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The relationship between civil aircraft noise and community annoyance in Korea

Changwoo Lim[a], Jaehwan Kim[b], Jiyoung Hong[b], Soogab Lee[b,*], Soojoo Lee[c]

[a]*BK21 School for Creative Engineering Design of Next Generation Mechanical and Aerospace Systems, School of Mechanical and Aerospace Engineering, Seoul National University, Room 105, Building 311, Seoul 151-744, Republic of Korea*

[b]*School of Mechanical and Aerospace Engineering, Seoul National University, Room 205, Building 44, Seoul 151-744, Republic of Korea*

[c]*Department of Neurology, Eulji University School of Medicine, Eulji University Hospital, 1306, Dunsan-dong, Seo-gu, Deajon 302-799, Republic of Korea*

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Abstract

Studies of community annoyance caused by civil aircraft noise exposure were carried out in 18 areas around Gimpo and Gimhae international airports in order to accumulate social survey data and assess the relationship between aircraft noise levels and annoyance responses in Korea. WECPNL, adopted as the aircraft noise index in Korea, and the percentage of respondents who felt highly annoyed (%HA) have been used to assess the dose–response of aircraft noise. Aircraft noise levels were measured automatically by airport noise monitoring system, B&K type 3597. Social surveys were carried out to people living within 100 m of noise measurement points. The Questionnaire used in the survey contained demographic factors, noise annoyance, interference with daily activities and health-related symptoms. The question relating to the aircraft noise annoyance was answered on an 11-point numerical scale. The randomly selected respondents who were aged between 18 and 70 years completed the questionnaire by themselves. In total, 705 respondents participated in the questionnaire. The results show that WECPNL, noise metric considering characteristics of event and intrusive noise, is more reasonable than L_{dn}, noise metric considering total sound, to assess the effects of aircraft noise on health. It is also shown that the annoyance responses caused by aircraft noise in Korea seems higher than those reported in other countries.

1. Introduction

Like many other environmental problems, environmental noise, mainly caused by transportation noise, continues to grow and has become a serious problem in many countries [1]. The environmental noise problem is difficult to define because it involves direct and cumulative adverse effects of noise on health. According to the International program on Chemical Safety [2], an adverse effect of noise is defined as "a change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of capacity to compensate for additional stress, or increases the susceptibility of an organism to the harmful effects of other environmental influences". This definition includes any temporary or long-term

*Corresponding author. Tel.: +82 2 880 7384; fax: +82 2 875 4360.
E-mail address: solee@plaza.snu.ac.kr (S. Lee).

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deterioration of the physical, psychological or social functioning of humans or human organs [1,2]. Thus, noise effects include various impacts on mental and physical health and interference with daily activities of humans [3–5]. The adverse effects of noise on health in accordance with 'Guidelines for community noise [1]' of the World Health Organization (WHO) are as follows:

Noise-induced hearing impairment
Interference with speech communication and performance
Sleep disturbance
Cardiovascular and physiological effects

Annoyance

Especially, annoyance and sleep disturbance are the most notable health effects of environmental noise exposure if L_{dn} is below 70 dB [6]. Therefore, WHO has recommended population annoyance and sleep disturbance as environmental health indicators to support the effects of environmental noise on health [7]. This paper, however, only concerns annoyance due to environmental noise. Annoyance is associated with disturbance, complaint, dissatisfaction, harassment, nuisance, vexation, discomfort, hate and uneasiness, since annoyance is strongly related to psychological stress mechanisms [8–10].

Annoyance reactions are sensitive not only to acoustical characteristics (source, noise level), but also to many non-acoustical factors such as social, psychological or economic nature [11,12]. There are considerable differences in individual reactions to the same noise [13]. Therefore, methods for evaluating these effects have been extensively studied.

Schultz synthesized the results of social surveys conducted in several countries with different languages to summarize the dosage-effects of transportation noise. He proposed the concept of 'highly annoyed', which counts the number of respondents on the upper 27–29% of the annoyance scale, and then he drew a curve showing the percentage of highly annoyed persons as a function of L_{dn} [13]. Kryter also suggested that people who responded on the upper 27–29% of the annoyance scale were likely to be a 'highly annoyed' person. However, he found that the effects of ground traffic noise (i.e., road and rail traffic) differed from air traffic noise at the same exposure level; aircraft noise is more annoying than ground traffic noise [14,15]. Approximately, one decade after the publication of the Schultz curve, Fidell et al. updated the original compilation of Schultz [16]. However, there were several debatable methodological problems in the synthesis of datasets. Therefore, Finegold et al. reanalyzed the survey data of Fidell et al. and recommended the three different curves to describe the community annoyance of aircraft, road traffic and railway noise using the logistic fitting algorithm [17]. This prediction curve was adopted by the US Federal Interagency Committee on Noise (FICON) [18] and American National Standards Institute (ANSI) [19] to use noise-related environmental impact analyses. Miedema et al. also reanalyzed 45 different social surveys and described different annoyance curves for different sources: aircraft, road traffic and railway noise [6]. It can be seen from his study that aircraft noise is more annoying than road traffic and railway noise at the same noise level. The difference increases with the noise level.

Although many social surveys on the effects of community noise have been performed throughout the world, they have been carried out in advanced countries, mainly in Europe and North America [11–17]. Even though noise levels and sources are the same, the results of annoyance responses differ from country to country, because annoyance responses to the noise are affected by several factors: different cultures, different languages, different annoyance questions, and different climatic conditions [10,20]. Therefore, the objective of this paper is confined to accumulate the social survey data to assess the relationship between civil aircraft noise levels and annoyance responses in Korea.

The outline of this paper is as follows: the process of field surveys which consist of noise measurements and social surveys are discussed in Section 2. Analysis results for social surveys with a questionnaire are presented in Section 3. In order to assess the effects of civil aircraft noise on health, the study of the relationship between aircraft noise levels in WECPNL and annoyance responses is carried out. Finally, the results of this study are compared with those of other researches.

2. Field survey

In assessing human response to civil aircraft noise, the authors employed the field survey, the most widely used way in this area, that consists of physical measurements and social surveys using a questionnaire.

2.1. Measurement

2.1.1. Site selection

Field surveys were performed in eighteen areas around two international airports in Korea (Gimpo and Gimhae international airports). The choice of these sites arose from the fact that the two airports have mainly civil aircraft operations. In that case, the exposure levels of aircraft noise are nearly similar in the whole year. Eleven areas were selected around Gimpo airport and seven sites were chosen in nearby Gimhae airport. Sites near Gimpo airport are almost urban communities located nearby Seoul. Those near Gimhae airport, however, are almost rural areas with rice fields.

These sites were chosen not only as they were under the paths of aircraft for landing and taking off, but also as they were flat and free of obstacles.

2.1.2. Noise measurement

Noise levels were calculated at the two international airports with different volumes of aircraft operations. The average operations of flights in Gimpo and Gimhae airports are 160 and 80 a day, respectively.

Noise measurements were carried out using not only airport noise monitoring systems, but portable precision sound level meters at eighteen points. The aircraft noise levels of 14 points were measured automatically by airport noise monitoring system, B&K type 3597. These equipments are managed by the 'Ministry of Environment' in Korea. The equipment was mounted on the rooftop of houses to avoid obstacles between the aircraft and the receiver. And then, the others were carried out by portable precision sound level meter, B&K type 2238. The equipment was also mounted on a tripod on the rooftop. Microphones were positioned at a height of 1.5 m above the ground, and at least 1 m from any other reflecting surface.

It was necessary to carry out extensive measurements to obtain more precise calculation results of the aircraft noise levels. So, the measurements of airport noise monitoring systems were performed around the clock every day: during periods from January to June in 2004. The reliable measurement records of the aircraft noise exposure levels were conducted by the 'Ministry of Environment' in Korea.

2.1.3. Noise-level descriptor

To analyze aircraft noise levels and community responses, physical descriptors of the aircraft noise, such as WECPNL, L_{dn}, were calculated. WECPNL was mainly used to assess the relationship between aircraft noise levels and annoyance responses, because WECPNL was adopted as the noise index for the evaluation of aircraft noise in Korea, and L_{dn} was used also for convenient comparison with other researches.

Day–night average sound level, L_{dn}, has been calculated based on the formula [21]:

$$L_{dn} = 10\log\left[\frac{15}{24}\times 10^{0.1\times L_{\mathrm{day}}} + \frac{9}{24}\times 10^{0.1\times(L_{\mathrm{night}}+10)}\right], \tag{1}$$

where L_{day} and L_{night} represent the day and night-time average sound levels, respectively. The day-time period runs from 07:00 to 22:00 and the night-time period from 22:00 to 07:00.

In 1971, WECPNL was recommended by International Civil Aviation Organization (ICAO) to measure and evaluate the aircraft noise [22]. WECPNL proposed by ICAO is based on PNL values of over-flight, while WECPNL proposed by Korean is based on maximum noise levels. Korean WECPNL is modified from the ICAO WECPNL to simplify the measurement and evaluation of the aircraft noise. The Korean WECPNL (abbr. WECPNL in the following discussion) is defined as follows [23]:

$$\mathrm{WECPNL} = \bar{L}_A + 10\log(N_2 + 3N_3 + 10(N_1 + N_4)) - 27, \tag{2}$$

where $\bar{L}_A$ denotes the energy mean of all maximum aircraft noise level during a day. N_2 is the number of events during the day time (07:00–19:00) and N_3 is the number of events during the evening time (19:00–22:00). N_1 and N_4 are the number of events during night time (00:00–07:00) and late night time (22:00–24:00), respectively.

Fig. 1 indicates the distributions of aircraft noise levels in field survey areas around Gimpo airport. The box plot in Fig. 1 shows median values (horizontal lines), interquartile ranges (boxes), the largest and smallest observations (whiskers) and outliers. Outliers are defined as lying 1.5 box lengths from the edge of the box. There are almost no outliers in this plot. This box plot is an effective way to represent a data distribution, especially to display the data difference.

2.2. Social survey

Subjective responses to aircraft noise were measured by means of a social survey using a questionnaire. The survey was performed in order to investigate the individual's attitude and opinion to different aspects of environmental noise, and it was administered to residents within about 100 m of field survey sites. Therefore, one can assumed that all of the respondents were exposed to similar aircraft noise levels. The questionnaire contained inquiries about demographic factors, noise annoyance, interferences with daily activities, psychological and physiological health-related symptoms and reactions to an aircraft noise.

Respondents were asked to answer 'how much aircraft noise bothered or annoyed you when you stayed at home for the last 12 months or so [24]', by selecting one of 11 categories from 0 (not annoyed at all) to 10 (extremely annoyed). The 11-point numerical scale is shown in Table 1. The choice for the 11-point numerical scale is based on the assumption that respondents are more cognitively familiar with 0–10 scaling than with the shorter 7 or 9-point numeric scales [25].

To avoid any biased opinion, surveys were not introduced to the interviewees in advance and respondents were randomly selected on the basis of simple random sampling method. Questionnaires were distributed in person, and then respondents completed the questionnaire by themselves while a researcher waited. Each questionnaire took about 20 minutes to complete. They were administered concurrently with the noise measurements at each site. 63.5% of the randomly selected respondents participated in the surveys, resulting in a total of 705 respondents for the analysis of exposure-effect relationships between aircraft noise levels and annoyance responses.

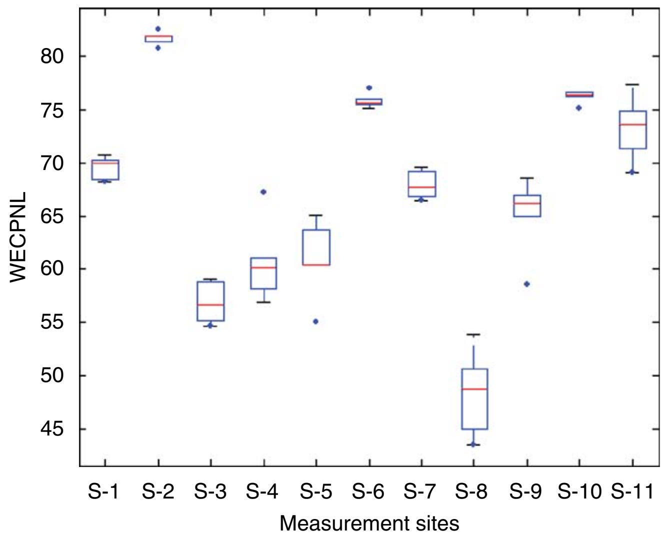

Fig. 1. Box plot showing the distribution of aircraft noise levels in WECPNL.

Table 1
Numerical scale

0	1	2	3	4	5	6	7	8	9	10
Not annoyed at all										Extremely annoyed

3. Results and analysis

In total, 33% of the respondents were male and 67% were female. The ages of the respondents exhibit a wide range: younger than 20 years (6%), 20–40 (37%), 40–60 (38%) and older than 60 years (19%). Most of respondents were female (67%) and married (80%). These results were affected by Korean culture that most females become a housewife after marriage. The resident duration of respondents indicate as follows: less than 1 year (7%), 1–3 years (18%), 3–10 years (36%), 10–30 years (32%) and more than 30 year (7%).

Regarding community responses to civil aircraft noise, about 51% of the interviewed people declared to be ''highly annoyed'', 24% ''rather annoyed'', 10% ''little annoyed'' and 15% ''not annoyed at all''.

Annoyance responses to civil aircraft noise were elicited by means of an 11-point numerical scale. When defined as parts of the annoyance scale, the term 'highly annoyed' is defined as the upper 27–28% of an annoyance scale. Therefore, the 'highly annoyed' variable of annoyance responses is calculated as binary data. Because of the binary nature of data, however, the equal variance assumption and the assumption that responses vary about the mean according to a normal distribution are not valid. In a case like that the variable is binary, the logistic regression analysis is more available [26,27].

The data, therefore, had to be dichotomized to conduct a logistic model. And so, the numerical scale of annoyance response was dichotomized as follows; Responses in the top three out of 11 categories (3/11) are 'highly annoyed' and the rests are not. The nature of responses is bounded between zero and one. The logistic model can be expressed as follows:

$$E(Y_i/X_i) = \frac{e^{(\beta_0+\beta_1 X_i)}}{1+e^{(\beta_0+\beta_1 X_i)}}, \tag{3}$$

where β_0 and β_1 are the intercept and the slope of logistic response function.

In the case of this study, maximum likelihood estimation (MLE) was used to dispose above assumption problems and to estimate the parameters of a logistic model [27,28].

To assess the effects of noise on health, the percentage of respondents who felt highly annoyed (%HA) is selected as the indicator of noise annoyance in many countries, such as the European Union, North America and Australia [6,13–17]. WHO also has recommended %HA as one of the environmental health indicators to support the effects of environmental noise on health [7]. Therefore, %HA was used to assess the dose–response of the aircraft noise in this study. And, WECPNL was used as the physical descriptor of the aircraft noise, because WECPNL was adopted as the aircraft noise index in Korea. L_{dn} was also used to compare with other researches.

In the case of aircraft noise, L_{dn} is calculated from aircraft noise exposure using the sound exposure levels of only aircraft noise events. In this study, however, the L_{dn} is calculated from the total sound including background noise, because typical L_{dn} is no stipulation of a minimum noise sampling threshold [29], and moreover which noise metrics, such as WECPNL, that noise metric considering characteristics of event and intruding noise, and L_{dn}, that noise metric considering total sound, are more reasonable to assess the health effects of aircraft noise with the characteristics of events and intrusive noises.

According to the latest research [30], exposed background noise level as well as the use of the reasonable noise metric is one of the important factors to study the health effects from the aircraft noise exposure. This paper, however, only concerns the assessment of dose–responses using a more reasonable descriptor. Therefore, the influences of background noise levels on judged annoyance responses to aircraft noise have been excluded from this paper.

Figs. 2 and 3 show the percentage of respondents who felt 'highly annoyed' (%HA) with respect to WECPNL and L_{dn} calculated from the total sound in field survey areas. Fig. 2 shows the rising tendency of %HA according to WECPNL, while Fig. 3 does not represent upward tendency of %HA as regards L_{dn}. The

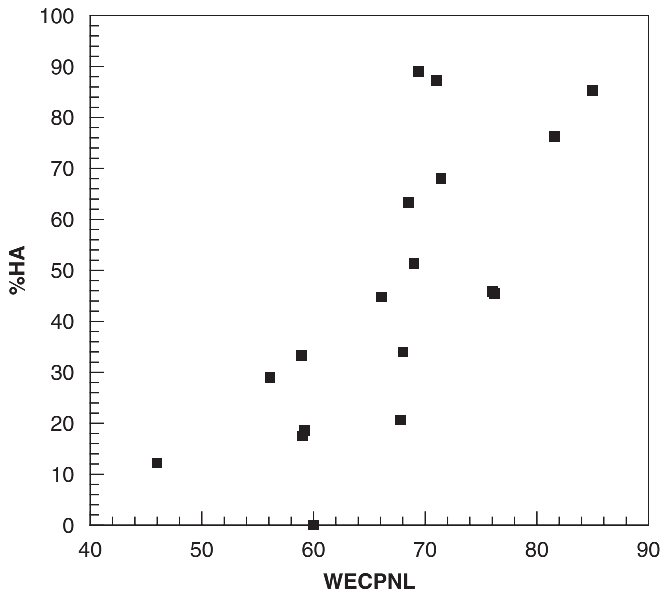

Fig. 2. %HA with respect to WECPNL.

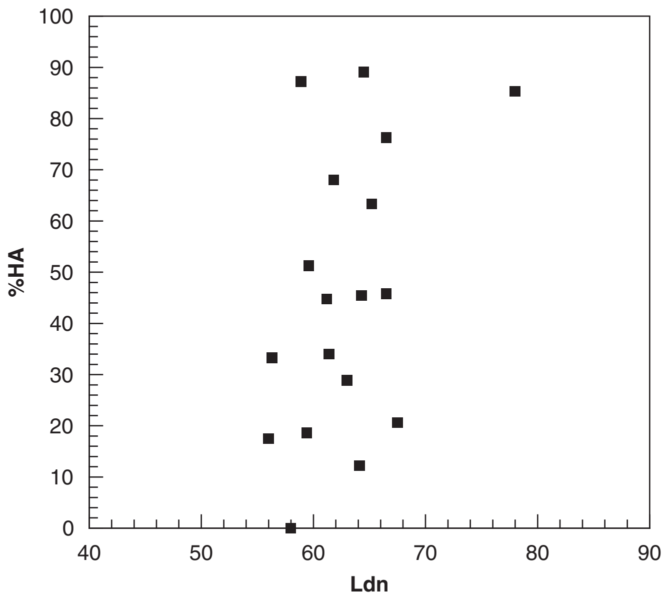

Fig. 3. %HA with respect to L_{dn}.

reason of the differences between the two results is caused by the different method of calculation between WECPNL and L_{dn}. WECPNL is calculated as the energy mean of maximum noise level ($L_{\max}$) when an aircraft passes by, while L_{dn} is computed the base on the equivalent sound level (L_{eq}) through the whole noise data, with a penalty of 10 dB for night-time noise events.

Table 2 shows the comparison of measurement data in some field survey area. As shown in this table, the values of WECPNL are different at the points 2 and 4, but L_{dn} values are almost similar despite different values of WECPNL at the two points. And, there is a difference in WECPNL about 8 dB(A) between the points 5 and 7, while there is almost no difference in L_{dn} including background noise even between two points.

Table 2
Comparison of measurement data in some field survey areas

Measurement point	WECPNL	L_{dn}
Point 2	60	58
Point 4	67.4	59.3
Point 5	71.4	61.8
Point 7	59.2	59.4

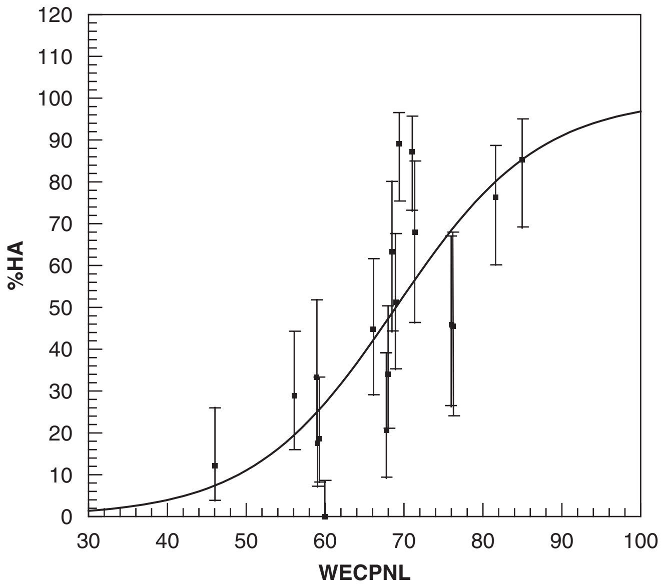

Fig. 4. %HA prediction curve of civil aircraft noise based on the noise exposure of the dwelling (WECPNL). Solid line is %HA prediction curve. Points are field survey data in eighteen areas. Bars are 95% confidence intervals for the data point. $N = 661$.

Because the point 5 is a rural area with rice fields while the point 7 is almost an urban area nearby Seoul, the background noise of point 7 is larger than that of point 5. Therefore, even though WECPNL owing to the aircraft noise is low, L_{dn} is somewhat high due to the loud background noise in the point 7. As briefly mentioned above, L_{dn} is no stipulation of a minimum noise sampling threshold in this case. Therefore, the value of L_{dn} depends on the influence of background noise levels and the number of flights. In addition, some recent studies have indicated that the use of L_{dn} alone may not be technically sufficient in many situations [29,31]. It is in point of public perception that a whole averaging metric from total sound, such as L_{dn} including background noise, does not correlate well with the public response to the short duration of the intruding aircraft noise. However, WECPNL only considered individual aircraft events when the over-flight happened. In other words, WECPNL is computed based on the maximum noise level when aircrafts pass by. From the above mentions, WECPNL is more reasonable metric for applying to the aircraft noise, because aircraft noise is not fluctuating noise but intermittent and intrusive noise characteristics. Therefore, the physical descriptor of the noise has to be considered carefully to assess the health effects of the aircraft noise.

3.1. Relationship between WECPNL and community annoyance

The physical descriptor of the noise, WECPNL was used to assess the effects of aircraft noise on health in terms of dose–effect relationships between aircraft noise levels and annoyance responses. Fig. 4 shows the percentage of respondents who felt highly annoyed (%HA) with respect to WECPNL for civil aircraft noise. Square spots are each field survey data showing %HA as a function of WECPNL. Bars represent the 95%

Table 3
The estimated coefficients of Eq. (3) using WECPNL as noise exposure metric

Parameter	Estimate	Std. error	p-Value
β_0	−7.498	0.761	<0.0001
β_1	0.109	0.011	<0.0001

confidence intervals at each data point. The 95% confidence intervals were calculated to estimate the distribution of 'highly annoyed' respondents at each field survey site. The levels of aircraft noise exposures range from 46 to 85. The solid line is %HA prediction curve that is determined by logistic fit procedure based on field survey data. The estimates of coefficients β_0, β_1 are presented in Table 3 with their estimated standard errors and significance levels. As shown in this table, the significance of p-value is less than 0.01. Consequently, parameters of this model are significantly effective. The next step estimates the measure of fit of the established logistic model. As a criterion of the explanatory power, the coefficient of determination, R^2, is used in linear regression models. Then again, the correct classification rate, CCR, is generally considered to estimate the measure of fit of logistic models. In this model, total CCR is 72.8%. It is showing a good relationship between aircraft noise levels and the percentages of respondents feeling 'highly annoyed'.

3.2. Comparison with results from other social surveys

Noise measurements of civil aircraft were carried out in various field survey areas. Each area was exposed to different background noise levels especially due to various traffic noise levels. As mentioned above, background noise levels have influence on the computation of noise levels in L_{dn} calculated from the total sound. However, one of the purposes of this paper is to compare the reactions of respondents with those of other researches when they are exposed to an aircraft noise, not any other noise source. Therefore, derivation of L_{dn} from WECPNL measured data using a transformation rule was carried out to compute noise levels in L_{dn} from only aircraft noise exposures. It was converted by the following equation [32,33]:

$$L_{dn} = \text{WECPNL} - 13, \tag{4}$$

where WECPNL is modified aircraft noise index in Korea and (−13) is a correction from perceived noise level to A-weighted sound pressure level. And then, the result of this study was compared with those of other researches. Fig. 5 indicates comparison between annoyance responses in this study and those in other surveys [6,32,34]. Square spots are each transformed data showing %HA as a function of L_{dn}. The solid line is %HA prediction curve of this study by logistic fit procedure. Gradient spots are social survey data around the Osaka international airport in Japan. The %HA is calculated for cutoff at 6 over on the 7 annoyance scale. The dashed line is %HA prediction curve that is based on a gradient spots. The curve is also determined by logistic fit procedure. The dashed–dot line and the dashed–dot–dot line are %HA prediction curve of Miedema et al. by polynominal fit and Finegold et al. by logistic fit, respectively. As shown in this figure, the noise annoyance responses of each survey are so different. Surveys can differ from one to another in many respects, such as different cultures, different languages, different annoyance questions, different climatic conditions, and different periods performed surveys. In Appendix A, forty differences are listed under three general headings [20]: (1) noise index calculation procedures, (2) annoyance measurement procedures, and (3) annoyance moderating conditions.

As estimated in Fig. 5, the annoyance responses reported in this study seems higher than those reported in other countries. Additionally contributory factors caused by the difference of results between this study and the others might be inferred that some residents are surprised at aircraft noise frequently in their living. About 68% of the respondents have been surprised at very loud and unexpected aircraft noise. And they consider that the aircraft noise is not good for their own health. They also raised complaints that the aircraft noise causes insomnia, nervousness and indigestion.

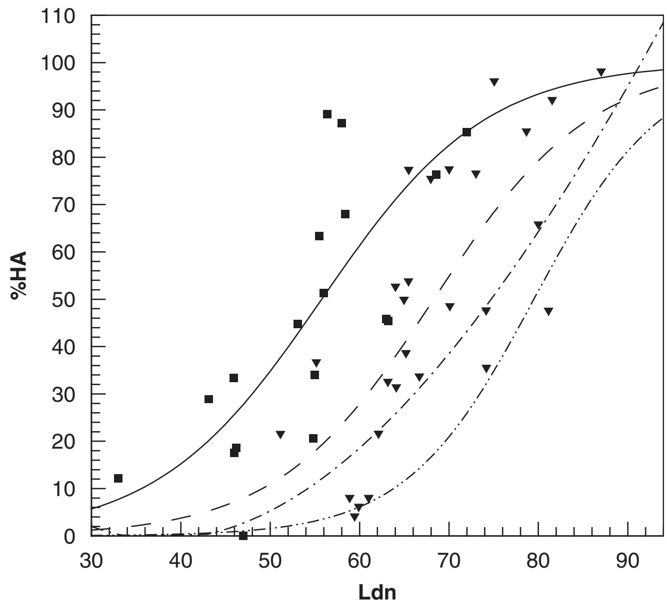

Fig. 5. Comparison between %HA prediction curve of civil aircraft noise in Korea and those in order country surveys (■ and ▼, field survey data in L_{dn} using a transformation rule in Korea and Japan, respectively; ———, %HA prediction curve in this study; – – –, %HA prediction curve of Osaka airport in Japan; — · —, Miedema's %HA prediction curve; — · · —, Finegold's %HA prediction curve).

4. Concluding remarks

Environmental noise, mainly caused by transportation noise, continues to grow and has become a serious global problem. This problem is difficult to define because it involves direct, cumulative adverse effects of noise on health. In recent years, therefore, the percentage of respondents who felt 'highly annoyed' prediction has become a critical component of environmental impact analyses for supporting environmental decisions regarding transportation noise. The WHO has recommended population annoyance as one of the environmental health indicators to support environmental noise policy-making and decision activities in many countries. However, WHO does not recommend international consensus on how to predict annoyance from transportation noise sources. Therefore, the study of community annoyance caused by civil aircraft noise exposure was carried out in order to accumulate social survey data and assess the relationship between aircraft noise levels and annoyance responses in Korea. Aircraft noise measurements were carried out in eighteen areas around Gimpo and Gimhae international airports in Korea. Social surveys were carried out to people living within about 100 m of noise measurement points, as a rule. The total number of respondents for the questionnaire was 705. According to the results of social surveys, about 51% of the interviewed people declared to be "highly annoyed", 24% "rather annoyed", 10% "little annoyed" and 15% "not annoyed at all". To assess the effects of noise on health, the percentage of respondents who felt highly annoyed (%HA) and WECPNL adopted as the noise index for the evaluation of aircraft noise in Korea were used in this study. There was a good relationship between aircraft noise level and %HA. By increasing aircraft noise levels, the %HA was also increased.

The results show that WECPNL, noise metric considering the characteristics of events and intrusive noises, is more reasonable than L_{dn}, noise metric considering total sound, to assess the effects of aircraft noise on health. It is also shown that annoyance responses caused by aircraft noise in this study seems higher than those reported in other countries.

It is believed that the following relationships can be used for environmental noise policy-making activities in the future.

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Appendix A. Factors affecting comparisons of annoyance by noise level relationships in residential areas [20]

I. Noise index calculation procedures

A. Prevailing conditions and procedures for noise measurement program

1. Frequency weighting network setting—A, B, C, D, linear, PNL
2. Reflection—distance form reflecting surface, characteristics of surfaces
3. Atmospheric—fair weather versus typical or worst noise propagation conditions
4. Time period (this may interact with event type or atmospheric conditions)
5. Source operating conditions
6. Method of counting noise events—observed versus estimated numbers of events, noise level threshold for defining event (constant arbitrary level, detectable effect on noise levels, audible)
7. Noise from other sources—included or excluded from measurements
8. Measurement variability and measurement error—size and source

B. Norminal conditions to which noise index is normalized

1. Summary noise index calculated (Leq, NNI, CNR, etc.)
2. Position of receiver at residence:
   (a) Out-of-doors—distance from dwelling, height of microphone, side of dwelling (front, noisiest side, noisiest side with windows)
   (b) Indoors—window position (open, closed, partially open), room in dwelling, position in room
3. Atmospheric—fair weather, typical or worst conditions
4. Time period—hours of day, day of week, season of year
5. Source operation conditions

C. Other aspects

1. Method of interpolation to unmeasured dwellings—propagation models
2. Sampling errors for summary indices
3. Method of averaging noise samples (arithmetic, logarithmic)

II. Measurements of human response

A. Measurement of response levels

1. Wording of question—number and wording of alternative responses
2. Language of administration
3. Location of questions in questionnaire
4. Presented purpose of questionnaire
5. Model of administration—interviewer, self-administered
6. Interviewer behavior
7. Treatment of missing data

B. Selection of respondents

1. Sampling of areas
2. Sampling of individuals

3 Call back policies if no one at home

III. Annoyance moderating conditions (affect subjectively felt impact of noise)

A. Uniform for whole survey

1. Season of survey
2. Year of survey
3. Noise source

4. Cultural valuation of quiet
5. Outdoor activity patterns

B. Uniform for each study site (possibly whole survey)
1. Ambient noise levels and competing noise sources
2. Timing of noise events (day, evening, night)
3. History of noise exposure and experience with noise source
4. Noise source operating conditions
5. Other neighborhood environmental conditions and amenities

C. Vary within study sites
1. Characteristics of dwellings—attenuation, construction, availability of rooms without noise exposure
2. Noise exposure away from residence (work, school, shopping)
3. Attitudes related to annoyance (fear, preventability)
4. Other individual characteristics

References

[1] WHO, *Guidelines for Community Noise*, World Health Organization, Geneva, Switzerland, 2000.
[2] WHO, Assessing human health risks of chemicals: derivation of guidance values for health-based exposure limits, *Environmental Health Criteria No. 170*, World Health Organization, Geneva, Switzerland, 1994.
[3] D. Ouis, Annoyance from road traffic noise: a review, *Journal of Environmental Psychology* 21 (2001) 101–120.
[4] K.D. Kryter, Community annoyance from aircraft and ground vehicle noise, *Journal of the Acoustical Society of America* 72 (1982) 1253–1257.
[5] F.J. Langdon, Noise nuisance caused by road traffic in residential areas: part I and part II, *Journal of Sound and Vibration* 47 (1976) 243–282.
[6] H.M.E. Miedema, H. Vos, Exposure–response relationships for transportation noise, *Journal of the Acoustical Society of America* 104 (1998) 3432–3445.
[7] WHO, *Environmental Health Indicators: Development of a Methodology for WHO European Region*, World Health Organization, Copenhagen, Denmark, 2000.
[8] R. Guski, U. Felscher-Suhr, The concept of noise annoyance: how international experts see it, *Journal of Sound and Vibration* 223 (1999) 513–527.
[9] H.S. Koelega, Environmental annoyance: characterization, measurement and control, *Proceedings of the International Symposium on Environmental Annoyance*, Amsterdam, 1987.
[10] R. Guski, Conceptual, methodological and dose–response problems related to annoyance and disturbance, *Inter-noise* 97 (1997) 1077–1082.
[11] J.M. Fields, Effects of personal and situational variables on noise annoyance in residential areas, *Journal of the Acoustical Society of America* 93 (1993) 2753–2763.
[12] H.M.E. Miedema, H. Vos, Demographic and attitudinal factors that modify annoyance from transportation noise, *Journal of the Acoustical Society of America* 105 (1999) 3336–3344.
[13] T.H.J. Schultz, Synthesis of social surveys on noise annoyance, *Journal of the Acoustical Society of America* 64 (1978) 377–405.
[14] K.D. Kryter, Community annoyance form aircraft and ground vehicle noise, *Journal of the Acoustical Society of America* 72 (1982) 1212–1242.
[15] K.D. Kryter, Community annoyance form aircraft and ground vehicle noise (Response of K.D. Kryter to modified comments by T.H.J. Schultz of K.D. Kryter's paper), *Journal of the Acoustical Society of America* 73 (1983) 1066–1068.
[16] S. Fidell, D.S. Barber, T.H.J. Schultz, Updating a dosage–effect relationship for the prevalence of annoyance due to general transportation noise, *Journal of the Acoustical Society of America* 89 (1991) 221–233.
[17] L.S. Finegold, C.S. Harris, H.E. von Gierke, Community annoyance and sleep disturbance: updated criteria for assessing the impacts of general transportation noise on people, *Noise Control Engineering Journal* 42 (1994) 25–30.
[18] Federal Interagency Committee on Noise (FICON), *Federal Agency Review of Selected Airport Noise Analysis Issues*, Spectrum Sciences and Software, Inc., Fort Walton Beach, FL, USA, 1992.
[19] American National Standards Institute (ANSI), *Quantities and Procedures for Description and Measurement of Environmental Sound—Part 4: Noise Assessment and Prediction of Long-term Community Response—Includes Errata (10/01/97)*, Acoustical Society of America, Melville, New York, 1996.
[20] J.M. Fields, J.G. Walker, Comparing the relationships between noise level and annoyance in different surveys: a railway noise vs. aircraft and road traffic comparison, *Journal of Sound and Vibration* 81 (1982) 51–80.
[21] H.M.E. Miedema, C.G.M. Oudshoorn, Annoyance from transportation noise: relationships with exposure metrics Ldn and Lden and their confidence intervals, *Environmental Health Perspectives* 109 (2001) 409–416.

[22] ICAO, *International Standards and Recommended Practices Environmental Protection Annex 16*, International Civil Aviation Organization, 1971.
[23] Ministry of Environment in Korea, *Noise and Vibration Control Act, Notice No. 2000-31*.
[24] C. Lim, S. Lee, *Questionnaire on Environmental Noise: The CORE Set*, Center for Environmental Noise and Vibration Research, 2003.
[25] International Standard Organization (ISO), Acoustics—assessment of noise annoyance by means of social and socio-acoustic surveys, *ISO/TS 15666*, 2003.
[26] S. Lee, S. Min, J. Park, S. Yun, *The Practice on Logit and Probit Model*, Pakyoungsa, 2005.
[27] P.D. Allison, *Logistic Regression Using the SAS System: Theory and Application*, SAS Institute, 1991.
[28] A.J. Dobson, *An Introduction to Generalized Linear Models*, Chapman & Hall, London, 1990.
[29] D. Billera, *Environmental Research Needs in Transportation*, US Federal Department of Transportation, 1997.
[30] C. Lim, Assessment Methods of Adverse Effects on Health from Environmental Noise, PhD Thesis, Seoul National University, 2006.
[31] W. Albee, *Why We Must Supplement DNL Noise Analysis*, Wyle Laboratories Acoustics Group, 2002.
[32] J. Igarashi, Comparison of community response to transportation noise: Japanese results and annoyance scale, *Journal of the Acoustical Society of Japan* 13 (1992) 301–309.
[33] H. Yoshioka, I. Yamada, Consideration to noise index for evaluating airport noise in Japan, *Inter-noise 2004*, Prague, Czech Republic, 2004.
[34] L.S. Finegold, Historical development and current status of exposure–response relationships between transportation noise and community annoyance, *Inter-noise 2003*, Jeju, South Korea, 2003.