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Exposure-response relationship of wind turbine noise with self-reported symptoms of sleep and health problems: A nationwide socioacoustic survey in Japan

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Abstract

The association of wind turbine noise (WTN) with sleep and physical/mental health has not been fully investigated. To investigate the relationship of WTN with the prevalence of self-reported symptoms of sleep and health problems, a socioacoustic survey of 1079 adult residents was conducted throughout Japan (2010-2012): 747 in 34 areas surrounding wind turbine plants and 332 in 16 control areas. During face-to-face interviews, the respondents were not informed of the purpose of the survey. Questions on symptoms such as sleeplessness and physical/mental complaints were asked without specifying reasons. Insomnia was defined as having one or any combination of the following that occurs three or more times a week and bothers a respondent: Difficulty initiating sleep, difficulty maintaining sleep, premature morning awakening, and feeling of light overnight sleep. Poor health was defined as having high scores for health complaints, as determined using the Total Health Index, exceeding the criteria proposed by the authors of the index. The noise descriptor for WTN was $L_{Aeq,n}$ outdoor, estimated from the results of actual measurement at some locations in each site. Multiple logistic analysis was applied to the $L_{Aeq,n}$ and insomnia or poor health. The odds ratio (OR) of insomnia was significantly higher when the noise exposure level exceeded 40 dB, whereas the self-reported sensitivity to noise and visual annoyance with wind turbines were also independently associated with insomnia. OR of poor health was not significant for noise exposure, but significant for noise sensitivity and visual annoyance. The above two moderators appear to indicate the features of respondents who are sensitive to stimuli or changes in their homeostasis.

Keywords: Field survey, insomnia, moderator, self-reported symptoms, wind turbine noise

Introduction

The possible adverse effects of wind turbine noise (WTN) on human health have been argued for a decade.[1,2] The relationship between WTN and sleep, however, has not been fully investigated. Previous studies on the relationship had the limitations on the evaluation of noise exposure and the definition of sleeplessness.[3] There are a few studies on the possible effects of WTN on physical/mental health other than sleep, and no conclusive evidence has been found.[2] We investigated the possible WTN impact on human health, and examined the association of WTN with self-reported symptoms related to sleep, physical health, and mental health in a field survey. The aim of this study was to clarify the exposure-response relationships between WTN and these self-reported symptoms, taking nonacoustic variables into account.

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Methods

Methodological review

Many previous studies focused on WTN-induced annoyance and showed positive relationships between outdoor sound levels and prevalence rate of annoyance with WTN.[4-10] The relationships seem to be modified by nonacoustic variables such as visual annoyance with wind turbines.[4,5,11,12] In the previous studies, however, WTN was not directly measured at residents' houses. Rather, their exposure to WTN was assessed on the basis of distance from the nearest wind turbine to their houses or using mathematical models to estimate the outdoor level of WTN.

WTN seems to increase the risk of self-reported sleep disturbance[2] as shown by the positive correlations between WTN and WTN-induced sleep disturbance in previous reports.[4,10,13] However, only a few researchers assessed sleep disturbance apart from WTN.[8] In general, sleep disturbance is caused by multiple factors, and it is sometimes difficult for an individual to specify the reason for his/her sleeplessness. It is possible that some factors before noise exposure mainly disturb sleep, and the noise is only a trigger of waking or an event perceived after waking.[14,15] In questionnaire surveys, questions about WTN-induced annoyance before questions about WTN-induced sleep disturbance may affect the subsequent responses to questions on sleeplessness.[6] To examine the possible effects of WTN on sleep, therefore, we should define insomnia symptoms regardless of the reason for sleeplessness and conceal the purpose of the survey.

Furthermore, the definition of sleeplessness in the above-mentioned studies often did not specify frequency or included infrequent sleeplessness, e.g., once a month. It is important for researchers to specify the frequency and aftereffects of sleeplessness.[16,17] Taking account of the above problems, sleeplessness should be defined on the basis of the international criterion for mental disorders including sleep disorders.[16,17] It should be noted that insomnia or sleep disorders in this criterion are defined as the sleep disturbance accompanied with significant distress or impairment in social, occupational, educational, academic, behavioral, or other important areas of functioning. To assess the above situation, at least, a question such as "Do you have any trouble with your sleep?" is required in questionnaire surveys.

As for the possible effects of WTN on physical/mental health other than sleep, only a few reports are available.[8,10,13] Moreover, journalistic reports on these effects often lack scientific evidence and medical explanation.[1] Since the effect of environmental noise on physical/mental health is usually mild[18] and it seems difficult to find evidence supporting the idea that WTN causes any diseases, we should systematically examine subclinical, self-reported symptoms among many residents before we conduct medical examinations, which are costly, to find the effects of WTN on health.

Taking the above situations into consideration, some intensive studies to evaluate the WTN impact on human health have been conducted in Japan.[19-24] Following these studies, we conducted a field survey to examine the association of WTN with self-reported symptoms related to sleep, physical health, and mental health.

Participants

Our survey was conducted in 34 sites near wind turbines (WT sites) and in 16 control sites, which have similar characteristics to the WT sites but without wind turbines (control sites). All the 50 sites were located in rural areas. Following the distribution of letters to ask almost all the households to cooperate with our study on the environment in the area where they live, trained interviewers visited each household to ask an adult aged 18 or above per household to participate in a face-to-face structured interview. In the WT sites, 747 adults participated (response rate, 49%), and 332 did in the control sites (response rate, 45%). Of these 1079 respondents, 387 (52%) in the WT sites and 203 (61%) in the control sites were females. Almost 80% of them were in their fifties or older in both sites. About 85% in both sites had been living for more than 10 years at the same places. About 25% were engaged in agriculture, fishery or forestry while about 40% had no job or were homemakers. No significant difference was observed in the above variables between the two sites except sex (Fisher's exact probability method, $P < 0.05$).

Noise measurement

The noise was measured in this study as follows: WTN exposures of the respondents' houses were estimated from the results of field measurements performed in the WTN sites during the same period in the social survey. The rated generation powers of the wind turbines under investigation were from 400 to 3000 kW; however, most were mainly more than 1500 kW. At each wind turbine site, seven measurement locations were uniformly distributed within a distance of about 100 m to 1 km from the nearest wind turbine, and an additional measurement point (reference point) was located near a wind turbine to observe the operation condition of a wind farm.

Because the effect of WTN on residents was particularly serious at night,[24] we chose the following noise descriptors. The time-averaged A-weighted sound pressure level of WTN under a rated operation condition from 22:00 to 6:00 ($L_{Aeq,n}$) was calculated as the energy mean of the time-averaged A-weighted sound pressure level over 10 min of each hour for five successive days. We carefully excluded the effects of other noise such as road traffic noise, on the basis of recordings. From the relationship between the distance from a wind turbine and $L_{Aeq,n}$ at the above measurement locations, distance-$L_{Aeq,n}$ curve was obtained for each site. On the basis of the curve, the noise exposure of each house was estimated. As for the environmental noise at the control sites, the 95 percentile A-weighted sound pressure level during nighttime ($L_{A95,n}$) was measured to assess the residual noise without any other specific noise such as intermittent road traffic noise.

Questionnaire

For the structured interview, the administered questionnaires were developed. In addition, to the questionnaire proposed by the Institute of Noise Control Engineering/Japan,[25] questions concerning sleep, mental/physical health, and the environment were asked as follows.

Insomnia was defined on the basis of the literature[16,17,26] [Appendix]. We asked a respondent whether he/she has any trouble with sleeping and if so, the frequency of difficulty initiating sleep (DIS), difficulty maintaining sleep (DMS), premature morning awakening (PMA), and a feeling of light overnight sleep (LOS). If the respondent had DIS, for example, which occurs three or more times a week, and complained of sleepiness which occurs three or more times a week, he/she was defined as having DIS. DMS, PMA, and LOS in respondents were defined similarly. Insomnia was defined as having one or any combination of these four conditions, regardless of the cause of sleeplessness. The respondents were then asked the reason for their sleep problems.

Physical/mental health was assessed on the basis of 54 self-reported symptoms concerning "respiration" (R), "eyes and skin" (E), "digestion" (D), "irregularity of life" (L), and "mental instability" (M), which were extracted from the Total Health Index (THI) developed by Suzuki *et al*.[27] Each symptom was scored 1-3 points, and summed up for the above five item groups to obtain five sub-scores; the more the complaints, the higher the sub-scores. Although these subscales were named by the authors of THI, it should be noted that the questions for the L scale do not represent irregular life itself but refer to the symptoms that suggest disorders of the circadian rhythm. The reliability and validity of the subscales were confirmed by the authors of THI. In this study, if an individual showed a higher score for the subscale R, for example, than the criteria proposed by the authors of THI, the individual was categorized into the high-R score-group. According to Suzuki *et al*.,[27] middle-aged women who complained of "WTN-induced health effects" exhibited significantly high scores for the above five subscales in THI, compared with the general population. If their complaints truly reflect the adverse effects of WTN on health, the above subscales in THI can be sensitive indicators of these effects.

Self-reported sensitivity to noise (sensitive vs. nonsensitive) was also one of the items in the questionnaire [Appendix]. Many researchers have argued about the moderating effects of noise sensitivity on the relationships between environmental noise and noise-induced annoyance since the 1970s,[28] and results similar to the above have also been reported for WTN.[1,5,11]

In addition to the above questions, some additional questions concerning wind turbines were asked only in the WT sites: Interest in environmental problems (present vs. absent), attitude to wind turbine power generation (positive vs. negative), benefits from wind turbine power generation (present vs. absent), and visual annoyance with wind turbines (present vs. absent). Some researchers suggest that these variables can moderate the effects of WTN on health.[1,11]

Data analysis

Noise exposure levels ($L_{Aeq,n}$ or $L_{A95,n}$) were categorized at 5 dB intervals. Bivariate analysis was performed using Fisher's exact probability method and the Mantel-Haenszel Chi-square (Chi^2_{MH}) test. Multiple logistic analysis[29] was performed to examine the association of independent variables such as noise exposure with insomnia and THI scores, e.g., high-R score. An odds ratio (OR) significantly higher or lower than 1 indicates a significant association of an independent variable with a dependent variable. For WT sites data, further forward stepwise logistic analyses were performed to examine the association of insomnia or THI scores with the variables concerning wind turbines, although noise exposure level was always a forced-entry variable in the logistic regression analysis models.

Results

Most of the estimated noise exposure levels of the respondents were 36-40 dB in the WT sites, whereas those of the respondents in the control sites were 35 dB or below. The difference in the noise exposure level between the two sites was statistically significant (Mann-Whitney U-test, $P < 0.001$).

Thirteen of the respondents (1.2%) were classified as insomniacs. The prevalence rate in the WT sites tended

Appendix

Questions concerning sleeplessness in the present survey were as follows:

1. Do you have any trouble with your sleep?
   1. Yes, 2. No

If you answered "yes" to the above question, please choose appropriate numbers for each item.

1 = more than 3 times a week: 2 = once or twice a week: 3 = occasionally

Item	1	2	3
Difficult to fall asleep			
When awakened during the night, it is difficult to sleep again			
Awakened early in the morning			
Do not feel as having slept well the next morning			
Sleepy during daytime and cannot work well			
Others			

to be higher than that in the control sites (1.5% vs. 0.6%), although not significant (Fisher's exact probability method, $P = 0.06$). In the WT sites, 82% of insomniac respondents attributed their sleeplessness to WTN. As shown in Table 1, the prevalence rates of insomnia, DSI, DMS, and LOS were particularly high when the noise exposure level exceeded 40 dB. This was confirmed by logistic regression analysis [Figure 1], in which the categories for the noise exposure levels of 35 dB and below were combined because insomnia cases were very infrequent. Compared with the reference category (noise exposure levels of 35 dB and below), the sex-age-adjusted ORs of insomnia were 5.55 for 41-45 dB, which is significantly higher than 1, and 4.79 for noise exposure levels above 45 dB. However, OR for sex or age was not significantly higher or lower than 1. Similarly, occupation did not correlate with insomnia.

As for the houses of respondents, 75% were detached, more than 90% were wooden, and more than 90% had single-glazing or pair glass windows. When these variables were added to the multiple logistic regression models as shown in Figure 1, they did not show significant association with insomnia.

Regarding nonacoustic variables, among the respondents in the WT sites, 61.4% showed interest in environmental problems, 7.3% exhibited a negative attitude toward wind turbine power generation, 15.8% obtained benefits from wind turbine generation, 10.5% were visually annoyed with the wind turbines, and 27.1% perceived themselves as being sensitive to noise. Among these nonacoustic variables, only visual annoyance positively correlated with $L_{Aeq,n}$ categories ($Chi^2_{MH} = 4.8$, $P < 0.05$). As shown in Table 2, insomnia was significantly prevalent among those who were interested in environmental problems, those who felt visually annoyed with the wind turbines, and also those who reported themselves sensitive to noise, compared with in the rest of the respondents. Attitude to wind turbine power generation and benefits from wind turbine generation, however, did not correlate with the prevalence rate of insomnia. Among the above three variables that correlated with insomnia, only noise sensitivity modified the relationship between noise exposure level and insomnia [Figure 2]. The relationship was positive in the noise sensitive group, but not in the nonnoise sensitive group; namely, most of the insomniac respondents were found in the sensitive group.

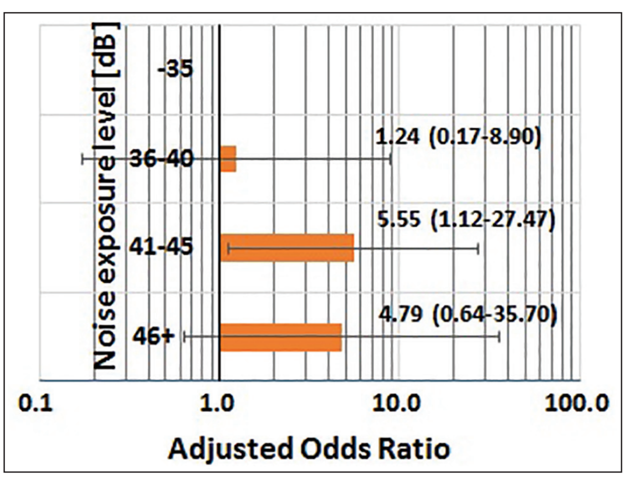

Figure 1: Odds ratio (95% confidential intervals) of insomnia for noise exposure categories. Odds ratio was calculated in reference to noise exposure levels 35 dB and below, adjusted for age and sex

The final analysis of insomnia in the WT sites was conducted by stepwise multiple logistic regression analysis [Figure 3], where the categories for noise exposure levels below 40 dB were combined because the prevalence rates of insomnia at these levels were very low, as shown above. Compared with the reference category (noise exposure levels of 40 dB and below), the adjusted ORs of insomnia were 7.93 for 41-45 dB, which is significantly higher than 1, and 6.61 for 46 dB and above (the trend was significant, $P < 0.01$). The adjusted ORs were 4.17 for those visually annoyed by the wind turbines and 24.44 for those who reported themselves as sensitive to noise, both of which were significantly higher than 1.

Table 1: Prevalence rate (%) of insomnia by noise exposure level categories

$L_{Aeq,n}$ or $L_{A95,n}$ (dB)	*n*	Insomnia	DIS	DMS	PMA	LOS
–30	156	0.7	0.0	0.0	0.7	0.0
31-35	249	0.5	0.5	0.5	0.0	0.5
36-40	329	0.7	0.4	0.7	0.4	0.7
41-45	261	3.1	2.2	3.1	1.3	2.6
46+	84	2.7	2.7	1.4	2.7	2.7
Chi^2_{MH}	1079	5.3*	6.9**	6.0*	3.7	6.3**

*$P < 0.05$, **$P < 0.01$, DIS = Difficulty initiating sleep, DMS = Difficulty maintaining sleep, PMA = Premature morning awakening, LOS = Light overnight sleep, Chi^2_{MH} = Mantel-Haenszel Chi-square

Table 2: Prevalence of insomnia and nonacoustical variables in wind turbines sites

Variables	Category	Insomnia	DIS	DMS	PMA	LOS
Interest in environmental issues	Absent	0.4	0.4	0.4	0.4	0.4
	Present	2.6	1.6	2.1	1.0	2.1
	Difference	**	NS	*	NS	*
Attitude to wind turbine generation	Positive	1.0	0.7	1.0	0.5	0.8
	Negative	2.1	0.0	2.1	0.0	2.1
	Difference	NS	NS	NS	NS	NS
Benefit from wind turbine generation	Present	1.0	1.0	1.0	1.0	1.0
	Absent	1.6	1.1	1.5	0.7	1.5
	Difference	NS	NS	NS	NS	NS
Visual annoyance	Absent	0.9	0.8	0.8	0.6	0.8
	Present	6.4	3.9	6.4	2.6	6.4
	Difference	**	*	**	NS	**
Sensitivity to noise	Absent	0.3	0.0	0.1	0.1	0.0
	Present	4.1	3.3	3.7	2.2	4.1
	Difference	***	***	***	***	***

Fisher's exact probability method, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, NS = Not significant, WT = Wind turbines, DIS = Difficulty initiating sleep, DMS = Difficulty maintaining sleep, PMA = Premature morning awakening, LOS = Light overnight sleep

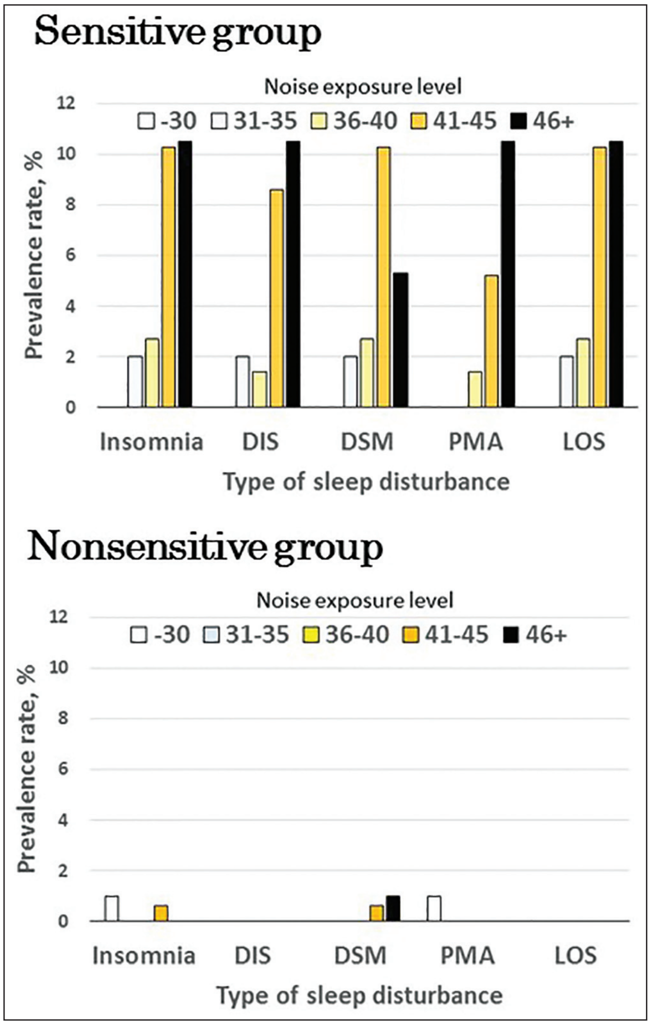

Figure 2: Modification of noise sensitivity with respect to relationships between wind turbine noise and sleep disturbance

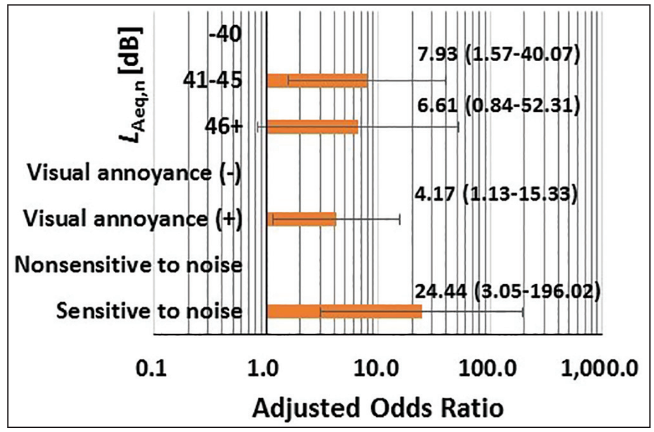

Figure 3: Stepwise logistic regression analysis of insomnia in WT sites odds ratios (95% confidential interval) of insomnia adjusted for other variables. $L_{Aeq,n}$ values for 40 dB and below, absence of visual annoyance with wind turbines, and nonsensitive to noise are reference categories

Table 3: Prevalence rate of high score group for Total Health Index by noise exposure category

Noise exposure (dB)	High-R (%)	High-E (%)	High-D (%)	High-L (%)	High-M (%)
–30	3.0	7.5	1.5	5.2	5.2
31-35	4.2	6.5	1.9	2.3	6.1
36-40	2.5	7.3	1.1	2.4	5.9
41-45	6.7	8.0	2.7	2.6	5.8
46+	8.2	6.9	2.7	1.4	2.7
Chi^2_{MH}	4.2 (P<0.05)	NS	NS	NS	NS

R = Respiration, E = Eyes and skin, D = Digestion, L = Irregularity of life, M = Mental instability, THI = Total Health Index, NS = Not significant, Chi^2_{MH} = Mantel–Haenszel Chi-square

On the other hand, basic relationships between noise exposure level and THI scores are summarized in Table 3. Noise exposure level did not correlate with the prevalence rate of high-E-, high-D-, high-L-, or high-M-group whereas it appeared to correlate with the prevalence rate of high-R-group. No correlation of THI scores with age, sex, or occupation was observed in this study.

Further analysis in the WT sites revealed that THI scores also correlated with the nonacoustic variables, i.e., having interest in environmental issues, feeling visually annoyed with the wind turbines, and self-reported sensitivity to noise. Therefore, these findings were examined again by multiple logistic regression analysis [Table 4]. The ORs of all the THI-high-score categories for being sensitive to noise were significantly greater than 1 but not for noise exposure levels. Namely, the significant relationship between noise exposure levels and high-R-group disappeared after statistical adjustment for noise sensitivity. Furthermore, ORs of high-E- and high-D-group for visual annoyance with the wind turbines were also significant. There was no significant correlation between other nonacoustic variables and THI scores.

Since sensitivity to noise was asked both in the control sites and the WT sites, we conducted additional analysis in the control sites to clarify the nature of noise sensitivity in more detail. As shown in Table 5, even in the control sites, the high-score groups for THI subscales tended to be prevalent in the noise sensitive group compared with the nonsensitive group.

Discussion

The prevalence rate of insomnia in the general population depends on the definition of insomnia. For example, Kim *et al.*[30] asked “Do you have difficulty falling asleep at night?”, and those who responded “often” or “always” were diagnosed as DIS. Namely, they did not confirm whether the respondents felt the symptom troublesome for daily living. In contrast, relatively severe sleep disturbance was defined as insomnia in this study. As a result, the prevalence rate obtained appears lower than

Table 4: Stepwise logistic regression analysis of high-score groups for Total Health Index in the wind turbines sites

Independent variable	Dependent variables					
	Category	High-R	High-E	High-D	High-L	High-M
Noise exposure level (dB)	–30	1.00	1.00	1.00	1.00	1.00
	31-35	1.45 (0.44-4.94)	1.01 (0.42-2.42)	1.35 (0.24-7.58)	0.44 (0.14-1.43)	1.21 (0.47-3.13)
	36-40	0.81 (0.23-8.83)	1.09 (0.48-2.46)	0.68 (0.11-4.19)	0.46 (0.16-1.33)	1.15 (0.46-2.85)
	41-45	2.36 (0.76-7.32)	1.15 (0.50-2.68)	1.66 (0.33-8.47)	0.50 (0.16-1.53)	1.12 (0.43-2.89)
	45+	2.94 (0.79-10.93)	1.03 (0.33-3.25)	1.91 (0.26-14.17)	0.25 (0.03-2.10)	0.51 (0.10-2.53)
Visual annoyance	Absent		1.00	1.00		
	Present		1.77* (1.05-2.98)	3.01* (1.01-9.00)		
Noise sensitivity	Absent	1.00	1.00	1.00	1.00	1.00
	Present	3.35* (1.77-6.32)	2.39* (1.41-4.04)	3.28* (1.19-9.06)	2.26* (1.02-5.00)	2.31* (1.30-4.01)

ORs adjusted for other variables shown in this table, calculated by stepwise multiple logistic regression analysis. Noise exposure level was a forced-entry variable. Other independent variables were selected by the stepwise analysis. Underlined are reference categories. *Significantly higher than 1 ($P < 0.05$). R = Respiration, E = Eyes and skin, D = Digestion, L = Irregularity of life, M = Mental instability, ORs = Odds ratios

Table 5: Prevalence rates of high-score groups for Total Health Index in the control sites

THI score	Sensitivity to noise		Statistical comparison by Fisher's exact probability method
	Present (n = 69) (%)	Absent (n = 263) (%)	
High-R	4.4	2.3	NS
High-E	11.6	6.2	NS
High-D	2.9	0.8	NS
High-L	7.3	2.3	NS (P=0.055)
High-M	10.1	3.1	P=0.021

THI = Total Health Index, NS = Not significant, R = Respiration, E = Eyes and skin, D = Digestion, L = Irregularity of life, M = Mental instability

those in previous reports for residents living close to wind turbines[5,10] or the general population in Japan.[30] If WTN causes relatively severe sleeplessness, while relatively mild sleeplessness is multi-causal, the dose-response relationship between WTN and sleep disturbance will be demonstrated more clearly by focusing on the severe sleep disturbance. However, this hypothesis itself was not examined in this study, because it was more important to examine whether WTN exposure was associated with relatively severe sleeplessness.

As shown in Figures 1 and 3, regardless of the difference in the definition of insomnia, the above-defined insomnia was significantly prevalent when noise exposure levels were from 40 to 45 dB [Figures 1 and 3]. This is in agreement with previous studies.[9,10,13] ORs of insomnia for 46 dB and above was as high as that for 40-45 dB although not significantly higher than 1, probably because the number of respondents was small. Since the noise exposure level was higher in the WT sites than in the control sites, insomnia tended to be prevalent in the WT sites. Moreover, most of the insomniac respondents attributed their sleeplessness to WTN. In general, intermittent noise more likely affects sleep than continuous noise, which is particularly true when the background level is low[18] as is the case in the WT sites in this study. Taking account of above together, it seems that WTN exposure exceeding 40 dB as outdoor $L_{\mathrm{Aeq,n}}$ levels affects sleep. This threshold (40 dB) is, however, not definite because of the following limitations.

One of the limitations in this study was that we measured WTN only for five successive days. It is desirable to measure WTN for many days during the year taking metrological and seasonal variation into account, although this is difficult in the setting of ecologic studies. Another limitation was that we did not measure personal exposure levels in bedrooms or sound insulation of participants' houses. For example, it is probable that WTN at a certain level tend to affect sleep more severely in the summer, if many residents keep windows open at night. On the other hand, some participants in WT site might guess our intention to study the association between WTN and sleep: Although we told them that this survey was concerning the environment in the area where they live, they might guess that the environment included wind turbines. If those who had negative attitude to wind turbines emphasized sleeplessness caused by WTN, this increased the prevalence rate of insomnia. In this study, however, the attitude to wind turbines or benefit from wind turbine generation did not correlate with insomnia [Table 2 and Figure 3]. It is, therefore, improbable that the above bias, if existed, affected the association between WTN and insomnia.

It was a new finding that the relationship between noise exposure level and insomnia was modified by self-reported noise sensitivity and visual impact [Figures 2 and 3]. These findings seem to be in line with those of previous studies on WTN-induced annoyance among residents.[1,2,5,11] If sensitive individuals firstly noticed their sensitivity when their sleep was disturbed by WTN, self-reports on noise sensitivity may not be a cause, but a result of insomnia. Because similar effects of self-reported noise sensitivity on annoyance induced by environmental noise have been discussed over four decades,[15,28] the nature of noise sensitivity should be clarified in more detail. On the other hand, the reason why visual annoyance with wind turbines is associated with insomnia cannot be explained from aspects of physiology or sleep medicine. Therefore, the background of these two moderators will be discussed later. The above modification should be considered in future studies.

The physical/mental health assessed in terms of THI was associated with noise sensitivity and visual annoyance with the wind turbines [Table 4]. It is interesting that these variables overlapped with the correlates to insomnia, as shown in Figure 3. After statistical adjustment for these variables, however, no association of noise exposure level with poor physical/mental health was found [Table 4]. Although respiration symptoms appeared to correlate with noise exposure level [Table 3], this correlation was probably observed by chance, because noise sensitivity did not correlate significantly with noise exposure level.

These findings were not in agreement with those of previous studies that suggested the correlation of WTN exposure level with health-related quality of life or physical symptoms.[8,13] In those studies, however, self-reported symptoms and diseases were not systematically examined, and the ORs obtained were relatively small. It is, therefore, possible that these correlations were obtained by chance. If this is true, we must carefully interpret the report by Suzuki *et al*.[27] that those who complained of "WTN-induced health effects" showed high scores in THI subscales examined in the present study. In their study, the participants voluntarily came to the researchers to get health check-up, although their exposure to WTN was not measured. Their THI scores were not compared with those in a control group, but compared with those in the general population obtained in a previous study. It is, therefore, probable that their complaints did not demonstrate the effects of WTN, but did the features of individuals who were sensitive to WTN. Namely, the above THI subscales may not be sensitive indicators of the effects of WTN on health, but may be indicators of the features of those who perceive themselves sensitive to noise.

Taking the above findings together, we can hypothesize that self-reports on noise sensitivity and visual annoyance with the wind turbines indicate the features of individuals who are sensitive to environmental stimuli or changes in their homeostasis, and that these individuals tend to complain of sleep problems, physical/mental disorders, or visual annoyance toward newly constructed wind turbines. This explains the modification of these two variables on the relationship between noise exposure level and sleep disturbance [Figures 2 and 3], and also the finding that health complaints tended to be prevalent in the noise-sensitive group even in the control sites [Table 5].

Although the nature of the features remains unclarified in the present study, the possible association of the noise sensitivity with hyperacusis should be discussed. Hyperacusis is defined as hypersensitivity and low tolerance to environmental sounds[30,31] however, its definition is inconsistent among researchers. There are only a few epidemiologic studies on the background of hyperacusis. Kumagai *et al*.[32] reported that hyperacusis among healthy students was related to self-reported symptoms of anxiety and depression, in addition to history of head and neck surgery. Herbert and Cassier[33] reported that hyperacusis in the elderly was related to sleeplessness assessed using the Pittsburgh sleep quality index. The associations among these factors should be investigated in future studies from the aspect of pathophysiology and environmental epidemiology.

As for the visual annoyance with the wind turbines, another hypothesis also should be discussed. Previous reports show that the visual annoyance with the wind turbines emphasizes the annoyance to WTN.[5,6] It is, therefore, possible that visually negative aspects of wind turbines emphasize the annoyance to WTN and to sleep disturbance, even if the sleep disturbance was assessed apart from WTN.

Finally, it is important to discuss the limitations of the present study. The respondents did not fully represent the population in the study areas. Although we made an effort to mask the purpose of our survey, some participants might guess our intention. It is difficult to completely mask the purpose of ecologic studies. Namely, it is possible that those interested in wind turbines or environmental issues tended to participate in this study. In our results, however, the attitude to wind turbines or interest in environmental issues did not correlate with insomnia or THI scores. It is, therefore, improbable that the above selection bias, if existed, affected the association of WTN with insomnia or THI scores. Our interviewers did not ask those with severe health problems and those absent during daytime to participate in this study. Because the former group is possibly a high-risk population for insomnia[26] or self-reported symptoms, this selection bias, if existed, might weaken the relationship between WTN exposure level and insomnia.

Since the present survey was cross-sectionally conducted, the causality between variables should be carefully interpreted. We did not ask some questions on risk factors for insomnia, e.g., recent life events,[26] and physical factors related to personal exposure levels to WTN, e.g., the location of bedrooms, because such questions, particularly those on personal issues, may invade the respondents' privacy. However, it is unlikely that these factors epidemiologically confounded the relationship between WTN exposure level and insomnia. Most of the respondents had lived in the same area for 10 years or longer, namely, since the year before the wind turbines were constructed. This suggests that there is no need to consider the effect of their move on the data obtained.

Regardless of these limitations, the obtained data show the association of outdoor WTN exposure with self-reported insomnia. If this is confirmed to be true, measures to prevent the adverse effects of WTN on sleep should be investigated. The association was modified by some nonacoustic factors. These modifiers should also be considered in future studies on the association between WTN and health.

Conclusions

Insomnia diagnosed on the basis of self-reported symptoms was significantly prevalent in the areas where noise exposure levels exceeded 40 dB, showing that WTN disturbed sleep among residents in the WT sites. No evidence was obtained concerning the adverse effects of WTN on physical/mental health on the basis of self-reported symptoms. Insomnia and these symptoms also seemed to be affected by personal features expressed as noise sensitivity and the feeling of visual annoyance with wind turbines. These features may show the tendency to be sensitive to environmental stimuli or changes in their homeostasis and should be considered in future field studies on the association between WTN and health.

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Conflicts of interest

There are no conflicts of interest.

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References

1. Knopper LD, Ollson CA. Health effects and wind turbines: A review of the literature. Environ Health 2011;10:78.
2. Schmidt JH, Klokker M. Health effects related to wind turbine noise exposure: A systematic review. PLoS One 2014;9:e114183.
3. Kageyama T, Yano T, Kuwano S, Sueoka S, Tachibana H. Exposure-Response Relationship of Wind Turbine Noise with Subjective Symptoms on Sleep and Health: A Nationwide Socio-acoustic Survey in Japan. Proceedings of the 11th International Congress on Noise as a Public Health Problem; 2014.
4. Pedersen E, Waye KP. Perception and annoyance due to wind turbine noise — A dose-response relationship. J Acoust Soc Am 2004;116:3460-70.
5. Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med 2007;64:480-6.
6. Van den Berg G, Pedersen QE, Bouma J, Bakker R. Project WINDFARM – Perception: Visual and Acoustic Impact of Wind Turbine Farms on Residents. Final Report, University of Groningen; 2008.
7. Krogh CM, Gillis L, Kouwen N, Aramini J. WindVOICe, a self-reporting survey: Adverse health effects, industrial wind turbines, and the need for vigilance monitoring. Bull Sci Technol Soc 2011;31:334-45.
8. Shepherd D, McBride D, Welch D, Dirks KN, Hill EM. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 2011;13:333-9.
9. Nissenbaum MA, Aramini JJ, Hanning CD. Effects of industrial wind turbine noise on sleep and health. Noise Health 2012;14:237-43.
10. Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Sci Total Environ 2012;425:42-51.
11. Pedersen E, van den Berg F, Bakker R, Bouma J. Response to noise from modern wind farms in the Netherlands. J Acoust Soc Am 2009; 126:634-43.
12. Janssen SA, Vos H, Eisses AR, Pedersen E. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. J Acoust Soc Am 2011; 130:3746-53.
13. Pedersen E. Health aspects associated with wind turbine noise — Results from three field studies. Noise Control Eng J 2011;59:47-53.
14. Pressman MR, Figueroa WG, Kendrick-Mohamed J, Greenspon LW, Peterson DD. Nocturia. A rarely recognized symptom of sleep apnea and other occult sleep disorders. Arch Intern Med 1996; 156:545-50.
15. Billiard M. Sleep Disorders in Adults; Biological Mechanisms Through which Sleep Disorders Affect the Health of Adults. Identification of Environmental Factors Leading to Clinical Sleep Disorders. In WHO Regional Office for Europe (2004) WHO Technical Meeting on Sleep and Health, WHO Regional Office for Europe European Centre for Environment and Health, Bonn; 2004. p. 62-81.
16. World Health Organization. International Classification of Diseases. Ver. 10. Geneva: World Health Organization; 1990.
17. American Academy of Sleep Medicine. The International Classification of Sleep Disorders, Diagnostic and Coding Manual. 2nd ed. Westchester (NY): American Academy of Sleep Medicine; 2005.
18. World Health Organization. Guidelines for Community Noise. Geneva: World Health Organization; 1999.
19. Tachibana H, Yano H, Fukushima A, Sueoka S. Nationwide field measurements of wind turbine noise in Japan. Noise Control Eng J 2014;62:90-101.
20. Fukushima A, Yamamoto K, Uchida H, Sueoka S, Kobayashi T, Tachibana H. Study on the amplitude modulation of wind turbine noise: Part 1 – Physical investigation. Inter-Noise; 2013.
21. Yokoyama S, Sakamoto S, Tachibana H. Perception of low frequency components contained in wind turbine noise. Noise Control Eng J 2013;62:295-305.
22. Yokoyama S, Sakamoto S, Tachibana H. Study on the amplitude modulation of wind turbine noise: Part 2 – Auditory experiments. Inter-Noise; 2013.
23. Sakamoto S, Yokoyama S, Tsujimura S, Tachibana H. Loudness evaluation of general environmental noise containing low frequency components. Inter-Noise; 2013.
24. Kuwano S, Yano T, Kageyama T, Sueoka S, Tachibana H. Social survey on wind turbine noise in Japan. Noise Control Eng J 2014;62: 503-20.
25. Kaku J, Kabuto M, Kageyama T, Kuno K, Kuwano S, Namba S, *et al*. Standardization of Social Survey Method in Japan, Proceedings of Inter-Noise; 2004.
26. Kageyama T, Kabuto M, Nitta H, Kurokawa Y, Taira K, Suzuki S, *et al.* A population study on risk factors for insomnia among adult Japanese women: A possible effect of road traffic volume. Sleep 1997;20:963-71.
27. Suzuki S, Asano H, Aoki S, Kurihara H. Health check questionnaire THI plus: Basic data for application and evaluation. Kitatachibana (Japan): NPO Eco-Health Kenkyu-kai; 2005.
28. Miedema HM, Vos H. Demographic and attitudinal factors that modify annoyance from transportation noise. J Acoust Soc Am 1999;195:3336-44.
29. Kahn HA, Sempos CT. Statistical Methods in Epidemiology. New York: Oxford University Press; 1989.

30. Kim K, Uchiyama M, Okawa M, Liu X, Ogihara R. An epidemiological study of insomnia among the Japanese general population. Sleep 2000;23:41-7.
31. Klein AJ, Armstrong BL, Greer MK, Brown FR 3rd. Hyperacusis and otitis media in individuals with Williams syndromes. Hear Disord 1990;55:339-44.
32. Kumagai S, Ayaya S, Takenaga T, Okuma H, Nakamura K. Prevalence and risk factors for hyperacusis in general college students. Audiol Jpn 2013;56:234-42.
33. Hébert S, Carrier J. Sleep complaints in elderly tinnitus patients: A controlled study. Ear Hear 2007;28:649-55.