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Psychological Evaluation of Environmental Noise in Field Using the Method of Continuous Judgment by Category

Tohru KATO, Jiro KAKU*, Sonoko KUWANO**
and Seiichiro NAMBA***

1. Introduction

One of the aims of noise research is to predict the annoyance of sound environment that consists of sounds from various sources. Many social surveys have been conducted in order to find the relation between physical indices of noise and the psychological responses. Social surveys have a merit that the responses in daily life can be obtained. But in many cases correlation between physical indices of noise and the psychological responses is not so high. This may be due to the fact that various physical, physiological and psychological factors are involved in the evaluation of annoyance. Besides, the structure of noise situation in daily life is much more complicated than that in laboratory condition (e. g. Berglund, 1991).

On the other hand, high correlation can be found between physical indices of noise and the psychological responses in laboratory conditions where physical properties of sounds can be precisely controlled. It is possible to find the physical index which shows good correlation with psychological responses in laboratory experiments. However, the situation in laboratory is very simple and different from in daily life situations. The findings in laboratory experiments cannot always be applied to daily life situations directly.

New approach has been developed called "simulated environment experiment" in order to obtain the responses to noise with high validity and reliability in laboratory situations. A typical furnished living room was constructed in the laboratory. The loudspeakers behind walls and/or ceiling can reproduce sounds with high fidelity. Subjects can

* Kobayashi Institute of Physics.
** Faculty of Human Science, Osaka University.
*** Takarazuka University of Art and Design.

feel at home in this room. Izumi (1986) examined the validity of these methods and reported that good agreement was found among the results of 3 laboratories. However, it cannot be avoided that sounds used in the experiments in simulated living rooms are edited artificially and simplified compared with real life situations. Borsky (1977) stated that there were distinct limits to reproduce real noise situations in the laboratory even with this method.

The other method that may bridge the gap between laboratory and real noise environment is to take subjects in the real noise environment and require them to judge the annoyance in that environment. One example of this approach is the experiment conducted by Robinson et al. (1963). They asked the subjects to judge the noise of aircraft flying overhead at the Farnborough Air Show (1961). The main reason for doing this experiment in field seems to get many samples of aircraft noise easily. Mulligan, et al. (1987) also made subjects evaluate the loudness in field. Their main purpose was to assess the effects of visibility of vegetation on loudness judgment and the stimulus was pure tone which was presented to subjects with loudspeakers.

Noteworthy investigations were conducted by Furihata & Yanagisawa (1988, 1989). They performed noise evaluation experiment in field to make an evaluation scale with high reliability and validity. Subjects were asked to evaluate the real noises around their dwelling places. The noises to be evaluated were assigned by the experimenter, and evaluated with the terms which were used to express the impressions of noises in everyday life. A psychological scale was constructed from these data. Their investigations using noise evaluation in field suggest the possibility to link physical indices and psychological evaluation more tightly than conventional social survey.

The stimulus of noise evaluation in field is the real environmental noise, and this is the most distinctive feature of this method. But the psychological structure of judgment in this method may be different from that of everyday life. The annoyance judgment to noise in everyday life is done under the situation that some behavior is disturbed by noise and the noise is not the target to listen to. It is very difficult to reproduce this psychological structure in experimental situation. Moreover, if the target sounds to be judged are different among subjects, the relation between stimulus and response would become ambiguous.

The final goal of our research is to predict the annoyance of environmental noise, but it would be advisable to start with less complicated situation. Many pschoacoustical factors such as sharpness, roughness, fluctuation strength etc are proposed that participate in a determination of annoyance. But loudness is the most important one among them. Khan et al. (1997) reported the multivariate analysis with the annoyance of heavy-duty diesel engine noise. In their results, loudness explained the most variance. Therefore, in this research, loudness judgment is selected instead of annoyance judgment. Loudness is one of the fundamental attributes of hearing. Loudness judgment of noise does not coincide with annoyance judgment in everyday life, but loudness is one of the main factors of annoyance. Loudness judgment is a perceptual judgment essentially, so the relation with stimulus is expected to become simpler than in the case of annoyance. Therefore, in the first place, the research will be performed in order to make clear the mechanism which determines the overall loudness of noises from mixed sound sources. Secondly, the relation between annoyance and loudness judgments will be investigated.

From this standpoint, the investigations by Hellbrück (1996) and Hellbrück & Zeitler (1996) in which the loudness of level fluctuating noises was measured in real environment, must be quoted as a very important precedent. They situated subjects in the field site between road and railway tracks, and requested them to evaluate the loudness of noises every 15 sec. A flush light was presented every 15 sec, and at that time subjects were asked to judge the loudness of sounds during the preceding 15 sec. The loudness of noises was judged using category subdivision scaling (CS scaling). Their result shows good correspondence between the loudness judgments of every observation interval (15 sec) and LAeq values measured with same interval. It is noteworthy not only that real environmental noises were used as stimuli in this investigation, but also that subjects judged loudness continuously.

Namba & Kuwano (e. g. Namba & Kuwano, 1980 ; Kuwano & Namba, 1985) have developed "the method of continuous judgment by category" in order to examine the instantaneous judgments of time-varying sounds continuously. When subjects are asked to judge the loudness of noise presented for long period, they will probably continue to judge the loudness at every moment on their subjective time axis. In other words, subjects make their judgment on the perceptual basis in this situation, and the good correspondence between LAeq value and loudness is usually found (Namba & Kuwano, 1980 ; Kuwano & Namba, 1985). At the same time, it would be assumed that the loudness of every moment remains in a memory during a limited time. It is also assumed that the overall loudness judgment for a certain period after the long exposure of sounds is based on the loudness memorized at every moment. Many problems remain unsolved about the judgment based on memories of perceived magnitude. The long term evaluation of noise in everyday life is considered to be based on such memories. It is very important to investigate the mechanism of the relation between perception and memory of sound.

In this investigation the experiment was conducted in field using real environmental noises in order to examine the relation between the continuously judged loudness of noise at every moment and the overall loudness judgment based on memory. The evaluation of noise in field was adopted intending to establish an evaluation method of environmental noise.

In this experiment, the method of continuous judgment by category developed by Namba & Kuwano (Namba & Kuwano, 1980 ; Kuwano & Namba, 1985) was adopted for continuous judgment. It is natural to judge the sounds continuously along the temporal stream. If sounds are split into small portions, they become unnatural and the consistency as a stream may be destroyed. For example Hellbrück (1996) reported that in their experiment the loudness was judged every 15 sec and the position of a high level peak of a train passing noise in 15 sec observation interval affected the relation between sound level and loudness evaluation. Since various sounds from relatively stable sound to impulsive one are included in real environmental noises, continuous judgment is desirable. Using the continuous judgment by category, it is able to record the category selected by subject with short sampling time, e. g. 0.1 sec. The temporal process of loudness impression is recorded accurately.

2. Experiment

2－1　Method

A response key box with 7 buttons was prepared for every subject. Each button was assigned to the categories from " 1 : very small" to " 7 : very loud". Subjects were required to judge the loudness of sounds in the surroundings continuously using the method of continuous judgment by category. Prior to the judgments, subjects were instructed that judgments had to be done instantaneously and press a button corresponding to their judgments. When a subject pressed a button, a red lamp was turned on. This lamp meant that the impression of the sound remained the same. When their impression of loudness changed, they were required to press an appropriate key. Subjects were also told that every sound in surroundings had to be involved in their judgments. The responses were recorded by a data recorder (SONY PC 208 A) in DC voltage corresponding to each category. The environmental noises during the experiment in every measure-

Table 1 Experiment sites

Site	Sound Source
① Obana, Kawanishi city	trains, road traffics
② Obana, Kawanishi city	trains, road traffics
③ Bank of Ina river	trains, road traffics, airplanes
④ Hattori, Toyonaka city	trains, road traffics, airplanes
⑤ Hattori, Toyonaka city	trains, road traffics, airplanes, high-way
⑥ Hattori, Toyonaka city	trains, road traffics, airplanes
⑦ Osaka University, Toyonaka	no prominent sound sources
⑧ Hotarugaike, Toyonaka city	trains, road traffics, airplanes, monorails
⑨ Honmachi, Koganei city	trains, road traffics
⑩ Kamimizuhonmachi, Kodaira city	trains, road traffics
⑪ Sakaemachi, Fucyuu city	trains, road traffics

ment site were also recorded by sound level meter (RION NL-05) and the same data recorder. After the instantaneous judgments about 20 min, subjects were required to judge the loudness of main sound sources (train, airplane, road traffic) and the overall loudness during the experiment using the same category.

Experiment sites : Table 1 shows eleven experiment sites and main sound sources in each site.

These experiments were conducted in four occasions. The dates were for the first experiment (①②③) : 1996. 10, the second (④⑤⑥) : 1997. 3, the third (⑦⑧) : 1997. 7, and the fourth (⑨⑩⑪) : 1997. 6.

Subjects : Six subjects with normal hearing participated in each experiment. In the first, the second and the fourth experiments, subjects were different from each other, but in the third experiment, every subject had experienced once in the first or the second experiment.

2-2 Results

2-2-1 The continuous judgment of loudness

LAeq, 0.1 sec were calculated from recorded sounds of each experiment site. The duration of 0.1 sec was selected because this value is nearly the time constant of "fast"-setting of sound level meter, and correspond to the upper limit of perceptual time window (Teranishi, 1984). Subject's categorical responses recorded continuously as DC voltage were sampled every 0.1 sec and converted into the original categorical values. This category scale is an ordinal scale, but apparent linear relationship was reported between this scale and the interval scale derived from original ordinal scale by the law of categorical judgment in the former study (Namba & Kuwano, 1998), so in this study the analyses described

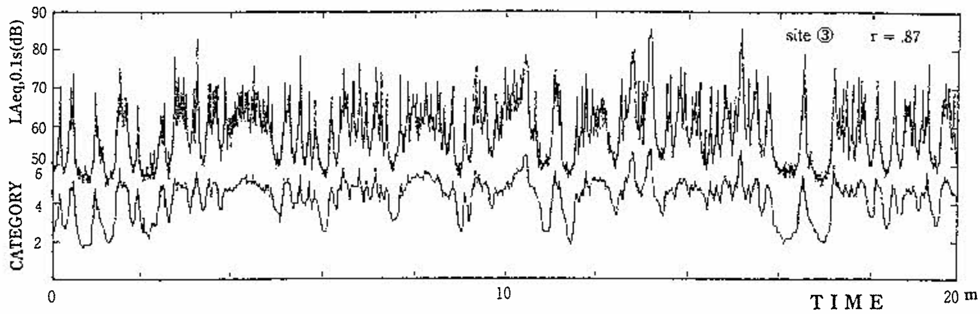

Fig. 1　An example of the time patterns of LAeq, 0.1 sec and continuous response by category (Experiment site ③)

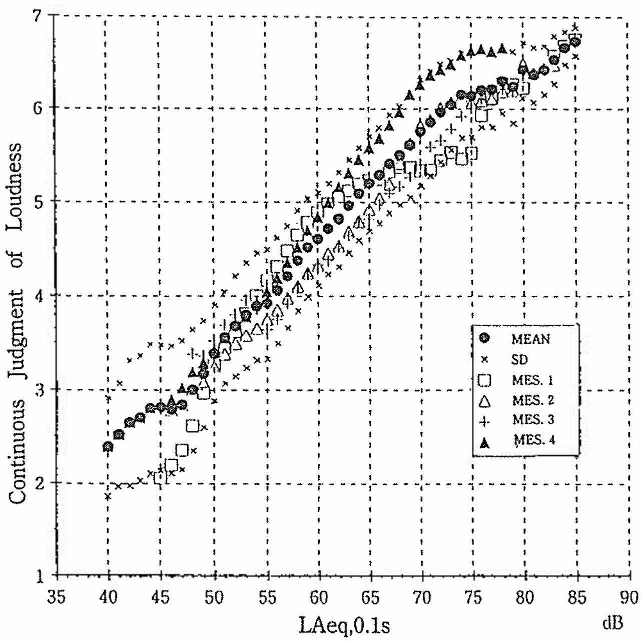

Fig. 2　Relation between continuous loudness judgment and LAeq

below were done using original categorical values as interval scale. Subject's responses were delayed owing to response time. So the responses of each subject were sifted on the time axis until the correlation coefficient between LAeq, 0.1 sec and the response reached the maximum value. After this correction, mean response values of category of all subjects were calculated and the relationships between LAeq and mean categorical response were investigated. An example of the results from experimental site ③ is shown in Fig.1. It is apparent that the time patterns of LAeq, 0.1 sec and categorical response are very similar.

In Fig. 2, the mean category values and standard deviations calculated for all subjects are plotted to every 1 dB of LAeq values. The results are also shown for each of the four measurements separately in Fig. 2. In the latter cases, the points that involve less than 10 data were omitted from this figure. Though the results of the fourth measurement show an apparent tendency that the averaged judgments become larger than the others at high LAeq values, the correlation coefficient between the mean category values for all 11 sites and LAeq, 0.1 sec is very high (0.99). This linear relationship suggests that the instantaneous judgment of loudness is primarily determined by the sound level.

2－2－2 Continuous judgment of loudness for main sound source

In order to obtain the sound levels for each of the three main sound sources (train, airplane, road traffic), the parts where a certain sound source was dominantly identified were extracted over the total interval by monitoring the recorded noises. The sound levels for the main sound sources were calculated from these data, and the relations between these sound levels and the continuous judgments of loudness were examined. In some sites, some main sources were not involved at all or masked entirely by other sources. So the number of sites used for analyses were ten for train, six for airplane and ten for road traffic.

Fig. 3 shows the relations between LAeq and the mean of continuous judgment for each of the three sound sources. The correlation coefficients are very high, but there are some differences between sites. The differences about one category are observed around 70 dB of road traffic noise. These variations may be due to the difference between subject groups or the differences in other physical properties between noises.

The results obtained at sites ④, ⑤, ⑥ were judged by the same subjects, and contained the three main sound sources. So, the results of the three sound sources are compared in these sites. Fig. 4 shows the results. All the relations between LAeq and continuous judgment of loudness with the main sound sources seem approximately linear, and the correlation coefficients are higher than 0.9. These results suggest that the continuous judgment of loudness is not affected by difference of sound sources, but judged as a perceptual judgment of instantaneous sound level.

2－2－3 The relations between loudness judged in three different ways.

The overall loudness judgments of each of the main sound sources and overall loudness of all the 20 min noises were required to subjects after their continuous judgments

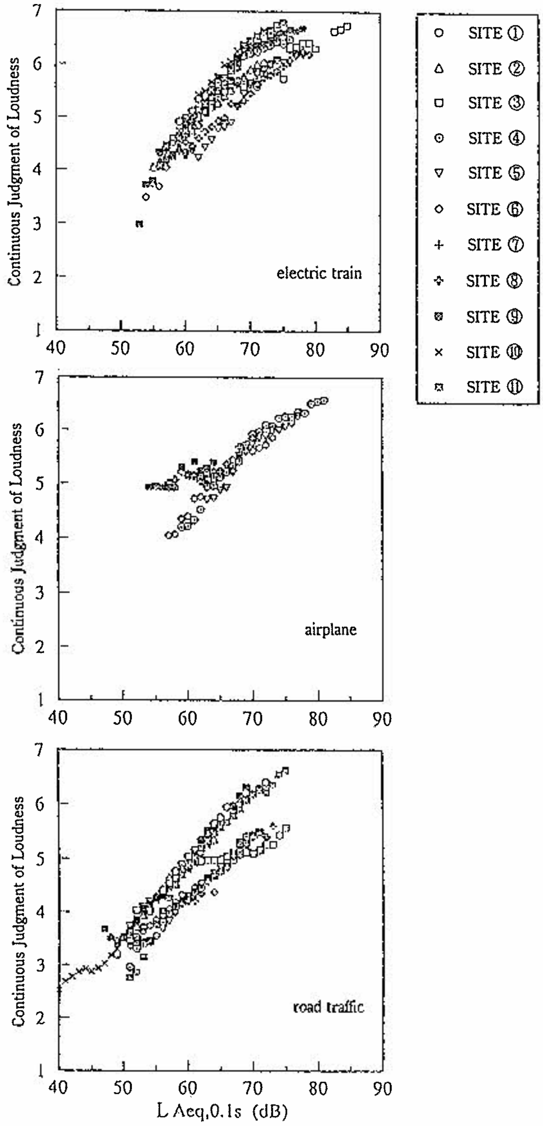

Fig. 3　Relation between continuous loudness judgment and LAeq for every sound source

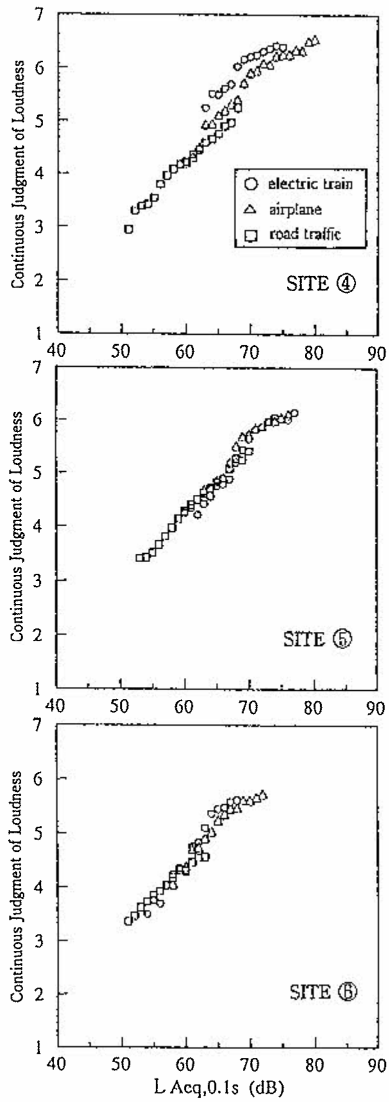

Fig. 4　Relation between continuous loudness judgment and LAeq with three main sound sources (site ④⑤⑥)

in this experiment. This procedure was adopted to make subjects evaluate the complex noise on the basis of perceptual judgment of loudness. In other words, the context of judgment is that the perceptual judgments of loudness are stored in memory in the process of continuous judgments, and the loudness of overall noise or each main sound source is judged by some psychological integration on the basis of such auditory memories. This is the basic assumption on which the results are investigated.

Table 2 shows the means of overall loudness, of continuous judgments and of each main sound source. Table 3 shows the correlation coefficients between these means. The means of continuous judgment were calculated by dividing the summation of continuous judgments sampled every 0.1 sec at one site by the observation interval. This mean of continuous judgments indicates the mean category value judged continuously at one site.

The mean of continuous judgments of loudness highly correlates with the overall loudness. In the context of this experiment, overall loudness is regarded as integrated mainly from the memories of instantaneous loudness. When the overall loudness and loudness of the main sound sources are compared in Table 2, the overall loudness is smaller than the largest value of judgment of individual sound sources of the same site. With the exception of airplane, which was not audible in some sites, the train noise is judged louder than road traffic noise in 8 of 11 sites, but the loudness of road traffic noise

Table 2 Means of loudness judged in three different ways

site	overall judgment	mean of cont. judg.	road traffic	train	airplane
①	5.0	4.6	5.7	5.5	—
②	4.4	4.2	5.3	5.7	—
③	4.6	4.3	5.2	6.5	5.3
④	5.0	4.4	4.7	5.8	6.2
⑤	5.2	4.5	5.2	6.0	6.0
⑥	3.8	3.9	4.0	5.2	5.3
⑦	4.0	3.9	4.2	3.3	5.3
⑧	5.3	4.1	5.0	6.2	5.7
⑨	5.3	4.3	4.7	6.3	3.3
⑩	4.3	3.7	4.7	5.7	2.5
⑪	6.0	4.9	6.2	5.7	2.3

Table 3 Correlation coefficients between judged loudness and LAeq

		mean cont. loudness	judged loudness of each sound source			LAeq of each sound source		
			road traffic	train	airplane	road traffic	train	airplane
overall loudness		n= 11 .812**	n= 11 .745**	n= 11 .521	n= 9 − .270	n= 10 .435	n= 10 .309	n= 6 − .316
mean cont. loudness			n= 11 .821**	n= 11 .347	n= 9 − .094	n= 10 .797**	n= 10 .117	n= 6 .154
LAeq of each sound source	road traffic		n= 10 .689*					
	train			n= 10 .872**				
	airplane				n= 6 .883*			

* p< .05 ** p< .01

shows higher correlation with overall loudness than that of train noise. It is suggested that the overall loudness is not determined by the loudest source, but by some weighted average of each sound source during the observation. It could be assumed that the road traffic noise which appeared continuously and relatively long in many environments played more significant role than the sound sources whose sound level was high, but which occurred intermittently as trains.

2－2－4　The relation between overall loudness judgment and sound level

Fig. 5 shows the relationship between the LAeq, 20 min of every site as global physical index of noise and the averaged overall loudness judged after the continuous judgment. A weak correlation can be seen between them. The correlation coefficient is only 0.48. The data of sites ③, ⑥, and ⑪ deviate largely from the regression line. In the measurement at site ⑥, an ambulance passed by during the experiment, and its siren increased the sound level in that site. In spite of the instruction that every sound audible in the observation interval is to be judged, subjects may have ignored this siren in the loudness judgment. Because the occurrence of this siren may be regarded by subjects as an accidental event, and as an exception. It is possible that if the contribution of the siren was eliminated in the calculating of LAeq of the site ⑥, the correlation coefficient becomes 0.62. Moreover, the correlation coefficient showed a little improvement, 0.71, when it was recalculated by eliminating the data of the fourth measurement where subjects showed a tendency of overestimation of continuous judgment than the others.

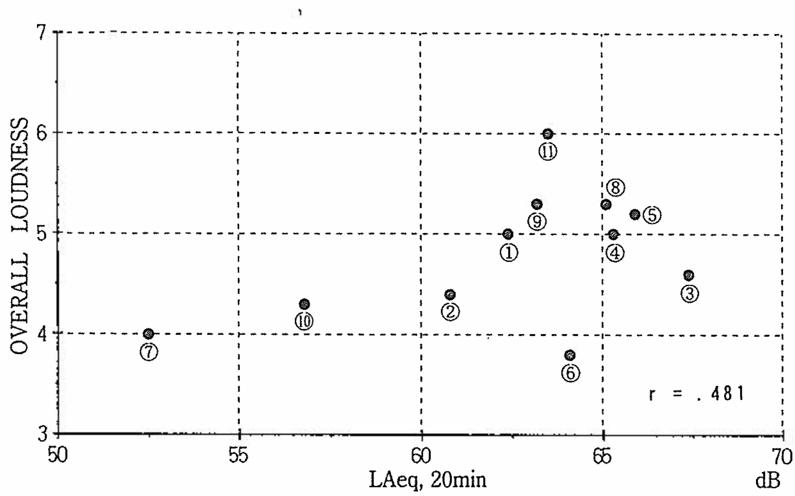

Fig. 5　Relation between LAeq and overall loudness

Two reasons may be considered why good correspondence was not found between the overall loudness judgment and the overall sound level. First, the sound such as a train, whose sound level is relatively high but intermittent, increases the LAeq value. But the relation between the overall loudness and that of each sound source suggests that such sound seems not to contribute to the overall loudness so much.

Second, the effect of background noise is also considerable. In the majority of measurement sites, the road traffic noise occupied the greater part of the observation period than other noises. In many sites, overall loudness was smaller than the loudness of road traffic of the same site (Table 2). Therefore, the effect of the time interval in which none of the sound sources were audible must be considered. For this purpose, the distribution of LAeq, 0.1 sec was investigated for each measurement site (Fig. 6). The values of overall loudness for site ③ and ⑥ are smaller than that predicted from the regression line, and this may be due to the distributions of LAeq, 0.1 sec, which show that the sound level under 50 dB occupies fairly large parts. The same explanation can be applied to the difference in overall loudness between the sites ⑨ and ⑪. The LAeq, 20 min values of site ⑨ and ⑪ are similar, and the same subjects judged the overall loudness. But the large portion of the sound level distribution of site ⑨ is under 50 dB, and the loudness of site ⑨ is judged smaller than that of site ⑪. The correlation coefficient between the overall loudness and lower terminal value of 90% range (L_{95}) is

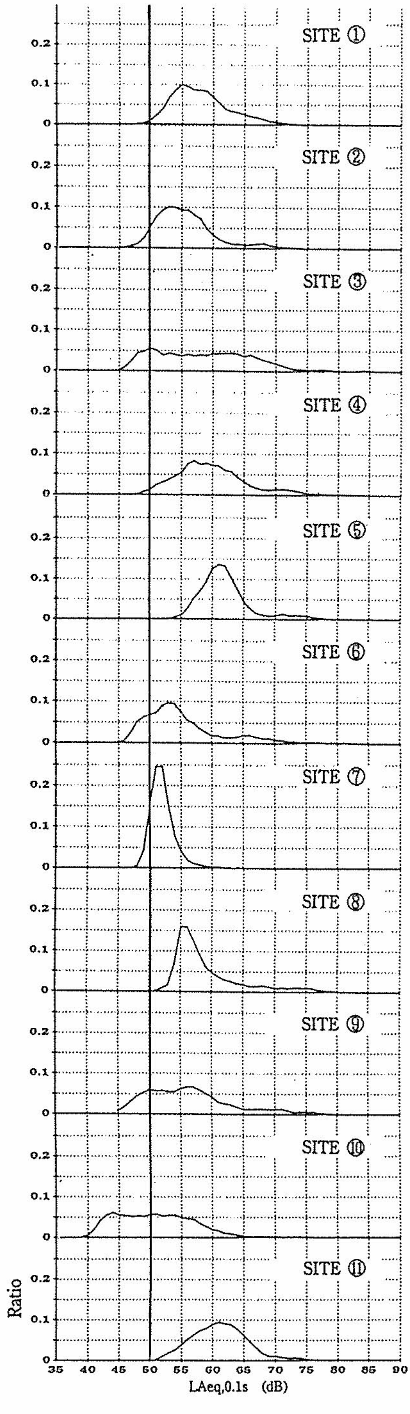

Fig. 6 Distribution of sound level

0.61, which suggests the effect of background sound level.

3. Discussion

Though the numbers of sites and subjects were not sufficient in this investigation, some important suggestions about the evaluation of environmental noise could be obtained by the field experiment using continuous judgment.

The instantaneous loudness of environmental noise showed high correlation with LAeq, 0.1 sec, and this relation is not affected with the difference of sound sources as far as they are judged in the same observation interval. Using the method of continuous judgment by category, it is possible to obtain instantaneous loudness judgment correlating with the sound level about the environmental noise where sounds from many sources occur simultaneously.

The overall loudness judgment through observation interval highly correlates with averaged instantaneous judgment of loudness, which suggests that overall judgment is based on the instantaneous judgment. There was a tendency that overall loudness is judged larger than averaged instantaneous loudness. This is also found in laboratory experiment using continuous judgment (Namba & Kuwano, 1980; Kuwano & Namba, 1985). Therefore, this trend is not peculiar in judgment of environmental noise. It must be investigated as a problem of mechanism that synthesizes every partial impression into a whole.

Using the method of continuous judgment by category, it is possible to obtain the loudness of complex noise about 20 min. as a judgment on the basis of perception. The average of instantaneous loudness judgment over whole interval also correlates with overall loudness judgment. This average has strong perceptual character. To elucidate complex stimulus factors, it must be useful to simplify the psychological judgment for complex noise in this method.

The number of sites in this experiment is small, but it is able to examine possible candidates of variables that can be used for estimating the loudness of environmental noise, from the correlation coefficients shown in Table 3. The coefficients between the loudness of each sound source and their LAeq show high values (.689, .872, .883). But the correlation coefficients between the overall loudness and the LAeq of each main sound source are not high (.435, .309, − .316). The loudness of road traffic correlates most highly to the overall loudness among the loudness of the three main sound sources

(.745). These results suggest that the loudness of road traffic noise plays a very important role in the overall loudness.

On the other hand, the overall loudness correlates highly to the average of continuous judgment over whole interval (.812), and the latter correlates to the loudness of road traffic and its LAeq (.821, .797). The road traffic noise occupied majority of these observation intervals. So this suggests that the averaged value of category which was memorized during the continuous judgment determines the overall loudness. In this study, road traffic noise may play the main role in evaluation of environmental noise.

Many models predicting annoyance of complex noise have been proposed (e.g. Taylor, 1982; Berglund & Nilsson, 1997). Taylor (1982) and Izumi (1989) also indicated the significance of road traffic noise in such model. The sustained noise such as road traffic and the intermittent noise such as train must play different role in determining annoyance or loudness of environmental noise.

In some sites where the correspondence of LAeq, 20 min and overall loudness is not so good, the distribution of LAeq, 0.1 sec shows a tendency deviating to lower levels. The correlation coefficients suggest that L_{95} relate to overall loudness in the same degree as LAeq, 20 min. The interval in which no sound from main source are audible and background sound level is relatively low may also influence the judgment of overall loudness. But it is not clear whether such effect will be generally found in other conditions. Further investigation will be needed.

In this investigation, loudness judgment is adopted to simplify the experimental condition. What is demanded finally is the prediction of annoyance. Annoyance judgment is regarded as an emotional judgment while loudness judgment is perceptual. It is probable that the temporal character of noise described above affects differently in these two attributes. The property of annoyance judgment must be investigated in connection with these stimulus conditions.

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