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Development of an Experimental Noise Annoyance Meter

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Summary
The application of exposure effect relationships to transform a SLM to a noise annoyance meter is described. An annoyance scale using the most frequently used category descriptors related to noise for community noise assessment in Japan was developed. These descriptors were elicited from a listening experiment where the subjects listened to various kinds of noise sources for five minutes in or near their houses in and around Nagano city. As the equivalent continuous A-weighted sound pressure level ($L_{\mathrm{Aeq,(5min)}}$ [dB]) was measured for each of the sounds, it became possible to link the noise level to the annoyance descriptor. Thereby an experimental noise annoyance meter which can evaluate psychological effects on humans at the same time as $L_{\mathrm{Aeq,(5min)}}$ was developed. After having constructed the annoyance meter, it was validated using a separate sample of residents from other typical cities in Japan. They were presented to similar noise stimuli and both the measured noise levels and associated annoyance descriptors associated with the sounds. Through this process, the annoyance meter was shown to have face validity. It is therefore proposed that the noise annoyance meter could be applied for combined noise exposure and noise impact rating in Japan.

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1. Introduction

In this paper, an experimental noise annoyance meter which can evaluate psychological effects on humans at the same time as $L_{\mathrm{Aeq,(5min)}}$ is proposed. The noise annoyance meter is designed for a practical instrument for residents exposed to noise to help them understand what a physical equivalent noise level given as dB values “means” with respect to annoyance.

The noise limits and environmental guidelines specify physical energy equivalent sound pressure levels: the average energy equivalent level of the A-weighted sound over a period T ($L_{\mathrm{Aeq,T}}$ [dB]), the noise exposure metrics day–night level (DNL) and day-evening-night level (DENL). Currently sound measurement is usually done using sound pressure level meters. Miedema and Vos [1] presented synthesis curves for the relationship between DNL and percentage highly annoyed for three transportation noise sources. They were derived from 45 surveys with a total of 58,065 respondents. A difference between sources was found for aircraft, road traffic, and railway noise. The recommended limit values (WHO guidelines for community noise) typically correspond to a noise level at which about 10–15 per cent (those most sensitive to noise) state that they are seriously annoyed by the noise. What do the recommended limit values mean? The limit values provide the basis for the authorities’ assessment of noise pollution. The limit values are only a guide and can be relaxed or tightened in specific cases if there are special circumstances to justify this.

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Generally speaking, the concepts of noise levels are only understood by key people such as noise control officers, acoustical consultants and regulatory officers. However, in order to judge “acceptable” noise levels, anyone interested in housing (residents, buyers, builders and researchers) will need to understand the significance of such noise levels to make housing more comfortable and individually suitable.

Therefore, planning and implementing an effective noise evaluation requires the following:

(a) Development of an annoyance scale with the aid of words to represent the degree of psychological effects caused by various kinds of noise sources evaluated by residents in and around an objective city.
(b) Establishing the relationship between the average degree of annoyance reported as a function of the measured noise level ($L_{\mathrm{Aeq,(5min)}}$) by analyzing data from a socio-acoustic survey in a Japanese city.

(c) Validating the results by investigating whether residents in other typical Japanese cities can understand the noise rating scale or not. To aid in the evaluation of typical noises, a noise annoyance meter was constructed. The noise annoyance meter is basically a sound level meter where $L_{\mathrm{Aeq,(5min)}}$-values are converted to the degree of annoyance on a seven point scale.

Sounds can be assessed subjectively along different perceptual dimensions. Of particular interest with respect to annoyance and also sound quality are the psycho-acoustic categories of loudness, sharpness, pitch strength, fluctuation strength, and roughness [2]. However, we cannot decide the permissible level of noise from these types of studies [3].

Perceived sounds are often associated with a psychological reaction. The words representing such reactions can vary with regional and other factors. Rating scales are used quite frequently in survey research and there are many different kinds of rating scales. In the past 30 years a variety of concepts of noise and measures has been introduced in the noise field. Psychological scales such as "loudness", "perceived loudness", "noisiness", "psychoacoustic annoyance", "annoyance", "dissatisfaction with noise", "interference with daily activities", "attitudes toward the noise producer", "anxiety", "concern", and "perceived affectedness" have been employed by many authors [4, 5, 6, 7, 8]. In many papers published to date, however, the methods of selecting rating words have not been examined. N. Levine did not involve any use of rating scales to assess "subjective response to noise levels" [9]. In the Community Response to Noise Team (Team 6) of the International Commission on the Biological Effects of Noise (ICBEN) [10], subjects indicated the intensity associated with each word (a pool of 21 modifiers of annoyance) by placing the word on its own 10 cm line that extended from "No/lowest degree of annoyance" to "Highest degree of annoyance" [11].

2. Methodology for selecting annoyance category descriptors

"What sorts of verbal categories are used in and around Nagano city in Japan to represent the degree of psychological effects caused by $L_{\mathrm{Aeq,(5min)}}$ [dB], which is measured while the subjects listened to various kinds of noise sources for five minutes in or near their houses?" This is the question that we set about answering. The most frequently used category descriptors related to noise in everyday life are effective and useful, because an easy to understand psychological scale can be provided for people of all ages. The procedure to collect the noise annoyance data used the following four tasks to evaluate various kinds of noise sources [12, 13]:

Task 1: We selected residents living in an area with a special noise source.

Task 2: Each subject listened to the noise for five minutes in or near one's house, and we measured the noise at the same place for the same time.

Table I. Noise sources chosen and the number of subjects *N* for on-the-spot investigations in and around Nagano city [12, 13].

Noise sources	*N*
Road traffic noise sources	
Noise from various kinds of vehicles. In the mornings (6 a.m.–8 a.m.) and evenings (6 p.m.–10 p.m.), the mean traffic volume was 1580 vehicles/h with 6.2% heavy vehicles, during the day (8 a.m.–6 p.m.), 1350 vehicles/h with 10.5% heavy vehicles, and at night (10 p.m.–6 a.m.), 850 vehicles/h with 7.4% heavy vehicles.	384
Steady noise sources	
Ventilating fans for airconditioning use	5
Air compressors and ventilators	21
Power-driven motors	6
Crushers and rubbing crushers of quarries for concrete use	8
Circular saw machines and planers for sawmill use	6
Train noise sources	
Three kinds of trains; limited express trains, local trains, and freight trains	100
Intermittent noise sources	
Ironworks (hammering of metal, welding burners, cranes, grinders, sheet metal works, scrap iron dismantling and collecting machines)	15
Press machine shops (various kinds of press machines)	5
Buildings under construction (hammering of metal, rivet guns, impact wrenches and concrete breakers)	12
Road repairing (rock drills)	10
Total	572

Task 3: Immediately after listening, we asked, "Please write freely your subjective impression of the degree of the psychological effects you felt due to the noise you listened to for the past five minutes."

Task 4: To collect various kinds of verbal categories, the subjects listened to the noise (the total listening time was fifteen minutes) in (windows opened and closed) and near (outdoors) their houses.

The words used as descriptors in a rating scale require some thought. Researchers who are interested in creating interval scales (scales in which the respondents perceived equal-sized gradations between the points on the scale) must be careful to choose category descriptors that are truly equal-interval. This is necessary if researchers wish to compute means and use parametric statistics. If the most frequently used adverbs representing degrees of the noise rating words have psychologically equal-appearing intervals, it can be said that the annoyance scale is more effective than the conventional forced-choice rating scales. A weakness with the methodology employed by the ICBEN team [10] is the implicit assumption that it is possible to place annoyance categories on a 0–100 annoyance scale irrespective of the sound stimulus. An alternative is to em-

Table II. Frequency of use and (percentage) of rating words ("…") used by residents in Nagano City for representing psychological effects caused by each kind of noise source.

	Road traffic noise sources		Steady noise sources		Train noise sources		Intermittent noise sources	
"Urusai"	355	(73.2)	30	(63.8)	30	(52.6)	20	(66.7)
"Kininaru"	73	(15.0)	8	(17.0)	11	(19.3)	3	(10.0)
Others	57	(11.8)	9	(19.2)	16	(28.1)	7	(23.3)
Total	485	(100.0)	47	(100.0)	57	(100.0)	30	(100.0)
"Kininaranai"	73	(40.1)	19	(38.0)	17	(27.4)	9	(32.1)
"Kuninaranai"	20	(11.0)	14	(28.0)	13	(21.0)	8	(25.0)
Others	89	(48.9)	17	(34.0)	32	(51.6)	11	(42.9)
Total	182	(100.0)	50	(100.0)	62	(100.0)	28	(100.0)

ploy a sound stimulus to elicit verbal descriptors, and afterwards select the descriptors that divide the annoyance scale evenly. Therefore, we discuss how an annoyance scale where respondents perceive truly equal-sized gradations between the points on a physical scale ($L_{\text{Aeq,T}}$ [dB]) can be constructed.

3. Development of a 7-point annoyance scale

As a first step, words expressing the degree of annoyance due to various noise stimuli characterized by the $L_{\text{Aeq,(5min)}}$ were collected. Internationally a five point annoyance scale has been recommended for eliciting annoyance responses. However, to obtain the necessary verbal resolution for a noise annoyance meter, a 7-point scale was deemed necessary.

3.1. Samples

Three studies in and around Nagano city in 1982/1983 [12], 1987 [13] and 1994 [14] were used to develop a 7-point annoyance scale.

Table I shows the noise sources we chose and the number of subjects for on-the-spot investigations in and around Nagano city [12, 13, 14]. We see that the major sources of noise in and around Nagano city are road traffic, trains, industrial machinery and buildings under construction.

3.2. Procedures for on-the-spot investigations

We selected residents living in an area with a special noise source. To exclude subjective variables from field conditions as much as possible, $L_{\text{Aeq,(5min)}}$ (RION NL-11) was measured while the subjects listened to various kinds of noise sources for five minutes in or near their houses. Immediately after listening, we asked, "Please write freely your subjective impression of the degree of the psychological effects you felt due to the noise you listened to for the past five minutes." To collect various kinds of verbal categories, the subjects listened to the noise (the total listening time was fifteen minutes) in (windows opened and closed) and near (outdoors) their houses.

Table III. Frequency of verbal categories representing the degrees of "Urusai" (a) and "Kininaranai" (b) for R: Road traffic noise sources, S: Steady noise sources, T: Train noise sources, I: Intermittent noise sources.

(a)	R	S	T	I	Total	(%)
"Hizyni Urusai"	23	0	2	2	27	6.2
"Sugôku Urusai"	5	2	1	0	8	1.8
Others	31	1	3	1	36	8.3
"Kanari Urusai"	54	3	5	2	64	14.7
"Sôtôni Urusai"	9	2	0	0	11	2.5
Others	8	1	1	2	12	2.8
"Urusai"	168	16	14	11	209	48.0
"Sukoshi Urusai"	28	5	3	2	38	8.7
"Tashô Urusai"	5	0	1	0	6	1.4
Others	24	0	0	0	24	5.5
Total	355	30	30	20	435	100.0
(b)	**R**	**S**	**T**	**I**	**Total**	**(%)**
"Amari Kininaranai"	10	7	5	5	27	22.9
"Sonnani Kininaranai"	6	3	3	1	13	11.0
Others	8	0	0	1	9	7.6
"Kininaranai"	35	4	4	2	45	38.1
"Mattaku Kininaranai"	11	3	3	0	17	14.4
"Hotondo Kininaranai"	2	2	2	0	6	5.1
Others	1	0	0	0	1	0.8
Total	73	19	17	9	118	100.0

3.3. Analyses

Table II presents the percentage of 941 rating words used by 572 residents in Nagano city for representing psychological effects caused by each noise source in daily life. From this table, it can be found that:

(a) In the case of noise annoyance, the most frequently used noise rating words was "Urusai", which was used by 73.2% of residents to describe road traffic noise sources, 63.8% to describe steady noise sources, 52.6% to describe train noise sources, 66.7% to describe intermittent noise sources.

(b) In the case of no annoyance, the most frequently used noise rating word was "Kininaranai" (road traffic noise sources: 40.1%, steady noise sources: 38.0%, train noise sources: 27.4%, intermittent noise sources: 32.1%).

As can be seen, the response words “Urusai” and “Kininaranai” are common throughout the noise sources in and around Nagano city.

Table III presents the frequency of verbal categories representing the degrees of “Urusai” and “Kininaranai” for each noise source. As can be seen, the verbal categories are clustered into seven levels by the frequency of use. The seven descriptors, therefore, are “Hizyôni Urusai” (6.2%), “Kanari Urusai” (14.7%), “Urusai” (48.0%), “Sukoshi Urusai” (8.7%), “Amari Kininaranai” (22.9%), “Kininaranai” (38.1%), and “Mattaku Kininaranai” (14.4%). We selected the above seven verbal categories.

4. Degrees of annoyance as a function of $L_{\mathrm{Aeq,(5min)}}$

4.1. A two-way contingency table

Since it is argued that a seven-point scale is desirable for showing a systematic relationship between annoyance reaction and $L_{\mathrm{Aeq,(5min)}}$, we can construct a two-way contingency table between $L_{\mathrm{Aeq,(5min)}}$ [dB] and an annoyance scale using seven typical descriptors selected from the most frequently used terms in everyday speech related to various kinds of noise sources in and around Nagano city. The table is necessary to verify whether the division between the 7-level annoyance scale and $L_{\mathrm{Aeq,(5min)}}$ is an optimal contingency table. The discrepancy of a model fitted to a set of observed data by the maximum likelihood method is evaluated by the statistic AIC defined by the following [15]:

$$AIC = (-2)\ln\big(\text{maximized likelihood}\big) + 2k, \quad (1)$$

where ln denotes the natural logarithm and k is the number of parameters within the model which are adjusted to attain the maximum likelihood.

Therefore, the AIC was calculated based on equation (1) and the data from Table IV (all the data [12, 13, 14]) as:

$$\begin{aligned} AIC &= (-2)\sum_{i=1}^{7}\sum_{j=1}^{6} n_{ij}\ln\left(\frac{nn_{ij}}{n_{i\bullet}n_{\bullet j}}\right) + 2(7-1)(6-1) \\ &= -1289.29, \end{aligned} \quad (2)$$

where

$$n = \sum_{i}^{7}\sum_{j}^{6} n_{ij} = 1539, \; n_{i\bullet} = \sum_{j}^{6} n_{ij}, \; n_{\bullet j} = \sum_{i}^{7} n_{ij}.$$

We regard the model with the smallest AIC as the best one between the 7-level annoyance scale and $L_{\mathrm{Aeq,(5min)}}$. For example, in the case of $L_{\mathrm{Aeq,(5min)}}$ (79.0–75.0 dB, 75.0–70.0 dB, 70.0–65.0 dB, 65.0–60.0 dB, 60.0–55.0 dB, 55.0–50.0 dB, 50.0–45.0 dB, 45.0–40.0 dB, 40.0–35.0 dB, 35.0–26.9 dB) zoned at the step 5 dB, the AIC value is −1234.63.

4.2. The method of successive categories [16]

The Gaussian or normal distribution is routinely used to model distributions of subjective quantities. The standard deviation of the distribution associated with a given stimulus is called the discriminal dispersion of that stimulus. The discriminal dispersions, as well as the scale values, may be different for different stimuli. We regarded the cumulative proportion as the observed value of the probability and translated from the normal deviate, which is normally distributed with zero mean and unit variance, into a standardized annoyance scale. We can apply almost all the statistical operations to the scale [16].

From the cumulative proportion calculated from Table IV, we calculated an interval scale (the seven typical descriptors selected from the most frequently used terms in everyday speech related noise) on $L_{\mathrm{Aeq,(5min)}}$ [dB].

The step by step procedure for obtaining scale values is:

1. Arrange the raw frequency data shown in Table IV where the rows are the levels of $L_{\mathrm{Aeq,(5min)}}$ and the columns are the verbal categories.
2. Compute relative cumulative frequencies for each row, and record these in a new table. The last column of this new table will consist of 1’s and may be omitted.
3. Treating these values as leftward areas under a Normal (0, 1) curve, go to a table of the normal distribution and find the z_c values defined as follows:

   $$z_c = (y_l - y_u)/(p_u - p_l). \quad (3)$$

   where

   $$y = \frac{1}{\sqrt{2\pi}}\mathrm{e}^{-z^2/2}, \quad p = \int y\,\mathrm{d}z,$$

   y_l is the lower bound of a category interval, y_u is the upper bound of the same category interval, p_l is the leftward area under a Normal (0, 1) curve at the lower bound or less, and p_u is its leftward area at the upper bound or less. Record these in a new table. This is the z_{cij} array for the computations which follow.
4. For each column j in the z_{cij} array, compute the column mean $\sum z_c/n$ on our scale.
5. Compute the intervals from each other column mean of 7-categories on our scale.
6. We set 1.00 as the mean score of the “Mattaku Kininaranai” (Not annoying at all) category. Then the mean score of the “Kininaranai” (Not annoying) category is 2.15. Also, the mean score of the “Amari Kininaranai” (A little annoying) category is 3.12, the score of the “Sukoshi Urusai” (Somewhat annoying) category is 3.96, the score of the “Urusai” (Annoying) category is 5.08, the score of the “Kanari Urusai” (Very annoying) category is 6.07, and the score of the “Hizyôni Urusai” (Extremely annoying) is 7.19.
7. Therefore, using the standardized 7-annoyance scores S_i obtained, compute each mean score

   $$Annoy_j = \sum_{i=1}^{7} n_{ij}S_i/n_{\bullet j}$$

Table IV. A two-way contingency table between an annoyance scale using seven typical terms selected from the most frequently used terms in everyday speech, I: "Mattaku Kininaranai" (Not annoying at all), II: "Kininaranai" (Not annoying), III: "Amari Kininaranai" (A little annoying), IV: "Sukoshi Urusai" (Annoying), V: "Urusai" (Somewhat annoying), VI: "Kanari Urusai" (Very annoying), VII: "Hizyôni Urusai" (Extremely annoying), related to various kinds of noise sources in and around Nagano city and $L_{\mathrm{Aeq,(5min)}}$, 1: 79.0 dB–77.5 dB, 2: 77.5 dB–66.5 dB, 3: 66.5 dB–55.5 dB, 4: 55.5 dB–44.5 dB, 5: 44.5 dB–33.5 dB, 6: 33.5 dB–26.9 dB [12, 13, 14].

	I	II	III	IV	V	VI	VII	Total
1	n_{11} 0	n_{21} 0	n_{31} 0	n_{41} 0	n_{51} 4	n_{61} 11	n_{71} 34	$n_{\cdot 1}$ 49
2	n_{12} 0	n_{22} 0	n_{32} 0	n_{42} 7	n_{52} 81	n_{62} 76	n_{72} 65	$n_{\cdot 2}$ 229
3	n_{13} 0	n_{23} 12	n_{33} 24	n_{43} 102	n_{53} 206	n_{63} 77	n_{73} 28	$n_{\cdot 3}$ 449
4	n_{14} 11	n_{24} 52	n_{34} 127	n_{44} 216	n_{54} 108	n_{64} 24	n_{74} 0	$n_{\cdot 4}$ 538
5	n_{15} 37	n_{25} 86	n_{35} 73	n_{45} 40	n_{55} 4	n_{65} 0	n_{75} 0	$n_{\cdot 5}$ 240
6	n_{16} 13	n_{26} 19	n_{36} 2	n_{46} 0	n_{56} 0	n_{66} 0	n_{76} 0	$n_{\cdot 6}$ 34
Total	$n_{1\cdot}$ 61	$n_{2\cdot}$ 169	$n_{3\cdot}$ 226	$n_{4\cdot}$ 365	$n_{5\cdot}$ 403	$n_{6\cdot}$ 188	$n_{7\cdot}$ 127	n 1539

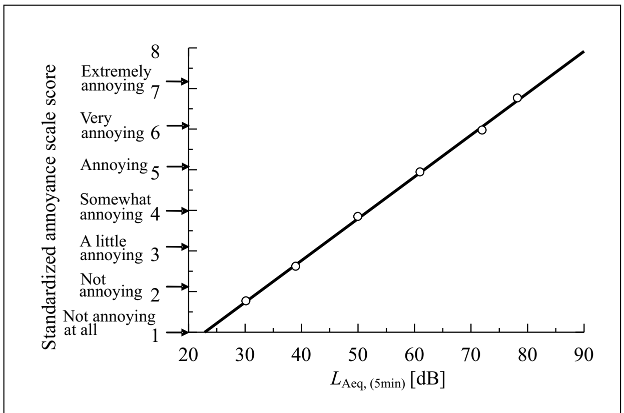

Figure 1. Relationship between our standardized annoyance scale score and $L_{\mathrm{Aeq,(5min)}}$ for various noise sources.

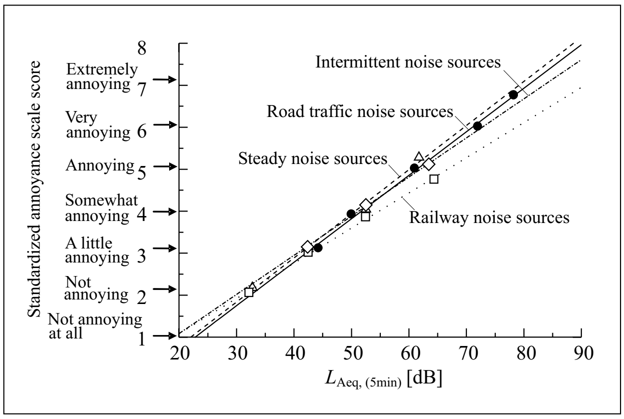

Figure 2. Comparison of regression lines giving the standardized annoyance scale score as a function of $L_{\mathrm{Aeq,(5min)}}$ for road traffic (●), steady (△), railway (□), and intermittent (◇) noise sources.

on the standardized annoyance scale from the Table IV for each column j of mean values $L_{\mathrm{Aeq,(5min)}}$.

8. Use a simple regression analysis to obtain the relationship between annoyance reaction and $L_{\mathrm{Aeq,(5min)}}$.

4.3. Graphical representation

Figure 1 shows the relationship between our standardized annoyance scale score and $L_{\mathrm{Aeq,(5min)}}$. We see that the seven descriptors mark off roughly equal-sized intervals: 7.19, 6.07, 5.08, 3.96, 3.12, 2.15, and 1.0. The relationship between each mean score of the standardized annoyance scale (Annoy = 6.76, 5.97, 4.94, 3.84, 2.62, and 1.77) and each mean value of $L_{\mathrm{Aeq,(5min)}}$ (78.3 dB, 72.0 dB, 61.0 dB, 50.0 dB, 39.0 dB, and 30.2 dB) for the above noise sources is shown in Table IV. The regression line is also shown in Figure 1. The equation of the regression line is:

$$Annoy = 0.103 L_{\mathrm{Aeq,(5min)}} - 1.357. \quad (4)$$

The coefficient of determination is $R^2 = 0.9992$. Therefore, it can be found that "extremely annoying" corresponds to 83.1 dB, "very annoying" to 72.3 dB, "annoying" to 62.6 dB, "somewhat annoying to 51.8 dB, "a little annoying" to 43.6 dB, "not annoying" to 34.2 dB, and "not annoying at all" to 23.1 dB.

Figure 2 shows the comparison of regression lines giving the standardized annoyance scale score as a function of $L_{\mathrm{Aeq,(5min)}}$ for road traffic noise, steady noise (air compressors and ventilators, crushers and rubbing crushers of quarries for concrete use, ventilating fans for air-conditioning use, power-driven motors, circular saw machines and planers for sawmill use), railway noise (limited express trains, local trains, and freight trains), and intermittent noise (ironworks; hammering of metal, welding burners, cranes, grinders, sheet metal works, scrap iron dismantling and collecting machines, buildings under construction; hammering of metal, rivet guns, impact wrenches and concrete breakers, road repairing; rock drills, and press machine shops; various kinds of press machines) sources. The regression lines are also shown in Figure 2. The equations of the regression lines are:

Road traffic:
$$Annoy = 0.104 L_{\mathrm{Aeq,(5min)}} - 1.360 \ (R^2 = 0.9962),$$
Steady:
$$Annoy = 0.105 L_{\mathrm{Aeq,(5min)}} - 1.315 \ (R^2 = 0.9926),$$
Railway:
$$Annoy = 0.084 L_{\mathrm{Aeq,(5min)}} - 0.590 \ (R^2 = 0.9976),$$
Intermittent:
$$Annoy = 0.093 L_{\mathrm{Aeq,(5min)}} - 0.779 \ (R^2 = 0.9992),$$

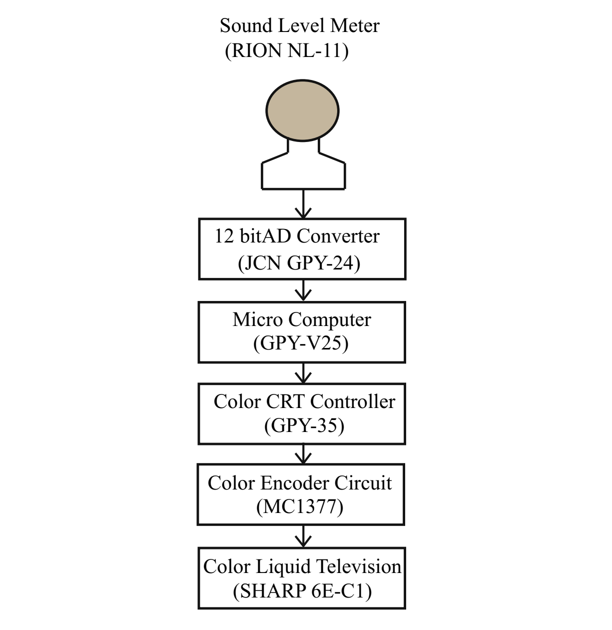

Figure 3. Block diagram of an experimental noise annoyance meter.

We see that the road traffic line in Figure 2 lies a little below the steady line, a little above the intermittent line, and above the railway line. Therefore, it can be found that "annoying" corresponds to 60.9 dB for steady noise, 61.9 dB for road traffic, 63.0 dB for intermittent noise, and 67.5 dB for railway noise sources. The "railway bonus" [17] is thus equal to 5 dB (67.5–61.9).

5. Development of a noise annoyance meter based on these results

5.1. A noise annoyance meter

5.1.1. Composition

An experimental noise annoyance meter with a color LCD can indicate each of the degrees of psychological effects of noise from $L_{\text{Aeq,T}}$ measured through the "annoyance" noise rating scale proposed. This compact noise annoyance meter consists of six main parts as shown in Figure 3. The output of a conventional SLM (RION NL-11) is the voltage of the A-weighted sound pressure level (L_{A} [dB]). This voltage is inputted to an analog to digital converter (JCN GPY-24). The sampling period is 33.3 ms because a graphical representation of L_{A} is continuously visible. The data is transformed into L_{A}, $L_{\text{Aeq,(1sec)}}$, $L_{\text{Aeq,T}}$ and $L_{\text{Aeq,(5min)}}$ with a microcomputer (JCN GPY-V25). In order to represent these physical indices on a color LCD television (TV: SHARP 6E-C3), a color cathode-ray tube controller (JCN GPY-35) is used to obtain an analog RGB signal. The color encoder circuit (MC1377) converts the RGB signal to a video composite signal.

5.1.2. Two-dimensional representation

Accordingly, the TV can display a few physical quantities on the horizontal axis of the color LCD as shown in Figure 4. The bar-graphic, C, is the same A-weighted sound pressure level as a conventional SLM. In order to show the fluctuating characteristics of noise sources, a histogram (D) shows the fluctuating level range, minimum, maximum and mode of $L_{\text{Aeq,(1sec)}}$ divided into 2.5 dB steps.

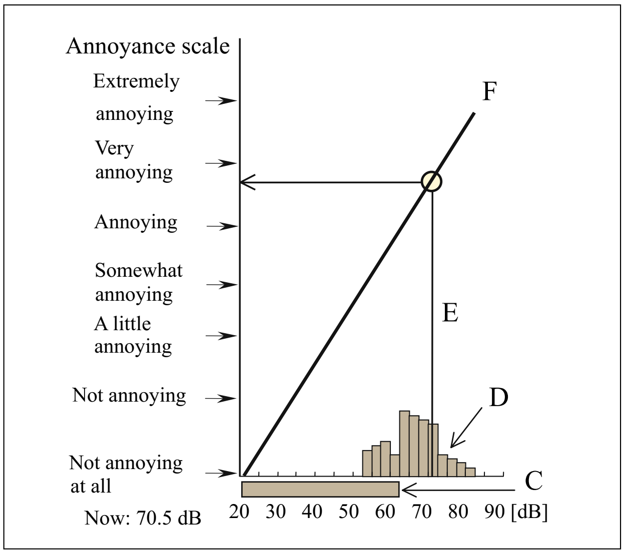

Figure 4. An example of the degree of psychological effects indicated on the display of the noise annoyance meter.

The display, E, is a perpendicular line from the value of $L_{\text{Aeq,T}}$. The subscript T is the time from the start of listening.

A common linear function, F, shows the noise rating scale given by equation (3) in Figure 1. The perpendicular line E drawn from the numerical value on the horizontal axis is extended horizontally from the point of intersection of the lines E and F.

On the vertical axis of its display, the "annoyance" scale is shown. As a first step, naming points that estimate the psychological effects ignores the fact that there is considerable individual variation. The psychological degree corresponding to the value of $L_{\text{Aeq,T}}$ [dB] is indicated with an arrow extended from line F horizontally. Consequently, this noise meter can directly relate "very annoying" to 70.5 dB as shown Figure 4.

As a second step, one might also think a histogram would be more appropriate than a point estimate.

5.2. Experiment

To verify whether our annoyance meter described in section 5.1 or a conventional one is more suitable for noise evaluation including the average degree of Japanese psychological effects, field tests were carried out at seven districts in Japan. These data were collected between 1994 and 1997.

5.2.1. Cities selected

An investigation was conducted for residents in the Hokkaidô, Tôhoku, Kanto, Hokuriku, Chûgoku, and Shikoku and Kyûshû districts. Those cities with some serious noise problems were selected from the seats of

Table V. Number of subjects classified by age and gender (M: Male, F: Female) in each region.

	Hokkaidô		Tôhoku		Kantô		Hokuriku		Chûgoku		Shikoku		Kyûshû		Total
Age	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
–19	16	14	22	17	28	14	6	12	8	7	7	5	11	26	193
20–29	12	7	9	20	16	13	1	7	16	14	5	12	12	10	154
30–39	5	4	8	10	12	13	3	4	5	6	1	1	3	5	80
40–49	4	7	6	9	15	19	4	5	2	11	2	4	7	15	110
50–59	10	10	11	15	15	14	3	3	6	4	6	3	5	1	106
60–69	4	6	17	4	12	5	0	1	3	6	6	5	3	2	74
70–	0	1	1	1	5	4	1	0	2	0	1	2	0	0	18
Total	51	49	74	46	103	82	18	32	42	48	28	32	41	59	735

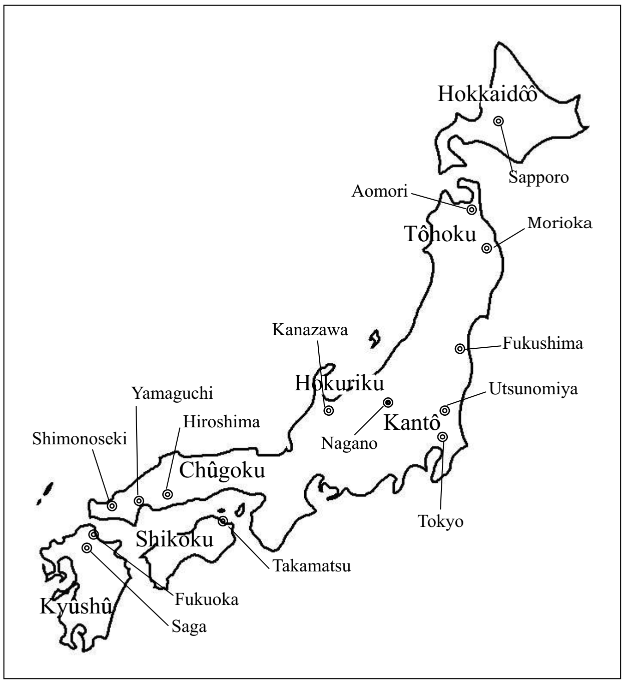

Figure 5. Map of Japan.

the metropolitan and prefectural governments as follows: Tokyo, Sapporo, Aomori, Morioka, Fukushima, Utsunomiya, Kanazawa, Hiroshima, Shimonoseki, Yamaguchi, Takamatsu, Fukuoka and Saga cities (see Figure 5).

5.2.2. Noise sources selected

The common noise sources selected in all cities were highway vehicles. Those selected in Tokyo were railway trains on the Tokaido Shinkansen line, jet aircraft taking off from and landing at Haneda airport, and construction equipment of a nearby building under construction at JR Ebisu station.

5.2.3. Actual audio-visual test

Even if some specific noises have the same value of $L_{\mathrm{Aeq},T}$ [dB], their psychological effects are influenced by individual sensitivities, living and hearing conditions, time zone etc. The establishment of a noise rating method taking into account the above factors is difficult. To solve this problem, a standard noise rating scale must be found. By means of this "annoyance", if many residents can easily understand the noise evaluation measure and realize again their vague impressions, it could help in communicating the problem; achieve social support to do something about the problem etc.

From this aspect, research showing that people like a SLM that uses annoyance categories is an initial validation that people can relate to such an instrument and that the idea of establishing a noise annoyance meter should not be outright rejected. A test was carried out at each conspicuous place selected outdoors out of the sun. To compare the two SLMs, each of the subjects saw the displays of two the SLMs and listened to the specific noise for a measurement time of five minutes.

5.2.4. Questionnaire

After five minutes, subjects evaluated the questions as follows:

- Q.1 Is the 7 annoyance scale levels used by residents in and around Nagano City easy to understand and a good representation of the degree of the psychological effects of the noises?
- Q.2 Which representation is best: the annoyance meter or the ordinary one (RION NL-11)?
- Q.3 Do your subjective impressions and the scale displayed correspond?
- Q.4 Would the new type of information make you more able to argue against noise pollution?
- Q.5 Can you determine whether a noise was over or under the allowable threshold (or translate dB limits into annoyance limits)? Please answer numerically an index value of L_{Aeq} to maintain your lifestyle and the condition of your health.

5.2.5. Subjects selected

Those subjects were the residents who consented to the actual audio-visual test on the new SLM. The test places were their houses, parks, underground passages, etc. selected in the surrounding residential areas of each noise source as described above. A total of 735 subjects were selected: 100 residents in Sapporo City, 50 in Aomori, 50 in Morioka, 50 in Fukushima, 50 in Utsunomiya, 135 in Tokyo, 50 in Kanazawa, 30 in Hiroshima, 26 in Yamaguchi, 34 in Shimonoseki, 60 in Takamatsu, 60 in Fukuoka and 40 in Saga.

Table VI. Measured $L_{Aeq(5min)}$ for various noise sources in various regions.

Regions	Noise sources	–69 dB	69.1–58 dB	58.1–49 dB	49.1–39.5 dB	Total
Hokkaidô	Vehicles	13	86	1	0	100
Tôhoku	Vehicles	14	78	52	6	150
Kantô	Vehicles	24	45	14	0	83
	Railway trains	3	29	1	0	33
	Jet aircraft	6	19	7	2	34
	Construction	4	31	0	0	35
Hokuriku	Vehicles	4	27	19	0	50
Chûgoku	Vehicles	41	46	3	0	90
Shikoku	Vehicles	7	53	0	0	60
Kyûsyû	Vehicles	16	80	4	0	100
Total		132	494	101	8	735
Percentage [%]		18	67.2	13.7	1.1	100

The age and gender of the test subjects in each district are shown in Table V. From this table, it can be said that both genders and all age groups were selected.

5.3. Results

5.3.1. $L_{Aeq,(5min)}$ measured

The values of $L_{Aeq,(5min)}$ [dB] measured are shown in Table VI. As can be seen from this table, 67.2% of those are in the range from 58 dB to 69 dB.

5.3.2. On the "annoyance" scale (Q.1)

With respect to the "annoyance" scale, 99.7% of the number of residents (735 subjects) answered that the representative words divided into seven levels on its display are an understandable representation for the degree of psychological effects of noise.

Accordingly, it can be said that the words separating the degree of annoyance on the "annoyance" scale are not specific for the population in and around Nagano City but commonly utilized in Japan. Ideally a new survey relating the degree of annoyance and noise levels should be undertaken to check not only whether the annoyance scale seems reasonable, but also whether people are equally annoyed at a given noise level.

5.3.3. On its "ease of understanding" (Q.2)

Table VII shows the frequency distribution of the results evaluating how well the noise annoyance meter could be understood. In the case of the noise annoyance meter, the percentage of the number of subjects who answered "highly understandable" (the top three out of seven categories) is 84.2%. The mean score is 5.4 i.e. more than "good understanding".

Hence, the noise annoyance meter is substantially effective in the seven districts investigated in Japan.

5.3.4. On its "correspondence" (Q.3)

Table VIII shows the frequency distribution of the results evaluating the degree of the correspondence between the scales displayed and the sensuous impressions heard. As can be seen from this table, the percentage of the number of subjects who responded "high correspondence" is 80.3%. The mean score is 5.0 i.e. "good correspondence".

5.3.5. On "the new type of information" (Q.4)

With respect to a unit called the decibel [dB], 81.3% of the number of residents (735 subjects) answered that "I have some knowledge of the decibel to noise pollution reported by the news media". However, almost all of the subjects were not aware of how noise makes their lives more stressful. Also they did not know what 70 dB or 65 dB noises utilized in the Japanese environmental quality standards were like.

By means of this noise annoyance meter, a predictable value of $L_{Aeq,(5min)}$ corresponding to the degree of the average psychological effect could be identified. Therefore, they were able to relate the value of $L_{Aeq,T}$ to the differences between the scales displayed and their impression heard. Noise tolerance levels vary from person to person. The subjects answered directly the value of L_{Aeq} of their allowable threshold.

5.3.6. On "the allowable threshold" (Q.5)

From the results shown in Table IX, the percentage of the number of residents (a random sample of 600 people in 13 typical cities in Japan) who began to feel the psychological effects (the allowable threshold) caused by vehicle noises at levels of L_{Aeq} between 30.0 dB and 52.4 dB is 74.0% and at levels between 52.5 dB and 70.0 dB is 26.0%. The mean value is 49.0 dB. Figure 6 shows the cumulative percentage of the data (Table IX). As can be seen from this figure, the cumulative percentage of the allowable noise levels caused by vehicle noise sources at 40 dB of L_{Aeq} corresponds to 10%, at 49 dB to 50%, at 58 dB to 90%.

Table VII. Frequency distribution of the responses to how well the "annoyance" SLM could be understood by different residents in each region. Seven scale points of understandability.

Regions	Noise sources	7 Extremely	6 Very Good	5 Good	4 Somewhat	3 A little	2 Not	1 Not at all	Mean scores
Hokkaidô	Vehicles	14	29	39	15	3	0	0	5.4
Tôhoku	Vehicles	20	40	60	26	3	1	0	5.3
Kanto	Vehicles	8	18	46	10	0	1	0	5.3
	Railway trains	7	8	10	5	3	0	0	5.3
	Jet aircraft	5	12	11	5	1	0	0	5.4
	Construction	3	7	18	6	1	0	0	5.1
Hokuriku	Vehicles	8	12	22	8	0	0	0	5.4
Chûgoku	Vehicles	10	27	45	6	1	1	0	5.4
Shikoku	Vehicles	9	21	25	4	1	0	0	5.5
Kyûsyû	Vehicles	16	26	43	11	3	1	0	5.4
Total		100	200	319	96	16	4	0	5.4
Percentage [%]		13.6	27.2	43.4	13.1	2.2	0.5	0	100

Table VIII. Frequency distribution of the responses to how well the scale displayed and the subjective impressions corresponded from different residents in each region. Seven scale points of understandability.

Regions	Noise sources	7 Extremely	6 Very Good	5 Good	4 Somewhat	3 A little	2 Not	1 Not at all	Mean scores
Hokkaidô	Vehicles	5	18	62	12	3	0	0	5.1
Tôhoku	Vehicles	8	22	77	29	9	4	1	4.8
Kanto	Vehicles	4	12	49	11	7	0	0	4.9
	Railway trains	2	6	21	4	0	0	0	5.2
	Jet aircraft	1	10	16	7	0	0	0	5.1
	Construction	1	10	17	6	1	0	0	5.1
Hokuriku	Vehicles	4	8	26	11	1	0	0	5.1
Chûgoku	Vehicles	3	25	51	5	5	1	0	5.1
Shikoku	Vehicles	3	15	34	6	2	0	0	5.2
Kyûsyû	Vehicles	4	19	57	14	6	0	0	5
Total		35	145	410	105	34	5	1	5
Percentage [%]		4.8	19.7	55.8	14.3	4.6	0.7	0.1	100

Table IX. Frequency distribution of the values of L_{Aeq} where 600 subjects felt the psychological effects caused by road vehicle noise sources started to appear.

Regions	70.0–62.5 dB	62.4–57.5 dB	57.4–47.5 dB	47.4–42.5 dB	42.4–37.5 dB	37.4–30.0 dB	Total
Hokkaidô	2	17	22	28	20	10	1
Tôhoku	5	14	24	58	24	22	3
Kantô	0	5	17	19	6	3	0
Hokuriku	0	2	7	22	12	6	1
Chûgoku	1	2	8	26	25	25	3
Shikoku	0	2	7	20	19	8	4
Kyûsyû	3	13	5	29	34	12	4
Total	11	55	90	202	140	86	16
Percentage [%]	1.8	9.2	15.0	33.7	23.3	14.3	2.7

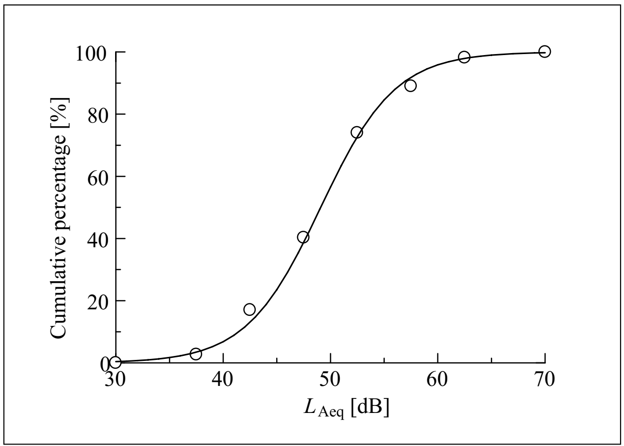

Figure 6. The cumulative percentage of the allowable noise levels caused by vehicle noise sources.

Therefore, it can be said that this noise annoyance meter is a useful instrument for examining people's attitudes toward a desirable environment to noise.

5.4. Discussion

The majority of subjects were able to understand the display representing the relationship between the "annoyance" scale and $L_{Aeq,T}$ [dB], in spite it being an entirely new experience for them. (a) The rating words; "Urusai", "Kininaranai" and the words representing the degree of the "annoyance" scale are used daily by many Japanese for representing the psychological effects caused by various kinds of noise sources. (b) Moreover, they learned these words as the common Japanese language during their compulsory education.

The above facts are also grounded in the results of an F-test on Table VII and Table VIII. In fact, from the results of the F-test evaluated at the 5% level of significance, it can be said that both the mean scores of understandability (5.4) and correspondence (5.0) bear no relation to each district, gender and age.

From these results, the experimental noise annoyance meter proposed here can use a common noise-rating scale for the degree of psychological effects on different subjects due to noise sources at the seven districts investigated in Japan. It gives insight into the field of improving building construction and design of more comfortable buildings for residents.

Such a noise annoyance meter would not solve the problem of describing the difference between average population responses and those of individuals. Subsequent research must determine whether one should provide calibration buttons for noise sensitive persons, hospitals or other sensitive areas.

6. Conclusion

In this paper, first, a 7-level annoyance scale ("Hizyôni Urusai", "Kanari Urusai", "Urusai", "Sukoshi Urusai, "Amari Kininaranai", "Kininaranai", and "Mattaku Kininaranai") was created by selecting seven typical category descriptors from the most frequently used words in everyday speech related to various kinds of noise sources in and around Nagano city. The results of the relationships between the 7-level annoyance scale and $L_{Aeq,(5min)}$ obtained for various kinds of noise sources are as follows:

(a) The seven descriptors mark off roughly equal-sized intervals: 7.19, 6.07, 5.08, 3.96, 3.12, 2.15, and 1.0.
(b) For all kinds of noise sources, "extremely annoying" corresponds to 83.1 dB, "very annoying" to 72.3 dB, "annoying" to 62.6 dB, "somewhat annoying to 51.8 dB, "a little annoying" to 43.6 dB, "not annoying" to 34.2 dB, and "not annoying at all" to 23.1 dB.
(c) For four kinds of noise sources, "annoying" corresponds to 60.9 dB for steady noise, 61.9 dB for road traffic, 63.0 dB for intermittent noise, and 67.5 dB for railway noise sources.

The usefulness of a new experimental noise annoyance meter, which was equipped with the "annoyance" scale representing the psychological effects, was demonstrated. The main conclusions are listed below.

(d) The "annoyance" scale, based on the evaluating words collected from residents in and around Nagano City, can be understood and related to by residents in other typical cities in Japan.
(e) The results measured with our noise annoyance meter are more understandable (the mean understanding score is 5.4 i.e. "good" and the mean correspondence score is 5.0 i.e. "good") and practical than a conventional SLM.
(f) The cumulative percentage of the allowable noise levels caused by vehicle noise sources at $L_{Aeq} = 40$ dB of corresponds to 10%, at 49 dB to 50%, and at 58 dB to 90%.

Accordingly, it can be said that the noise annoyance meter proposed here is a practical instrument for residents exposed to noise to help them understand what a physical equivalent noise level given as dB values "means" with respect to annoyance. The noise annoyance meter can be employed for measuring the impact of various kinds of noise sources at the seven districts investigated in Japan.

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