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Exposure—Response Relationship Between Aircraft Noise and Sleep Quality: A Community-based Cross-sectional Study

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Abstract

Objectives: Exposure to aircraft noise has been shown to have adverse health effects, causing annoyance and affecting the health-related quality of life, sleep, and mental states of those exposed to it. This study aimed to determine sleep quality in participants residing near an airfield and to evaluate the relationship between the levels of aircraft noise and sleep quality.

Methods: Neighboring regions of a military airfield were divided into three groups: a high exposure group, a low exposure group, and a control group. A total of 1082 participants (aged 30–79 years) completed a comprehensive self-administered questionnaire requesting information about demographics, medical history, lifestyle, and the Pittsburgh Sleep Quality Index.

Results: Of the 1082 participants, 1005 qualified for this study. The prevalence of sleep disturbance was 45.5% in the control group, 71.8% in the low exposure group, and 77.1% in the high exposure group (p for trend < 0.001). After adjusting for potential confounding factors, we determined the exposure—response relationship between the degree of aircraft noise and sleep quality. Of the participants with a normal mental status, the prevalence of sleep disturbance was 2.61-fold higher in the low exposure group and 3.52-fold higher in the high exposure group than in the control group.

Conclusion: The relationship between aircraft noise and health should be further evaluated through a large-scale follow-up study.

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1. Introduction

Recent research has shown that aircraft noise is associated with a number of health problems, such as hearing loss, poor self-rated health, a poor quality of life, and an increased risk of cardiovascular disease, hypertension, annoyance, and psychiatric disorders [1–4].

Prolonged exposure to an environmental stressor such as aircraft noise may affect sleep [5]. Exposure to aircraft noise leads to an increased frequency of awakening, decreased slow wave sleep, changes to sleep stage 1, use of sleep drugs or sedatives, and a poor quality of sleep [1]. Poor sleep quality also has secondary effects, such as excessive daytime fatigue, a low capacity for work, and an increased accident rate [5]. Exposure to noise is also associated with negative emotions such as depression, anxiety, and stress [6]. A survey in Japan found that exposure to noise reaching a 95 weighted equivalent continuous perceived noise level (WECPNL) or more is associated with increased depression and perceived psychological disorders [6].

Although several studies have investigated the association between noise and noise-induced sleep disturbance, large-scale epidemiological studies are still insufficient to explain clearly the relationship between exposure to aircraft noise and sleep quality affecting mental disorders. We assessed the relationship between noise levels and sleep quality after adjusting for mental disorders such as depression, anxiety, stress, and other covariates.

2. Materials and methods

2.1. Study location and noise mapping

A community-based cross-sectional survey was carried out to study residents of the Oksumyun, Necho-dong, and Okguup districts, rural areas in the vicinity of Kunsan Airport, Republic of Korea. Kunsan Airport is a large military airport, located on the west coast of Korea and used by United States and Korean air forces. Kunsan Airport carries out regular tactical training during the day (08:00–19:00) and night (19:00–22:00) from Monday to Friday. The maximum number of aircraft per day was 150, with an average of about 40.

Aircraft noise radiated down to rural areas in Kunsan was measured as a maximum sound pressure level by using NL-20 and NL-21 sound meters (Rion Co., Ltd. (Kokubunji, Tokyo, Japan)) according to the national standard specified by the Korea Ministry of Environment [7]. Aircraft noise measurements were recorded for 7 days (from June 23, 2009 to July 1, 2009) at four different locations representing the most severely noise-influenced regions of Kunsan City; these locations did not have any obstacles to the radiation of aircraft noise. After the noise measurements, we calculated the maximum noise intensity (\overline{L}_A), i.e., the mean energy of all peak levels of any one day, and the \overline{WECPNL} , which is an international index of the

daily level of aircraft noise, using the following equations and the noise measurement data:

$$\overline{L}_A = 10 \log \left[1/N \left(\sum_{i=1}^N 10^{0.1L_i} \right) \right] \text{ dB(A)} \quad (1)$$

$$\overline{WECPNL} = \overline{L}_A + 10 \log N - 27 \quad (2)$$

where N = number of measurements of daily aircraft noise; L_i = peak level of i th aircraft crossing. $N = N_2 + 3N_3 + 10(N_1 + N_4)$, where N_1 is the number of aircraft between 00:00 AM and 07:00 AM, N_2 is the number of aircraft between 07:00 AM and 07:00 PM, N_3 is the number of aircraft between 07:00 PM and 10:00 PM, and N_4 is the number of aircraft between 10:00 PM and 12:00 PM.

To investigate the influence of aircraft noise on the entire region of Kunsan City, we created a noise map using the Integrated Noise Model (INM), which was developed by the Federal Aviation Agency and is now being considered as a worldwide standard tool for mapping aircraft noise in most countries [8]. The noise simulation was created using the INM code with input data of aircraft specifications, flight patterns, flight paths, average number of aircraft passages, and geological information for the Kunsan area. The noise map of the Kunsan area is shown in Figure 1 with iso-WECPNL contours. The noise map predicted through the INM simulation was compared with the measurement data and its prediction accuracy was verified within a few per cent relative error in WECPNL.

Using the noise map, the regions neighboring Kunsan airfield were divided into three groups: a high exposure

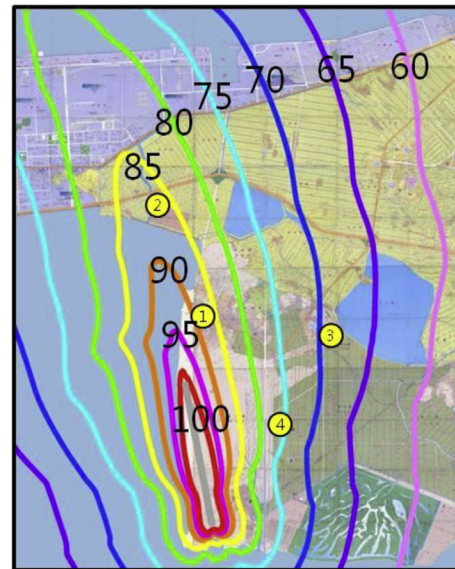


Figure 1. Aircraft noise mapping in the vicinity of Kunsan Airport. The noise simulation was made by the INM code with the input data of aircraft specifications, flight patterns, flight paths, averaged number of aircraft passage and geological information of the Kunsan area. 1, 2, 3 and 4 indicate the four different locations which represent the most severely noise-influenced regions of the Kunsan city.

group (HEG, >80 WECPNL), a low exposure group (LEG, 60–80 WECPNL), and a control group (CTL, <60 WECPNL).

2.2. Study population

Of a total of 4788 male and female residents aged 20–79 years, 2116 potential participants (1075 high exposure, 750 low exposure, and 291 controls) were selected using stratified random sampling. All the potential participants selected were initially contacted by a letter describing the purpose, participation, and support related to the study. Finally, 1082 volunteers participated in a comprehensive health examination and on-site interviews from August 4, 2009 to August 22, 2009. All participants completed interviewer-based questionnaires requesting information on demographics, medical history, the Pittsburgh Sleep Quality Index (PSQI) [9], and the Depression Anxiety Stress Scale (DASS) [10]. Of the 1082 participants, 55 participants aged in their 20s and 80s were excluded due to a small sample size. After excluding an additional 22 participants who did not have PSQI information, 1005 participants were included in the study. Written informed consent was obtained from all participants. The study protocol was approved by the Ajou University Medical Center Ethical Committee, Suwon, Korea.

2.3. Subjective sleep quality

Sleep quality in the past month was assessed with the PSQI, which is a self-administered questionnaire comprising seven components, such as subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleeping drugs, and daytime dysfunction. Each component is given a score from 0 to 3 and the sum of all items produces a global PSQI score between 0 and 21 [9]. We used a global PSQI score ≥ 6 as the definition of sleep disturbance because the test has 98.7% sensitivity and 84.4% specificity with this criterion [11].

2.4. Mental disorders

We used the DASS to measure depression, anxiety, and stress. DASS-Depression is characterized by low positive affects, loss of self-esteem and incentive, and a sense of hopelessness (absence of positive affect). DASS-Anxiety is characterized by autonomic arousal and fearfulness (psychological hyperarousal). DASS-Stress is characterized by persistent tension, irritability, and a low threshold for becoming upset or frustrated (negative affects). DASS has been primarily applied to nonclinical participants, which has provided strong support for the internal consistency and convergent and divergent validity of its three scales [10]. Each DASS category contains 14 items. Participants use four-point severity scales to rate the extent to which they have experienced each state over the past week. Scores for each DASS category are calculated by summing the scores for the relevant items.

2.5. Statistical analysis

Mean differences in age, years of residence, DASS score, and PSQI global score were tested according to the noise level using analysis of variance. The comparison of sex, occupational class, current smoking status, and doctor-diagnosed chronic disease with noise level was tested using a Chi-square test. To evaluate the impact of aircraft noise on sleep disturbance, multiple logistic regressions were conducted. All p values are two-tailed, with $p < 0.05$ considered to be statistically significant. All statistical analyses were conducted using PASW Statistics 17.0 (SPSS Korea DataSolution, Chicago, IL, USA).

3. Results

Table 1 gives the general characteristics of the participants. The mean age of the CTL group was significantly higher than the other groups. There was no significant difference in sex by group. The proportion of

Table 1. General characteristics of the study participants

	CTL ($n = 134$)	LEG ($n = 517$)	HEG ($n = 354$)	p or p for trend*
Age (y)	65.0 \pm 10.1	61.9 \pm 12.1	59.7 \pm 12.5	<0.001
Male sex	44.8	40.2	43.2	0.522
Residence time (y)	48.1 \pm 18.4	45.3 \pm 18.5	42.7 \pm 18.9	0.011
Participants with doctor-diagnosed chronic disease ^a	40.3	38.5	29.9	0.008*
Participants with doctor-diagnosed mental disease ^b	1.5	1.9	1.7	0.929
DASS score				
Depression	8.7 \pm 8.3	10.6 \pm 9.4	12.1 \pm 9.9	0.001
Anxiety	7.6 \pm 7.0	9.8 \pm 8.5	11.6 \pm 9.1	<0.001
Stress	9.5 \pm 8.8	11.8 \pm 9.5	14.1 \pm 9.9	<0.001
Global PSQI score	5.8 \pm 2.8	7.6 \pm 3.1	8.1 \pm 3.2	<0.001

^aHypertension, hyperlipidemia, stroke, myocardial infarction, angina pectoris, arrhythmia, heart failure, or diabetes mellitus; ^bDepression, nervousness, neurosis, insomnia, or schizophrenia. Data are presented as mean \pm SD or %. CTL = control group; DASS = Depression Anxiety Stress Scale; HEG = high exposure group; LEG = low exposure group; PSQI = Pittsburgh Sleep Quality Index.

Table 2. Prevalence of sleep disturbance and mean score on Pittsburgh Sleep Quality Index subscale according to noise level

	CTL (<i>n</i> = 134)	LEG (<i>n</i> = 517)	HEG (<i>n</i> = 354)	<i>p</i> or <i>p</i> for trend*
PSQI diagnosis				
Normal	73 (54.5)	146 (28.2)	81 (22.9)	<0.001*
Sleep disturbance	61 (45.5)	371 (71.8)	273 (77.1)	
PSQI subscale				
Sleep quality	1.20 ± 0.67	1.62 ± 0.71	1.72 ± 0.70	<0.001*
Sleep latency	1.31 ± 0.57	1.36 ± 0.61	1.41 ± 0.64	0.230
Sleep duration	0.69 ± 0.98	1.03 ± 1.04	1.06 ± 1.03	<0.001*
Sleep efficiency	0.40 ± 0.79	0.52 ± 0.90	0.66 ± 1.00	<0.01*
Sleep disturbance	1.37 ± 0.57	1.61 ± 0.67	1.69 ± 0.69	<0.001*
Use of sleeping medication	0.10 ± 0.40	0.31 ± 0.79	0.29 ± 0.76	0.011
Daytime dysfunction	0.73 ± 0.89	1.15 ± 1.04	1.22 ± 1.04	<0.001*

Data are presented as *n* (%) or mean ± SD. CTL = control group; HEG = high exposure group; LEG = low exposure group; PSQI = Pittsburgh Sleep Quality Index.

manual workers in the CTL group was significantly higher than in the other groups. The years of residence of the CTL group was slightly longer than the other groups. The percentage of patients with doctor-diagnosed chronic disease was low in the HEG and it appeared to increase with the decrease in noise levels (*p* for trend = 0.008). All the DASS scores and PSQI global scores were increased in the order of noise level with statistical significance.

The prevalence of sleep disturbance was high in the order of noise level (*p* for trend < 0.001). The mean scores of the PSQI subscale were high, increasing with the level of noise, except in the case of sleep latency and use of sleeping drugs (Table 2). Participants with sleep disturbance had a higher global score of depression, anxiety, and stress than those of normal participants across all levels of noise (*p* < 0.01; Table 3).

The odds ratios of the LEG and HEG on sleep disturbance compared with the CTL in the normal and abnormal groups (depression, anxiety, or stress) in mental health are given in Table 4. In the normal group, the LEG and HEG had a 2.61 and 3.52 increase in odds ratio compared with the CTL group after adjusting for covariates. The LEG had a 5.71 higher risk of sleep disturbance compared with

the CTL group in participants with mental health problems, whereas the HEG was not significant. The odds ratios of general characteristics such as age and sex were not significant in all models (Table 4).

4. Discussion

This study identifies three key findings. Firstly, the prevalence of sleep disturbance significantly differed according to the noise level (*p* for trend < 0.001). Secondly, participants with mental disorders had a higher prevalence of sleep disturbance (*p* < 0.001). Finally, after adjustment of covariates, exposure–response relationships between noise level and sleep disturbance were observed in participants without mental health problems.

In this community-based cross-sectional study, we observed that exposure to noise was positively associated with sleep disturbance and the exposure–response relationship was determined after controlling for depression, anxiety, and stress.

Over the past 30 years, several workers have studied the relationship between noise and sleep. These studies indicate that, although aircraft noise is possibly

Table 3. Relationship between sleep quality and Depression Anxiety Stress Scale according to the noise level

	CTL (<i>n</i> = 134)		LEG (<i>n</i> = 489)		HEG (<i>n</i> = 346)	
	Normal (<i>n</i> = 72)	Sleep disturbance (<i>n</i> = 58)	Normal (<i>n</i> = 140)	Sleep disturbance (<i>n</i> = 349)	Normal (<i>n</i> = 78)	Sleep disturbance (<i>n</i> = 268)
Depression	6.6 ± 7.1 10 (13.9)	11.2 ± 9.0** 17 (29.3)*	6.5 ± 7.3 15 (10.7)	12.3 ± 9.6** 118 (33.8)***	7.8 ± 7.5 13 (16.7)	13.3 ± 10.1** 103 (38.4)***
Anxiety	5.4 ± 5.7 1 (1.4)	10.4 ± 7.6** 6 (10.3)*	5.1 ± 5.7 4 (2.9)	11.7 ± 8.3** 59 (16.9)***	7.7 ± 7.3 8 (10.3)	12.7 ± 9.2** 56 (20.9)*
Stress	7.6 ± 8.0 1 (1.4)	11.9 ± 9.2** 5 (8.6)	7.0 ± 7.3 4 (2.9)	13.7 ± 9.6** 45 (12.9)**	9.8 ± 7.9 5 (6.4)	15.4 ± 10.1** 48 (17.9)*

Data are presented as *n* (%) or mean ± SD. **p* < 0.05. ***p* < 0.01. ****p* < 0.001. CTL = control group; DASS = Depression Anxiety Stress Scale; HEG = high exposure group; LEG = low exposure group.

Table 4. Odds ratios of sleep disturbance according to related factors

	Mental health			
	Normal		Abnormal	
	Age- and sex-adjusted OR (95% CI) (<i>n</i> = 672)	Fully adjusted OR (95% CI) (<i>n</i> = 595)	Age- and sex-adjusted OR (95% CI) (<i>n</i> = 293)	Fully adjusted OR (95% CI) (<i>n</i> = 243)
Noise exposure (reference control)				
Low	2.74 (1.74–4.32)	2.61 (1.58–4.32)	4.18 (1.62–10.78)	5.71 (1.66–19.67)
High	3.89 (2.36–6.41)	3.52 (2.03–6.10)	3.26 (1.26–8.41)	3.31 (0.99–11.10)
Age	0.99 (0.98–1.01)	0.99 (0.96–1.01)	0.97 (0.94–1.01)	1.02 (0.96–1.07)
Sex (reference male)	0.89 (0.64–1.22)	1.10 (0.68–1.78)	0.84 (0.42–1.68)	0.77 (0.25–2.40)
Marital status (reference single)				
Married		1.57 (0.68–3.67)		NA
Separated, divorced, bereaved		2.32 (0.88–6.11)		NA
Educational level (reference ≤11 y)				
≥12 y		1.08 (0.70–1.66)		1.62 (0.39–6.80)
Occupational class (reference manual)				
Non-manual		0.55 (0.30–1.02)		4.46 (0.49–40.93)
Other		1.08 (0.70–1.66)		0.82 (0.35–1.92)
Annual household income (reference <\$20,000)				
≥\$20,000		1.20 (0.74–1.93)		1.81 (0.34–9.67)
Residence time (y)		0.99 (0.98–1.01)		0.98 (0.95–1.01)
Body mass index		0.97 (0.92–1.03)		0.92 (0.82–1.04)
Current smoking (reference “no”)		0.84 (0.50–1.41)		1.44 (0.40–5.23)
Current alcohol drinking (reference “no”)		1.11 (0.75–1.64)		0.41 (0.17–0.99)
Regular exercise (reference “no”)		1.07 (0.75–1.52)		2.18 (0.92–5.15)
Doctor-diagnosed chronic disease ^a (reference “no”)		0.99 (0.68–1.45)		1.08 (0.44–2.66)
Doctor-diagnosed mental disease ^b (reference “no”)		1.26 (0.11–15.01)		1.63 (0.17–15.82)

^aHypertension, hyperlipidemia, stroke, myocardial infarction, angina pectoris, arrhythmia, heart failure, or diabetes mellitus; ^bDepression, nervousness, neurosis, insomnia, or schizophrenia. CI = confidence interval; NA = not applicable; OR = odds ratio.

associated with sleep loss and an increased frequency of waking, further evidence outlining a clear exposure–response relationship is required to associate aircraft noise with a reduced quality of sleep and electroencephalography (EEG) changes [5,12,13]. It has previously been established that increased noise exposure leads to sleep disturbance [14–16]. This study, which was conducted with Korean adults, also showed that aircraft noise interfered with sleep, including sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleeping drugs, and daytime dysfunction as subscales, with an obvious exposure–response relationship by noise level (*p* for trend < 0.001).

Although there have been many studies on the association between environmental noise and mental health, the results have so far been inconsistent [2,4,6,17]. Among 6000 people living near Heathrow Airport (London, England), those living in higher noise areas were found to have a higher prevalence of depression than those living in average noise areas [4]. An

exposure–response relationship was found between exposure to higher levels of military aircraft noise around Kadana Airport in Japan and depressiveness and nervousness [6]. Road traffic was not associated with mental health symptoms after adjusting for socio-demographic factors in a longitudinal analysis [17].

Our data show a positive association between the prevalence of depression disorder, anxiety disorder, and stress disorder, which increased with the level of noise. The prevalence of depression disorder in the CTL group, LEG, and HEG was 5.2%, 47.0%, and 47.8% (*p* for trend < 0.001), respectively. The prevalence of anxiety disorder in the CTL group, LEG, and HEG was 20.8%, 27.2%, and 33.5% (*p* for trend < 0.01), respectively. The prevalence of stress disorder in the CTL group, LEG, and HEG was 4.6%, 10.0%, and 15.3% (*p* for trend < 0.001), respectively (data not shown).

In many clinical and community settings, mental disorders accompany sleep disturbances [18,19]. Japanese women with depression have a 1.2-fold higher chance of

developing insomnia [19]. In a community-based cross-sectional study involving 33,051 men aged 67 years and older, depressed men had a 3.7-fold higher risk of poor sleep quality [20]. Therefore these results suggest that mental disorders should be considered as a controlling factor in studies evaluating sleep. This has been reported in previous studies and it is also treated as an important issue in this study, as follows. (1) Aircraft noise affects sleep disorders. Noise as a biological stressor can influence both the sympathetic nervous system and the autonomic nervous system, including the hypothalamus-pituitary-adrenal axis and the adrenal medulla of the neuroendocrine system; as a result, stress hormones such as adrenaline, noradrenaline, and cortisol are released [14,21,22]. (2) Aircraft noise affects mental disorders such as depression, anxiety, and stress. Chronic exposure to noise can influence central autonomic arousal, resulting in an increased psychiatric syndrome such as depression, anxiety, and stress [2]. (3) Socio-economic factors, health-related factors, and health behavioral factors may mediate sleep disorders. (4) Poor sleep quality and depression are linked. As the results of studies on sleep in depression using polysomnographic recordings have shown, sleep disturbance produces decreased sleep efficiency, decreased slow-wave sleep, reduced rapid eye movement latency, and increased rapid eye movement intensity. In addition to the direct relationship between sleep disturbance and depression, disturbed sleep is associated with alterations in glucose metabolism and may represent a risk factor for the development of obesity. Sleep architecture is also influenced by sex and age [23]. As a result, mental disorders and socio-economic factors may need to be well controlled to be able to assess the independent effect that aircraft noise has on sleep disorders. This study cannot provide an accurate cause-and-effect relationship as it is not a prospective cohort study.

Previous studies on the association between noise and sleep disturbance did not consider pre-existing mental disorders, whereas we analyzed groups with or without a mental health problem (depression, anxiety, or stress) to identify the independent effect of noise on sleep disturbance. A remarkably strong association between the degree of noise and sleep disturbance was observed.

Our study has several limitations. Firstly, we cannot exclude the possibility of the misclassification of exposure. However, areas not affected by noise other than aircraft noise (ambient background noise, traffic noise, rail noise) were selected for measuring noise. In other words, areas where other noise is at least 20 dB lower than aircraft noise and can thus be ignored were chosen for measurements. In addition, when processing the noise measurement results, data affected by unexpected traffic noise or night-time noise were excluded and only pure aircraft noise was assessed. Furthermore, to take into consideration the effect of the night when assessing the WECPNL for this study, the WECPNL for night-time aircraft noise was calculated with about three

times the weight compared with daytime noise. By comparing the difference between the noise levels predicted using the noise map and the actual noise levels measured, the research team confirmed that the results were highly reliable with a difference of 3.6 dB or less. Additionally, Kunsan, the test area for this study, is an agricultural region located near narrow farm roads rather than roads for cars. There is a low possibility of exposure misclassification, because Korea's agricultural towns show hardly any activity after 07:00 PM. Secondly, previous studies on the effects of noise on sleep have measured brain activity and sleep quality using objective measures of sleep assessment, such as EEG or polysomnography [24]. However, due to constraints of time and cost in using an objective method to conduct an epidemiological study of a population group, most researchers have chosen the subjective method [14,15,25]. In terms of the prevalence of sleep disturbance, the CTL group is assessed to be high (45.5%) and both the LEG (71.8%) and the HEG (77.8%) very high. Ohayon and Hong [26] reported that the prevalence of subjective insomnia occurring at least three times a week in an average Korean is 17.0%. Such a discrepancy between these two figures may be attributed mainly to the difference in the research method (face-to-face interview and telephone interview) and survey tools (PSQI and Sleep-EVAL) used in the two studies. In a recent study, subjective sleep disturbance was assessed using the question "How much have you been disturbed in your sleep by railway noise (or road traffic noise) at night when you are sleeping in your house over the last 12 months?" On a scale of 0 to 10, those who answered 8 or higher were defined as a highly sleep-disturbed population and those who answered 6 or higher were considered to be a sleep-disturbed population. As a result, exposures to 60 dB and 80 dB of railway noise resulted in a sleep-disturbed prevalence of about 40% and 90%, respectively. Those exposed to road traffic noise showed a lower prevalence than those exposed to railway noise [27]. Such large differences in the prevalence in each study can be explained by the difference in the research methods, including the survey tools. Thirdly, noise sensitivity, noise annoyance, and coffee consumption are variables related to sleep, but they have not been surveyed. In the previous research, a high noise sensitivity score was related to a high level of noise annoyance [28] and there was a positive association between noise sensitivity and self-reported mental health [29].

Given that all participants in this study were volunteers, there is a possibility that the participants in the experimental group are those who are highly stressed in daily life, particularly due to aircraft noise, or who have health issues including sleep disturbance. In addition, even though trained investigators tried to obtain truthful answers from the participants during the course of this study, it is possible that, due to psychological effects,

participants in the experimental group who did not actually have sleep disturbances or health issues responded that they did have such problems. As a result, we cannot rule out the possibility that there was an overestimation of the prevalence of sleep disturbance or of mental disorders in the experimental group compared with the control group not exposed to aircraft noise. Finally, we did not measure the levels of noise inside dwellings, the types of windows in the dwelling, the bedroom window position, nor window opening behaviors, which may be noise exposure moderators. A total of 96% of participants were living in houses and Korea's houses and installations in rural areas are similar. As there is a sufficient number of participants, it is assumed that the opening and closing of windows will not have a significant effect on the study results as the participants would have opened and closed their windows a relatively equivalent number of times.

Conflicts of interest

None to declare.

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