00	0·7237	3·00	0·6056	20	2·00	2	2	3
	Railway	3·05	3·00	1·6289	5·00	0·7413	20	2·00	2	3	4
40	Road	3·38	2·50	2·8393	4·00	0·6457	8	—	—	—	—
	Aircraft	3·00	2·50	4·6667	5·00	1·1903	4	—	—	—	—
	Railway	3·75	3·50	2·9167	4·00	0·7528	4	—	—	—	—
45	Road	3·83	4·00	1·0606	3·00	−0·8101	12	4·00	3·25	4	4·75
	Aircraft	3·50	4·00	2·0526	5·00	−0·0597	20	2·00	2	4	5
	Railway	3·55	3·50	2·3658	6·00	0·1849	20	3·00	2·25	3·5	5
50	Road	5·50	5·50	1·7143	4·00	−0·7638	8	—	—	—	—
	Aircraft	4·00	4·00	3·3333	4·00	0·0000	4	—	—	—	—
	Railway	6·00	6·00	0·6667	2·00	0·0000	4	—	—	—	—
55	Road	5·13	6·00	2·1250	4·00	−1·7582	8	6·00	4·25	6	6
	Aircraft	5·00	5·00	1·3333	4·00	0·2969	16	4·00	4	5	6
	Railway	5·36	5·50	1·9833	4·00	−0·6086	16	5·00	5	5·5	6·75

(c) When the results of this experimental study were compared with those of the field surveys after indoor-outdoor calibration, the noise dose and response relationships, especially for railway noise diverged from the field findings in terms of the slope and the intercept, yielding a higher annoyance (0·2–1·5 average scores at the same noise level) [5].

4.5. DISCUSSION

Consequently, some contradictions between the patterns of noise annoyance obtained in these experiments and in some of the previous investigations, might emerge probably for the following reasons.

(1) Time differences between this study and those which were carried out 6–15 years before, might have caused a remarkable decrease of the tolerance of humans for noise. This issue has already been discussed in the literature.

(2) Annoyance from environmental noise sources has been evidenced to be dependent upon national differences, cultural and social factors as discussed in references [31, 32]. The greater percentage of the Japanese subjects who took part in this experiment were middle and high-class respondents from the standpoint of socio-economical and educational level and they gave higher priority to railway noise as a source of nuisance. Because the public transportation in Japan is mainly dependent on the surface railway system, which perhaps has a much more extensive network all over the country than in some European cities. The layout of buildings which are very close to railway routes in typical Japanese cities, as

well as the construction type of traditional houses having relatively poorer sound insulation, might contribute to the higher degrees of annoyance from railway noise, due to the subjects' previous experience to noise.

(3) As was mentioned before, the annoyance degrees in the laboratory experiment were not dispersed widely as they are in the field studies for identical noise conditions, due to the subjects' judgments being more concentrated, leading to higher annoyance degrees. Besides the correlation coefficients between the noise and annoyance appeared to be greater.

(4) The statistical analyses have shown that the effect of the source type was significant for the overall annoyance response during the entire 30 min of test duration. The reason for not finding a satisfactory significance level for the home-projected annoyance question might be because of the difficulty in evaluating it, since it has been observed that the subjects' responses indicate an overreaction to this question.

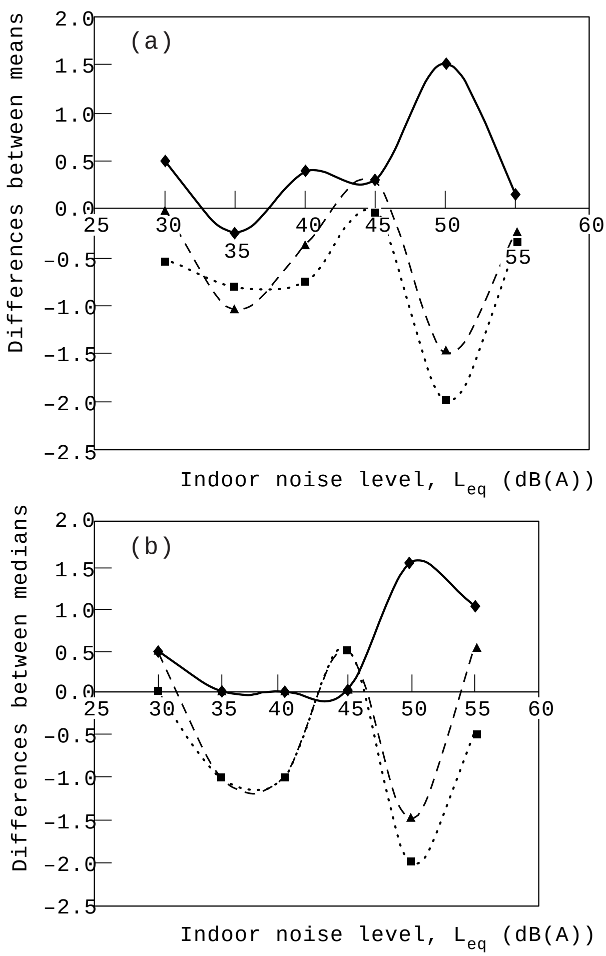

Figure 5. Comparison of size of differences in means and medians of individual responses at each noise level (Overall annoyance: OAQ). (a) Between means; (b) between medians. ●, Road-aircraft; ■, aircraft-railway; ▲, road-railway.

TABLE 6

Summary of variance analysis to determine the main effects of level and source type on individual annoyance scores (INDIV DATA $n = 192$) ($P < 0{\cdot}05$); *OAQ, overall annoyance; HAQ, home projected annoyance; SUMMIN, average responses of four annoyance questions including reading and listening annoyance*

Source of variation	Unique method: Sum of squares	d.f.	Mean square	*F*	Signif. of *F*
OAQ by LEVEL and SOURCE					
Main effects					
(Combined)	244·113	7	34·873	20·817	0·000
LEVEL	232·987	5	46·597	27·816	0·000
SOURCE	11·137	2	5·568	3·324	0·038
2-way interactions					
LEVEL AND SOURCE	12·761	10	1·276	0·762	0·665
Model	274·220	17	16·131	9·629	0·000
Residual	291·483	174	1·675		
Total	565·703	191	2·962		
HAQ by LEVEL and SOURCE					
Main effects					
(Combined)	309·265	7	44·181	17·405	0·000
LEVEL	305·318	5	61·064	24·056	0·000
SOURCE	3·593	2	1·797	0·708	0·494
2-way interactions					
LEVEL AND SOURCE	17·415	10	1·742	0·686	0·737
Model	352·274	17	20·722	8·163	0·000
Residual	441·679	174	2·538		
Total	793·953	191	4·157		
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		

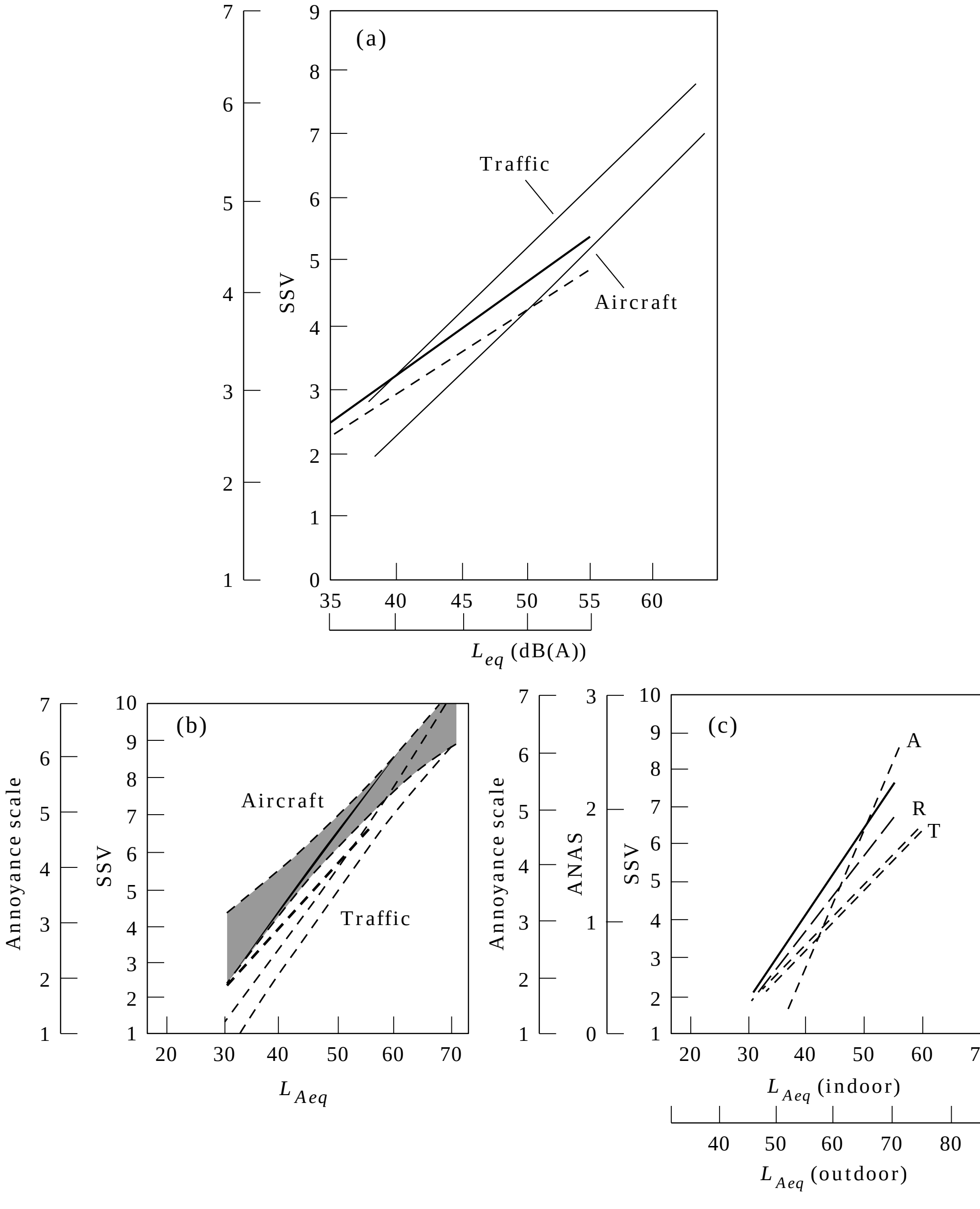

Figure 6. (a) Comparison of the experimental results with the chart given by Rice [12] (linear regression by using GROUP DATA). ——, OAQ for road traffic noise; – – –, OAQ for aircraft noise. (b) Comparison of the experimental results with the chart given by Izumi [14] (linear regression by using GROUP DATA). ——, road traffic noise; – – –, aircraft noise. (c) Comparison of the experimental results with the chart given by Cooper [7] (linear regression by using GROUP DATA). ——, road; – – –, aircraft; A, aircraft; R, traffic; T, total.

(5) Aircraft traffic has not been proved to be the highest source of annoyance in this experiment, contrary to the findings of some earlier studies. One possible explanation of this can be that the Japanese subjects had definitely less previous experience with aircraft noise, which is not a widely common source of noise there, than with railway and road noises. On the other hand, this experiment was designed in such a way that the aircraft flyovers were only side-flights, the noise intruding on the façade; therefore the "fear of crashing", which was evidenced in former experiments, was eliminated, thus this fact might have also reduced the annoyance [10].

5. CONCLUSION

The results of this experiment can be summarized as follows.

(1) The annoyance responses obtained from this laboratory study reveal a noticeable intensity compared with the previous experimental and field results.

(2) The dependence of annoyance scores on noise levels was found to be much more important than the source-type in indoor environments, except for aircraft flying over the buildings. The effect of source type was also found significant for half of the given questions about annoyance, i.e. overall (total) annoyance and listening annoyance (as will be described in Part 2). Reading and home-projected annoyance questions did not yield a satisfactory significance level. Summindex, taking into account the average answers to the above mentioned four question, also supports the significance of the source type effect.

(3) On the other hand, railway noise seems to be more prominent among the other transportation noise sources, especially in countries like Japan where railways are widely used as the surface transportation system.

(4) In this study, it was possible to predict the relative source-specific noise and annoyance for three type of the most common noise source and to compare the regressions both with each other and with the results of the other studies. The previous suggestions about the indoor limit of 45 dB(A) has been also supported by this study, since regardless of the source type this level seems to be a crossover-point at which the annoyance lines for three sources coincide in noise and annoyance line charts and which is much emphasized in the activity disturbances, (as will be explained in Part 2). The 45 dB(A) (L_{eq}) corresponds to the fourth degree of annoyance which is somewhat the neutral situation in living rooms and, above this level, a sudden increase in annoyance responses may readily be encountered.

The findings of this study indicate that the source type is not always a deterministic factor in the annoyance responses of the people at home while they are concentrating on various indoor activities, but the effect of the noise level is much more pronounced (with the steeper dose and annoyance line) compared to that shown in the field study results. The significance of this judgement also comes from the methodology applied in this study; i.e., the provision of similar test conditions for the subjects except for the varying source characteristics. The statistical differences of the annoyance responses for the three sources cannot be denied in some cases, but they are definitely less than the noise level and activity type.

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. The data were statistically analyzed and evaluated in Istanbul Technical University. We would like to thank especially Mr Sakagami, from Kobe University, Mr Tanaka from Ken-On Company 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.

REFERENCES

1. J. M. FIELDS, R. DE JONG, A. BROWN, I. FLINDELL, T. GJESTLAND, S. JOB, S. KURRA, P. LERCHER, A. SCHEUMER, M. VALLET and T. YANO 1997 *Journal of Sound and Vibration* **206**(5), 685–695. Guidelines for reporting core information from community noise reaction surveys.
2. V. KNALL and R. SCHEUMER 1983 *Journal of Sound and Vibration* **87**(2), 321–326. The differing annoyance levels of rail and traffic noise.
3. F. J. LANGDON 1985 in *The Noise Handbook* (Edition W. Tempest). London: Academic Press, Section 6.
4. J. B. OLLERHEAD 1980 *Noise as a Public Health Problem*, *ASHA Report* 10, *ICBEN*. Assesment of community noise exposure to account for time of day and multiple source effects.
5. S. KURRA, M. MORIMOTO, Z. MAEKAWA, K. SAKAGAMI *et al*., 1992 *Research Report*, *Kobe University*, *Japan*. Comparison of community disturbances from different transportation noise sources through a simulated environment study.
6. B. BERRY 1983 *Proceedings of Inter-Noise* **83**(2), 993–996. L_{Aeq} and subjective reaction to different noise sources: review of research.
7. P. J. COOPER, C. G. RICE, I. D. DIAMOND, J. G. WALKER 1983 *Technical Report*, *Institute of Sound and Vibration Research*, *Southampton University*, Heathrow International Airport study.
8. J. M. FIELDS and J. G. WALKER 1982 *Journal of Sound and Vibration* **81**(1), 51–80. Comparing the relationship between noise level and annoyance in different surveys: railway noise vs. aircraft and road traffic comparison.
9. J. M. FIELDS and J. G. WALKER 1982 *Journal of Sound and Vibration* **85**(2), 177–255. The response to railway noise in residential areas in Great Britain.
10. K. D. KRYTER 1985 *The Effect of Noise on Man*. New York: Academic Press.
11. F.L. HALL, S. E. BIRNIE, S. M. TAYLOR and J. E. PALMER 1981 *Journal of the Acoustical Society of America* **70**, 1690–1698. Direct comparison of community response to road traffic noise and to aircraft noise.
12. C. G. RICE 1977 *Journal of Sound and Vibration* **52**(3), 345–364. Development of cumulative noise measures for the prediction of general annoyance in an average population.
13. E. ÖHSTRÖM, M. BJÖRKMAN and R. RYLANDER, 1980 *Journal of Sound and Vibration* **70**(3), 334–341. Laboratory annoyance and different traffic noise sources.
14. K. IZUMI 1986 *Muroran Institute of Technology*, *H*-86-35 *N*. 85-10-2. On the measurement of annoyance in the laboratory.
15. H. MIEDAMA 1993 *Nederlands Instituut voor Preventieve Gezonheidszorg TNO*, *Pub*. *No*. 92021. Response functions for environmental noise in residential areas.

16. S. Fidell, D. Barber and T. J. Schultz 1991 *Journal of the Acoustical Society of America* **89**, 221–233. Updating a dosage effect relationship for the prevalence of annoyance due to general transportation noise.
17. L. Finegold, S. Harris and H. E. von Gierke 1994 *Noise Control Engineering Journal* **42**(1), 25–30. Community reaction to noise.
18. F. J. Langdon and I. B. Buller 1977 *BRE Current paper* 10. The effects of road traffic noise in residential areas.
19. I. H. Flindell 1983 *NASA Technical Memorandum* 85647. A laboratory study of the perceived benefit of additional noise attenuation by houses.
20. M. Björkman 1989 *PhD. Thesis, University of Gothenburg*. Community noise annoyance: importance of noise levels and number of events.
21. K. B. Rasmussen 1979 *Journal of Sound and Vibration* **65**(2), 203–214. Annoyance from simulated road traffic noise.
22. G. Labiale 1983 *Journal of Sound and Vibration* **90**(3), 361–371. Laboratory study of the influence of noise level and vehicle number and annoyance.
23. C. G. Rice 1977 *Journal of Sound and Vibration* **52**(3), 385–344. Investigation of trade-off effects of aircraft noise and number.
24. J. M. Fields, 1984 *Journal of the Acoustical Society of America* **75**(2), 447–467. The effect of numbers of noise events on people's reaction to noise: an analysis of existing survey data.
25. K. Izumi, 1988 *Healthy Buildings* 88, *Swedish Council for Building Research*, *Sweden* **3**. Annoyance due to road traffic and railroad noises in the domestic environment.
26. S. Lambert, F. Simonnet and M. Vallet 1984 *Journal of Sound and Vibration* **92**(2), 154–172. Patterns of behavior in dwellings exposed to road traffic noise.
27. S. Kurra 1989 *CIB Proceedings* **2**, 363–372. Traffic noise control by facade insulation: implementations based on a noise survey.
28. J. M. Fields 1992, *Report*, *Office of Environment and Energy*, *USA*. Effect of personal and situational variables on noise annoyance: with special reference to implications for en-route noise.
29. M. Vallet 1990 *Conference a l'Université Technique d'Istanbul*. Les effets du bruit routier et son controle dans la ville.
30. S. Namba, S. Kuwano and A. Schickj 1986 *Journal of the Acoustical Society of Japan* [E] **7**(5), 279–289. A cross cultural study on noise problems.
31. S. Namba, S. Kuwano, *et al*. 1991 *Journal of the Acoustical Society of Japan* [E] **12**(1). Verbal expression of emotions and impression of sound: a cross cultural study.
32. T. J. Schultz 1982 *Community Noise Rating*, London: Applied Science Publishers.