Effect of background noise levels on community annoyance from aircraft noise

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A study of community annoyance caused by exposures to civil aircraft noise was carried out in 20 sites around Gimpo and Gimhae international airports to investigate the effect of background noise in terms of dose-effect relationships between aircraft noise levels and annoyance responses under real conditions. Aircraft noise levels were mainly measured using airport noise monitoring systems, B&K type 3597. Social surveys were administered to people living within 100 m of noise measurement sites. The question relating to the annoyance of aircraft noise was answered on an 11-point numerical scale. The randomly selected respondents, who were aged between 18 and 70 years, completed the questionnaire independently. In total, 753 respondents participated in social surveys. The result shows that annoyance responses in low background noise regions are much higher than those in high background noise regions, even though aircraft noise levels are the same. It can be concluded that the background noise level is one of the important factors on the estimation of community annoyance from aircraft noise exposure.
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I. INTRODUCTION

Background noise level is an important factor on community annoyance response to aircraft noise exposure because subjective responses to aircraft noise were found to decrease with increasing background noise levels. The influence of background noise levels for annoyance responses to aircraft noise has been studied.[1–6]

Pearsons carried out the first study of background noise in 1966.[1] He studied the effects of background noise on perceived noisiness, and reported that the addition of background noise decreased the perceived noisiness of aircraft noise. Wells found that "noise complaint potential" was a function of the difference between aircraft noise and background noise as well as the background noise levels.[2] Powell and Rice found that average annoyance decreased with increasing background noise levels when the background level was held continuous over a test session.[3] Increasing the background noise from 32 to 46 dB reduced annoyance responses by an amount equivalent to 5 dB reduction in aircraft noise level. They concluded that increases in background noise levels caused decreases in subjective responses to aircraft noise. Bottom obtained annoyance scores at nine sites under the conditions of combining three different aircraft noises and three different traffic flows.[4] Traffic flows show strong relationship to traffic noise, with heavier traffic flow causing higher traffic noise. He found that mean annoyance scores were regressed against traffic flows. He concluded that the lower background noise levels were, the greater annoyance responses were at a given aircraft noise level. Johnston and Haasz analyzed annoyance judgments made by 35 subjects under different conditions of background noise levels and signal durations.[5] They also obtained that the increase of background noise levels was associated with reduced annoyance scores. Several authors also reported that background noise levels were relevant to the subjective responses to aircraft noise.[6]

Although several studies on the effects of background noise have been performed, they have mainly been carried out in laboratory situations to determine the subjective responses to aircraft noise in different background noise levels. However, laboratory situations are not real conditions. According to the result reported by Taylor *et al.*, background noise levels do not significantly affect either individual or aggregate responses to aircraft noise in real world conditions, because laboratory studies based on judgments of single flyover events may not be generalizable to the real world conditions of long term exposure to multiple events.[7] Fields also reported that ambient noise levels have no effect in community annoyance because intrusive noise levels which are high enough to be annoying are usually high enough so that they are not usually masked, even by high ambient noise levels.[8] However, in the Swiss study of response to aircraft noise, it was found that annoyance response to a given level of aircraft noise was less in neighborhoods with heavy road traffic

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than where the road traffic was light.[9] A similar result was reported by Waters and Bottom.[10] Accordingly, a final conclusion about the effects of background noise on the assessment of community noise remains still uncertain under real situations. Therefore, the objective of this paper is to investigate the effect of background noise in terms of community reactions to residents exposed to real noise conditions like long term aircraft noise exposure, and to make sure whether these results are consistent with those reported in laboratory studies as already discussed.

II. METHODOLOGY

In assessing human responses to the aircraft noise under different background noise conditions, the authors employed a field survey that consists of physical measurements and social surveys using a questionnaire.

A. Noise measurement

1. Site selection

Field surveys were performed in 20 sites around two international airports in Korea to investigate the effect of background noise level on community reactions. Eleven sites were selected around Gimpo airport and the others were chosen around Gimhae airport. These areas were chosen, because while both airports mainly service civil aircraft operations that are fixed routes and the regular volumes of flights, their surrounding areas are exposed to similar aircraft noise levels in the whole year.

Areas near Gimpo airport are mostly urban located near by Seoul, while those near Gimhae airport are mostly rural areas with rice fields. Therefore, the two areas are clearly divided into two different background noise levels. The difference of background noise levels between these areas is about 10 dB(A). Measurement sites were mostly under the paths of the aircrafts during landing and take off, and they were also flat and free of obstacles.

Figure 1 shows field survey sites around Gimpo and Gimhae international airports. Most of the houses in the field survey sites around Gimpo airport are apartment buildings built out of ferroconcretes and the majority of houses in those around Gimhae airport are detached houses of bricks.

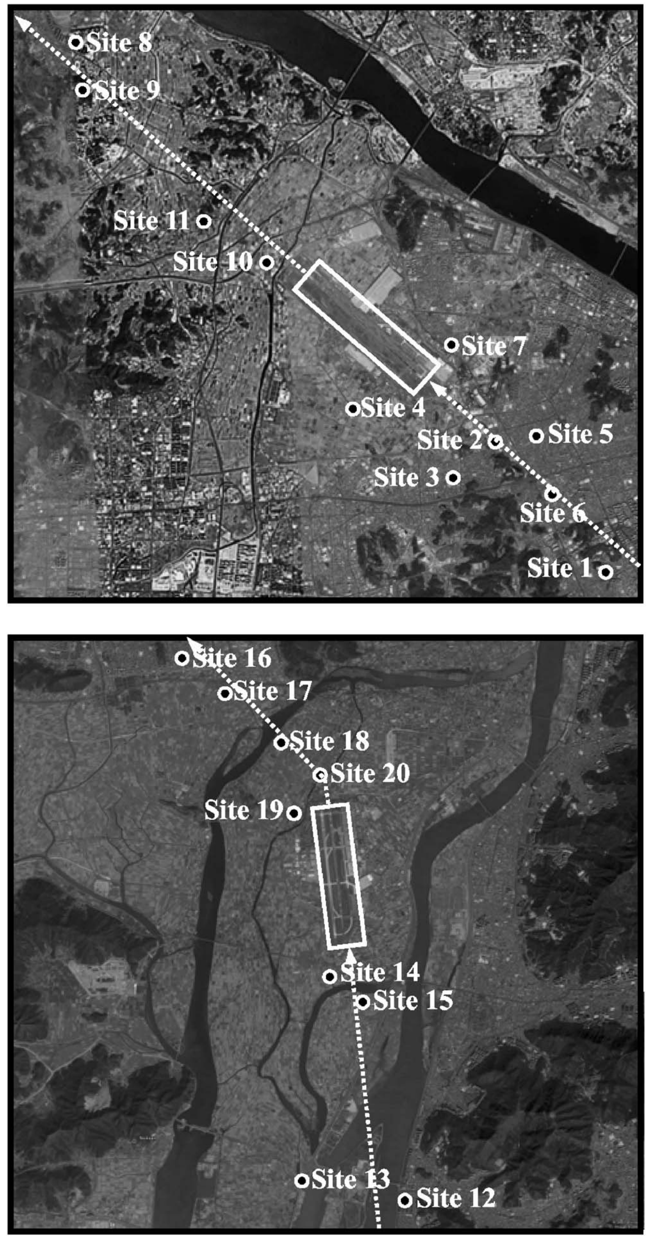

FIG. 1. Field survey sites around Gimpo (above) and Gimhae (below) international airports.

2. Noise measurement

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

The measurements of aircraft noise were carried out not only with airport noise monitoring systems, but also with portable precision sound level meters at the field survey sites. The aircraft noise levels of 16 sites were measured automatically using airport noise monitoring systems, B&K type 3597. The equipment, managed by the Ministry of Environment in Korea, were mounted on the rooftops of houses to avoid any obtrusions caused by obstacles between the aircraft and the receiver. The others were measured with portable precision sound level meters, B&K type 2238. They were also mounted on the rooftops with a tripod. Microphones were positioned at a height of 1.5 m above the flat, and at least 1 m from any other reflecting surfaces.

It was necessary to carry out extensive measurements to obtain more precisely calculated results of aircraft noise levels. The measurements of airport noise monitoring systems were performed around the clock every day, from January to June of 2004.

WECPNL (weighted equivalent continuous perceived noise level) was used to assess the relationship between aircraft noise levels and annoyance responses, and to investigate the effect of background noise on annoyance reactions. The international civil aviation organization (ICAO) recommended the use of WECPNL to measure and evaluate the aircraft noise at first.[11] In Korea, however, WECPNL was modified from the WECPNL recommended by ICAO to sim-

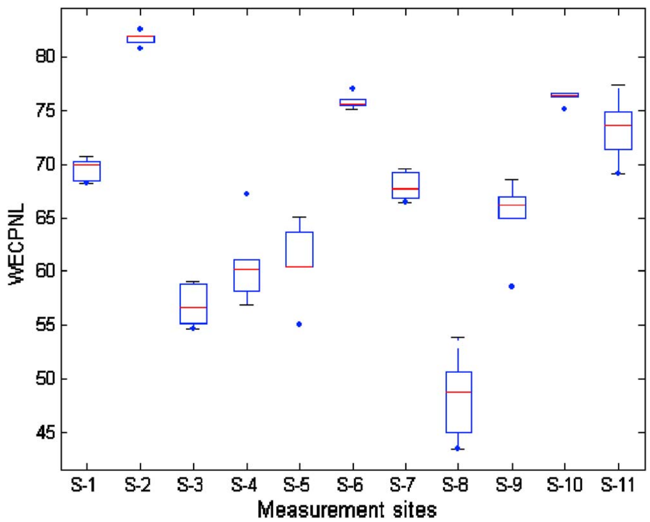

FIG. 2. (Color online) Box plots showing the distribution of aircraft noise levels in field survey sites around Gimpo airport (see Ref. 11).

plify the measurement and evaluation of the aircraft noise. The WECPNL used in Korea (abbr. WECPNL in the following discussion) is defined as follows:[12]

$$\text{WECPNL} = \bar{L}_A + 10\log(N_2 + 3N_3 + 10(N_1 + N_4)) - 27, \quad (1)$$

where, $\bar{L}_A$ denotes the energy mean of all maximum aircraft noise level during a day. N_2 and N_3 are the number of events during the daytime from 07:00 to 19:00 and the nighttime from 19:00 to 22:00. N_1 and N_4 are the number of events during midnight from 00:00 to 07:00 and late nighttime from 22:00 to 24:00, respectively.

Figure 2 indicates the distributions of aircraft noise levels in field survey sites around Gimpo airport.[13] The box plots in Fig. 2 show median values (horizontal lines), interquartile ranges (boxes) that consist of lower quartile (Q1) and upper quartile (Q3), the largest and smallest observations (whiskers) and outliers. Outliers are defined as lying exterior data of 1.5 box lengths from the edge of the box. As shown in this figure, there are almost no outliers, and the interquartile ranges are small. In a word, the exposure levels of aircraft noise in each field survey area are nearly similar during the whole year.

B. 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 in regards to different aspects of aircraft noise, and it was administered to residents living within about 100 m of the noise measurement sites. Therefore, it can be assumed residents living in a given area were exposed to similar noise levels with negligible differences.

Questionnaires were comprised of questions relating to the assessments of aircraft noise, as well as some general questions of residents, even if they do not relate to noise. Questions were arranged in three basic sections. The first section sought to obtain demographic data, the second asked questions about nuisance perception from aircraft noise, and the third dealt with health-related symptom questions. Therefore, the questionnaire contained demographic questions, degree of noise annoyance, interferences with daily activities, psychological and physiological health-related symptoms, and reaction to aircraft noise. In order to assess the annoyance responses to aircraft noise, specifically, people were asked questions like "how much were you bothered or annoyed by the aircraft noise, while staying at home, in the last 12 months.[14] The respondents then used an 11 category response ranging from 0 (not annoyed at all) to 10 (extremely annoyed). The 11-point numerical scale is shown in Table I. The 11-point numerical scale was chosen over the shorter 7 or 9-point numeric scales with the assumption that respondents are more cognitively familiar with the 0 to 10 scaling.[15]

To avoid any bias in opinion, the surveys were not introduced to the interviewees in advance and the respondents were randomly selected from residents near the measurement sites based on simple random sampling method. Questionnaires were distributed in person and the questionnaires were completed independently while researchers waited. Each questionnaire took about 20 min to complete and the social surveys were carried out within a given period of the noise measurement at each site. 63.5% of the randomly selected respondents participated in this survey, resulting in a total of 753 respondents for the analysis of exposure-effect relationships between aircraft noise levels and annoyance responses.

III. RESULTS

Thirty three percent 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 (36%), 40–60 (38%) and older than 60 years (20%). Most of respondents were female (67%) and were married (80%). These results were due to the nature of the Korean culture where most women become housewives after marriage. The duration of residency of the respondents was as follows: less than 1 year (7%), 1–3 years (17%), 3–10 years (35%), 10–30 years (33%) and more than 30 years (8%). Regarding community response to aircraft noise 70% of the respondents reported that they were worried by aircraft noise. About 68% of the respondents have been surprised at very loud and unexpected aircraft noise. About 35% of them consider that the aircraft

TABLE I. Numerical scale.

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

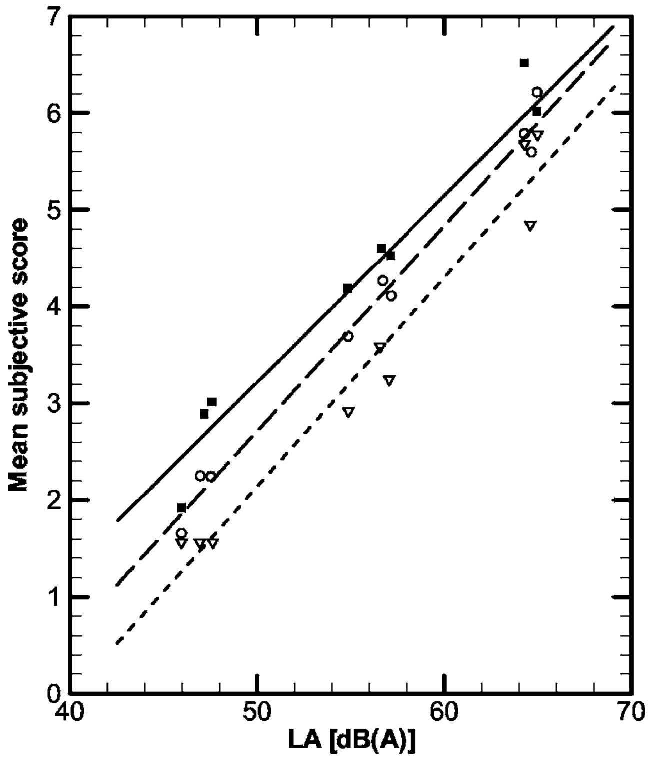

FIG. 3. Regressions of mean subjective scores on L_A for continuous background noise. (Mean background noise level in dB(A): ■—, 32.3;○---, 37.1;▽………., 46.4) (see Ref. 3).

noise is not good for their own health. They also raised complaints that the aircraft noise causes insomnia, nervousness and indigestion.

Annoyance responses to civil aircraft noise were elicited by means of an 11-point numerical scale. Under the definition of the annoyance scale, the term "highly annoyed" is defined as the upper 27–28% of the annoyance scale. Given the goals of the study, the relationships between the civil aircraft noise and the percentage of respondents who were "highly annoyed" according to different background noise levels were compared, and also made sure whether the results of this study were consistent with those reported in laboratory studies like Fig. 3 in showing that subject response to aircraft noise was significantly affected by variations in background conditions.[3]

To assess the effects of noise on health, the percentage of respondents who felt highly annoyed (*%HA*) was selected as the indicator of noise annoyance in many countries.[16–18] The World Health Organization (WHO) also has recommended *%HA* as one of the environmental health indicators

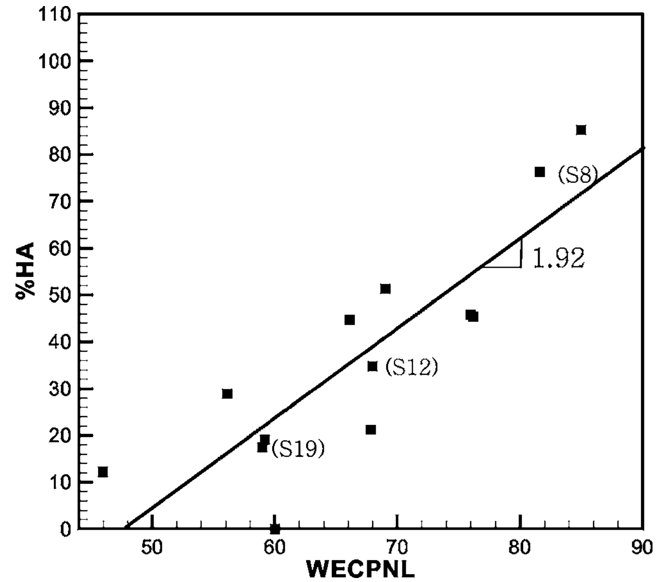

FIG. 4. *%HA* with respect to WECPNL in relatively high background noise levels.

to support the effects of environmental noise on health.[19] Therefore, *%HA* was used to assess the effects of background noise in terms of dose-effect relationships between aircraft noise levels and annoyance responses, and WECPNL was used also as the physical descriptor of aircraft noise in this study, because that is used to evaluate the aircraft noise in Korea.

In order to investigate the influence of background noise, field survey data were divided into two groups based on background noise levels. Groups 1 and 2 are field survey data in relatively low and high background noise levels, respectively. Background noise levels, excluding aircraft noises, were measured. The descriptor for background noise is A-weighted Equivalent Sound Level which is cumulated 1 h exposure, $L_{Aeq,1\ h}$. The information on background noise for each group is shown in Table II. As shown in this table, the mean background noise levels of group 1 (low background noise group) and group 2 (high background noise group) are 42 and 55.5 dB(A), and the difference in the mean values between the two groups is about 13 dB(A).

Figures 4 and figure 5 show *%HA* with respect to WECPNL in relatively high and low background noise levels, respectively. These figures show the rising tendency of *%HA* according to WECPNL, but the rising tendency of *%HA* in Fig. 5 is steeper than that in Fig. 4. Namely, the subjective responses to aircraft noise are different at the

TABLE II. Information about background noise levels.

	L_{Aeq}(max)[a]	L_{Aeq}(min)[b]	L_{Aeq}(mean)[c]	Standard deviation
Group 1 (Low background noise)	45	39	42	2
Group 2 (High background noise)	60	51	55.5	2.9

The greatest noise levels which were calculated except aircraft noise in the group.
The lowest noise levels which were calculated except aircraft noise in the group.
The mean background noise level in the group.

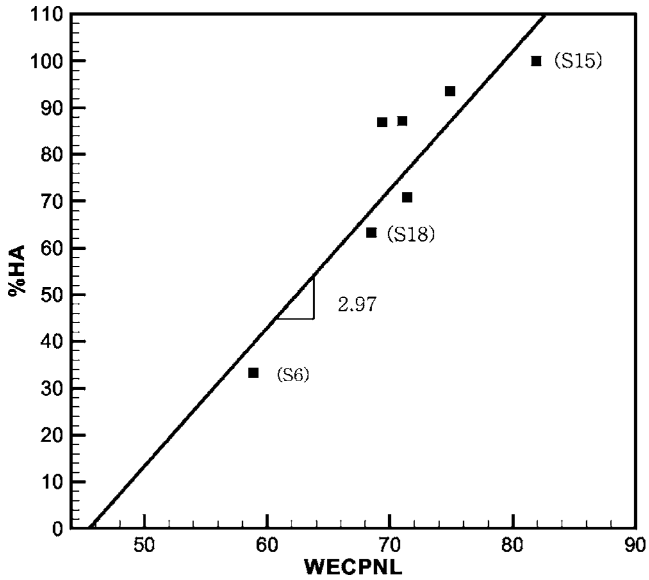

FIG. 5. *%HA* with respect to WECPNL in relatively low background noise levels.

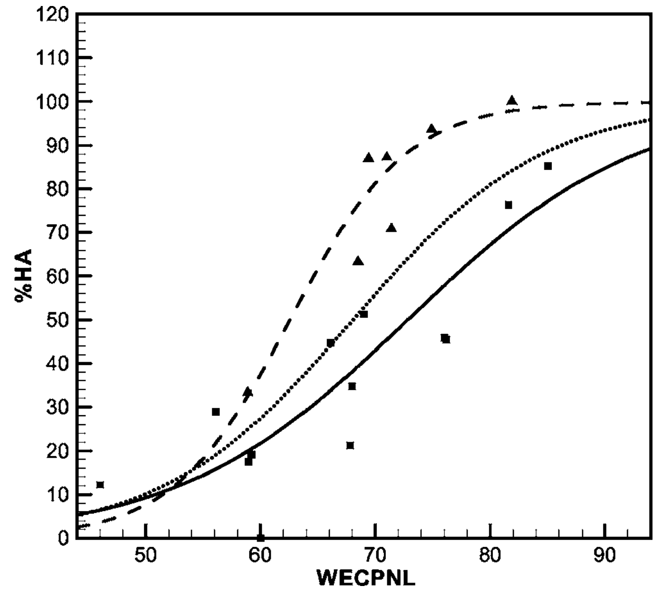

FIG. 6. Comparison between *%HA* prediction curve of civil aircraft noise according to background noise levels. (▲ and ■, field survey data in low and high background noise levels, respectively; ---, *%HA* prediction curve based on field survey data in low background noise group, $N=487$; —, *%HA* prediction curve based on field survey data in high background noise group, $N=212$).

same values of WECPNL. The difference increases with the noise level. Table III shows the comparison of measurement data in some field survey sites. As shown in this table, the values of WECPNL are similar at each category C1, C2 and C3, but *%HA* values are different. In other words, there is almost no difference in WECPNL between the site 18 and site 12 in category C2, while there is a difference in *%HA* of about 28% between the two sites. Categories C1 and C3 are just the same. Because the sites 6, 15, 18 are a rural area with rice fields while the sites 8, 12, 19 are an urban area nearby Seoul, the background noise levels of sites 8, 12, 19 are higher than those of sites 6, 15, 18. In view of the results of this table, background noise levels have influence on annoyance responses.

Figure 6 shows the annoyance responses of residents exposed to civil aircraft noise with respect to different background noise levels in WECPNL. The level of aircraft noise exposure ranges from 46 to 85. Triangle and square spots are field survey data showing *%HA* as a function of WECPNL in group 1 and group 2, respectively. The dashed and solid lines are *%HA* prediction curves that are based on field survey data in group 1 and group 2, respectively. As shown in this figure, the annoyance responses of group 1 are much higher than those of group 2 at the same noise levels. The average difference in annoyance responses between group 1 and group 2 is about 35% even though noise levels are the same. The difference increases with the increase in the level. Before the results are accepted, however, they must be verified whether or not the difference of annoyance responses between group 1 and group 2 is valid result, or a simple standard error. A *t* test is used to assess whether the means of two groups are statistically significant or not. The *t* test was performed by SAS ver. 8.2[20] to compare the means of two groups. The results of the *t* test are shown in Table IV. As shown in this table, the variances of the two groups are significantly different. When significant difference is observed in the variances of the two groups, Satterthwaite's estimate is performed.[21] Therefore, the *t* value is −8.23 and the significance level of the *t* value is less than 0.0001 where the variances of the two groups are statistically different ($P<0.05$). Based on the results, therefore, the null hypothesis (H_0), the means of the two groups are the same, is rejected. It is shown statistically that annoyance responses between group 1 and group 2 are significantly different. This means that the difference of annoyance responses between group 1 and group 2 is not from standard errors, but from the properties of the

TABLE III. Comparison of measurement data in some field survey sites.

Category	Measurement site	*WECPNL*	*%HA*	Group
C1	Site 3	58.9	33.3	1[a]
	Site 5	59	17.5	2[b]
C2	Site 7	68.5	63.3	1[a]
	Site 10	68	34.8	2[b]
C3	Site 18	81.9	100	1[a]
	Site 19	81.6	76.3	2[b]

Relatively low background noise level group.
Relatively high background noise level group.

TABLE IV. Summary of *t* test about annoyance response to aircraft noise exposure.

	Method	Variances	*d. f.*	*t* value	Pr>|*t*|
	Pooled	Equal	466	−7.99	<0.0001
t test	Satterthwaite	Unequal	458	−8.23	<0.0001
Equality of variance	Method	Num *d. f.*	Den *d. f.*	*F* value	Pr>*F*
	Folded *F*	255	211	1.91	0.0001

groups. The results of the statistical analysis show that there is significant difference in the annoyance responses to the same levels of aircraft noise between areas of high and low background noise levels. In other words, it seems that the annoyance response to a given level of aircraft noise is less in neighborhoods with high background noise than those with low background noise.

Consequently, the increase of background noise levels causes a decrease of subjective responses to aircraft noise under real conditions, which is also reported in many laboratory studies. Therefore, it can be concluded that background noise level is an important factor on community annoyance from aircraft noise exposure not only in the laboratory, but also in the field.

IV. CONCLUSIONS

Several studies have been conducted to investigate the difference of subjective responses to aircraft noise in relations to background noise levels. However, they have been mainly carried out in laboratory situations. Since laboratory situations are not real conditions and a final conclusion about the effects of background noise on the assessment of community noise is still premature under real situations, the results of these effects remain uncertain under real conditions. Therefore, the study of community annoyance caused by civil aircraft noise exposures was carried out in 20 sites around Gimpo and Gimhae international airports to investigate the effects of background noise in terms of dose-effect relationships between aircraft noise levels and annoyance responses under real conditions. To assess the dose responses to aircraft noise, the percentage of respondents who felt highly annoyed ($\%HA$) and WECPNL, the aircraft noise index in Korea, were used in this study.

The result shows that annoyance responses in low background noise regions are much higher than those in high background noise regions, even though aircraft noise levels are the same. The difference in annoyance responses between the two regions occurred up to about 45% due to background noise levels. Therefore, it can be concluded that annoyance responses to intrusive noise, such as aircraft noise, are not independent of background noise levels, and background noise level plays an important role in the estimation of community annoyance from aircraft noise exposure.

ACKNOWLEDGMENTS

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