Exposure-response relationship of wind turbine noise with subjective symptoms on sleep and health: a nationwide socio-acoustic survey in Japan

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ABSTRACT

To investigate the relationship of wind turbine noise (WTN) with the prevalence of subjective symptoms of sleep and health, a socio-acoustic survey was conducted throughout Japan (2010-2012). Face-to-face interviews on sleep, health, and wind turbine noise were carried out with 1079 adult residents, 747 in 34 areas surrounding wind turbine plants and 332 in 16 control areas. Questions for symptoms about sleep and health were asked without specifying reasons. Noise descriptor for WTN was LAeq,n outdoor, estimated on the bases of actual measurement. Insomnia was defined as any combination of difficulty in initiating sleep, intermittent waking, premature morning waking, and light overnight sleep which occurs three or more times a week and have persisted for at least one month, causing aftereffects. Using the Total Health Index (Suzuki et al., 2005), poor health was defined as having a large amount of health complaints exceeding the criteria proposed by authors of the index. Prevalence of insomnia was significantly higher when noise exposure exceeded 40dB. The relationship was particularly strong among those who reported themselves as being noise-sensitive. Multiple logistic analysis showed visual annoyance also independently associated with insomnia. Prevalence of poor health was not correlated with noise exposure, but with noise sensitivity and visual annoyance. The above two moderators appear to show the complaining-prone features among respondents.

BACKGROUND & METHODS

Possible adverse effects of wind turbine noise (WTN) on human health have been argued for a decade (Knoppen & Olson 2012). Previous studies on this issue mainly focused on WTN-induced annoyance, showing positive relationships between outdoor sound levels and % of residents annoyed by WTN (Pedersen & Waye 2004; Bakker et al 2009; Pedersen et al 2009). The relationships seem to be modified by non-acoustic variables such as visual annoyance (Pedersen et al. 2004; Pedersen et al. 2007; Pedersen et al. 2009; Janssen & Voss 2011).

On the other hand, the relationship between WTN and sleep has not been fully investigated. Although the positive correlations between WTN and WTN-induced sleep disturbance have been reported (Pedersen & Waye 2004; Pedersen& Waye 2011; Bakker et al 2012), only a few researchers focused on sleep disturbance apart from WTN (Shepherd et al 2012). In general, sleep disturbance is multicausal, and it is sometimes difficult for an individual to specify the reason for sleeplessness (Pressman 1996). Questions about WTN-induced annoyance may affect the responses to subsequent questions (in a questionnaire) about WTN-induced sleeplessness (van den Berg 2012). Furthermore the definition of sleeplessness in the above studies often lacks specifying frequency, or includes infrequent sleeplessness, e.g. once a month. To define insomnia, however, researchers should specify frequency and aftereffects of sleeplessness (American Psychiatric Association 1987; American Academy of Sleep Medicine, 2005).

As for possible effects of WTN on physical/mental health other than sleep, only a few reports are available (Shepherd 2011; Pedersen 2011; Bakker et al. 2012), while journalistic reports on these effects often lack scientific evidence and medical explanation (Knoppen & Olson 2012). Since the effect of environmental noise on physical/mental health is weak (WHO, 2001), subclinical symptoms should be systematically examined prior to clinical diseases.

We therefore conducted a research project on evaluation of WTN impact on human health over three years from fiscal year 2010, taking the above into consideration, and being funded by the Ministry of the Environment, Japan (Tachibana et al. 2013; Kuwano et al. 2013; Yano et al. 2013). From this project, we report the results of a survey about WTN, sleep, and physical/mental health. The aim of this study was to clarify the exposure-response relationships of WTN with these subjective symptoms, taking non-acoustic variables into account.

Respondents, noise descriptor, and questionnaire

A survey was conducted in 34 sites near wind turbines (WT site) and in 16 control sites which have similar characteristics to WT site but are not affected by wind turbines (control site). All of 50 sites were located in rural areas. Following the distribution of letters to ask almost all the households to cooperate with our study on ”environment”, 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 WT site 747 adults (49%) agreed, and 332 (45%) did in control site. Out of 1079 respondents, 387 (52%) in WT site and 203 (61%) in control site were females. Almost 80% of them were aged in their fifties or above 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 housewives. No significant site difference was observed for the above variables except sex ($p<.05$).

WTN exposures of the respondents’ houses were estimated from the results of field measurement performed in WTN site, where WTN was measured at eight points per site (Tachibana et al. 2013). Since the effect of WTN was particularly serious at night, average sound pressure level under a rated operation condition from 22:00 to 6:00 (LAeq,n) was calculated from 10 min recording of every one hour. However, we carefully excluded the effects of other noise such as road traffic noise, based on the recordings. Based on the relationship between distance from wind turbine and LAeq,n among the above measurement points in each site, noise exposure of each

house was estimated. As for residual noise in control site, 95 percentile levels of A-weighted sound pressure level over 10 min of every hour at night was obtained, and the representative values (LA95,n) were calculated as the energy-means of the respective sound pressure levels over 10 min .

Administered-questionnaires were used for structured interview. In addition to the questionnaire developed by the INCE/Japan (Kaku et al. 2004), questions concerning sleep, mental/physical health, and environment were used, as follows:

Questions for sleep disturbance were developed on the basis of previous literature (American Academy of Sleep Medicine 2005; Kageyama et al. 1997). Insomnia was defined as having any trouble with sleep because of any combination of the following four symptoms; difficulty in initiating sleep (DIS), difficulty in sleep maintenance (DSM), premature morning waking (PMW), and a feeling of light overnight sleep (LOS). Each symptom must occur three or more times a week. Thus insomnia was defined regardless of the reason for sleeplessness, and then the respondents were asked whether their sleep disturbance is due to WTN.

Physical and mental health was assessed in terms of 54 subjective symptoms concerning respiration (R), eye 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. (2005). A response to each symptom was scored into 1-3 points, and summed up by the above item groups for calculating five scores. Reliability and validity of these subscales are supported by the authors of THI. If an individual shows higher score for subscale R, for example, than the criteria proposed by the authors of THI, the individual is abbreviated to high-R in this paper. Suzuki et al. (2005) reported that those who complained of “WTN-induced health effects” exhibited significantly high scores for the above five subscales in THI, compared with the general population.

Some additional questions concerning wind turbines were used only in WT sites.

Data Analysis

Noise exposure levels (LAeq,n or LA95,n) were categorized by the 5 dB. Bivariate analysis was performed using Fisher’s exact probability method and Mantel-Haensel chi-square (chi2MH) test. Multiple logistic analysis was performed to examine the association of independent variables such as noise exposure with insomnia and THI scores (Kahn & Sempos 1989). Odds ratio (OR) being significantly greater or smaller than 1 means association of an independent variable with a dependent variable. In WT site data, forward stepwise logistic analyses were performed to examine the insomnia or THI scores with the following independent variables; interest in environmental problems (present vs. absent), attitude to wind turbine power generation (positive vs. negative), benefit of wind turbine generation (present vs. absent), visual annoyance of wind turbine (present vs. absent), and self-reported noise sensitivity (sensitive vs. non-sensitive). However, forced entry in the regression analysis was applied to noise exposure.

RESULTS

Estimated noise exposure levels were most prevalent for 36-40 dB in WT sites, while those for most respondents in control site were 35dB or below. Difference in noise exposure levels among two sites was statistically significant ($p<.001$).

Thirteen respondents (1.2%) were classified as insomniacs (1.5% in WT site and 0.6% in control site; site difference was not significant). In WT site, 82% of insomniac

respondents attributed their sleeplessness to WTN. As shown in Table 1, % of insomnia, DSI, DSM, and LOS were particularly high when noise exposure exceeded 40 dB. This was confirmed by sex-age-adjusted OR obtained through logistic analysis (Figure 1), where the categories for noise exposure below 35 dB were combined because insomniac cases were very infrequent. OR (95% confidential interval) of insomnia was 5.55 (1.12-27.47) for 41-45 dB, and 4.79 (0.64-35.70) for noise exposure above 45dB, compared with noise exposure below 35 dB. However, OR for sex or age was not significant.

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

$L_{Aeq,night}$ [dB]	Insomnia	DSI	DSM	PMW	LOS
-30	0.7	0.0	0.0	0.7	0.0
31-35	0.5	0.5	0.5	0.0	0.5
36-40	0.7	0.4	0.7	0.4	0.7
41-45	3.1	2.2	3.1	1.3	2.6
46+	2.7	2.7	1.4	2.7	2.7
chi^2_{MH}	5.3*	6.9**	6.0*	3.7(NS)	6.3**

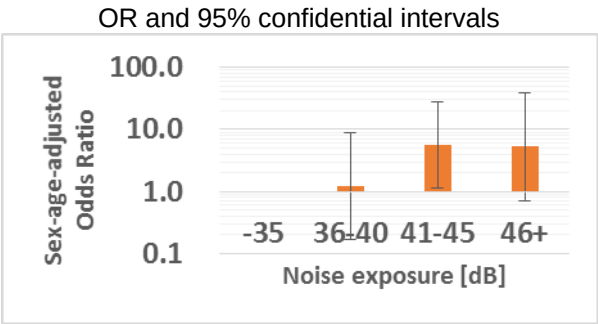

Figure 1: Odds ratio of insomnia for noise exposure categories

In WT site, attitude to wind turbine power generation and benefit of wind turbine generation did not correlate with % of insomnia. Insomnia was significantly prevalent in those who were interested in environmental problems, those who feel visual annoyance of wind turbine, and also those who reported themselves sensitive to noise, compared with in the rest of the respondents. Among these three variables, only noise-sensitivity exhibited a modification effect to exposure-response relationships between noise exposure and insomnia (Figure 2); namely, the relationship was positive among noise-sensitive group, but not among non-sensitive group. Stepwise logistic analysis for insomnia (Table 2) showed that OR was significant not only for noise exposure but also for presence of visual annoyance and being sensitive to noise.

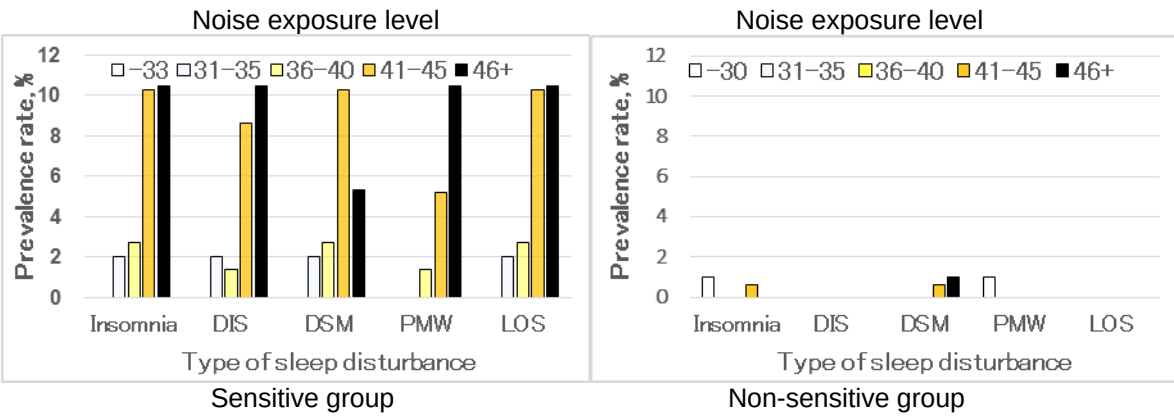

Figure 2: Modification of noise-sensitivity to relationships between WTN and sleep disturbance

Table 2: Stepwise multiple logistic analysis for insomnia

Independent variable	Category	Adjusted OR (95% confidential)
Noise exposure [dB]	-40	1.00
	41-45	7.93(1.57-40.07)
	45+	6.61(0.84-52.31)
Visual annoyance	Absent	1.00
	Present	4.17(1.13-15.33)
Noise sensitivity	Non-sensitive	1.00
	Sensitive	24.44(3.05-196.02)

OR (95% confidential interval). Noise exposure was forced entry. Other independent variables were selected through stepwise method. Underlined are reference categories.

As for THI, noise exposure levels did not correlate with % of high-E, high-D, high-L, or high-M (Table 3), while the levels appeared to correlate with % of high-R. This correlation, however, disappeared after statistical adjustment for noise-sensitivity by stepwise logistic analysis (Table 4). ORs of all the types of subjective symptoms for being sensitive to noise were significant, while ORs for noise exposure levels were not. ORs of high-E and high-D for visual annoyance were also significant.

Table 3: Prevalence rate of high score group for THI by noise exposure category

Noise exposure [dB]	high-R	high-E	high-D	high-L	high-M
-30	3.0%	0.5%	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<.05)	NS	NS	NS	NS

Table 4: Forward stepwise logistic analysis for THI in WT site

Independent variables	Category	Dependent variables				
		high-R	high-E	high-D	high-L	high-M
Noise exposure [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	non-sensitive	1.00	1.00	1.00	1.00	1.00
	sensitive	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)

Adjusted OR (95% confidential interval). Noise exposure was forced entry. Other independent variables were selected through stepwise method. Underlined are reference categories.

DISCUSSION

Since relatively severe sleep disturbance was defined as insomnia in this study, its prevalence rate appears low, compared with previous reports (Pedersen & Waye 2007; Bakker et al. 2012). Regardless of difference in the definition, insomnia based on self-report was significantly prevalent when noise exposure levels exceed 40dB, in agreement with Pedersen & Waye (2007). Since noise exposure level was higher in WT site than in control site, , insomnia tended to be prevalent in WT site. Moreover, most of insomniac respondents attributed their sleeplessness to WTN. These facts suggest their sleep is disturbed by WTN when noise exposure levels exceed 40dB.

It was a new finding that the relationship between noise exposure and sleep disturbance was modified by noise-sensitivity and visual impact. If sensitive individuals firstly noticed their sensitivity when their sleep was disturbed by WTN, self-reports on noise-sensitivity may not be cause, but a result of insomnia. However, the reason why visual annoyance for wind turbine associated with insomnia remains unclear. Anyway, the above modification effects should be considered in future studies.

Another finding is that poor physical/mental health in terms of subjective symptoms was not associated with noise exposure. This is in disagreement with previous studies (Pedersen et al. 2011; Shepherd et al. 2011). However, mental/physical health symptoms were associated with noise sensitivity and visual annoyance for wind turbines. Since noise-sensitive or visually annoyed respondents were prevalent in sites where noise exposure levels were relatively high, the levels appeared to correlate with high-R.

Taking the above results together into consideration, it can be hypothesized that self-reports on noise-sensitivity and visual annoyance present the features of individuals who are nervous about environmental stimuli or changes in their homeostasis, and that these individuals tend to complain of sleep problems or physical/mental disorders. This hypothesis may explain the fact that noise-sensitivity and visual annoyance modify the relationship between noise exposures and sleep disturbance.

CONCLUSION

Insomnia diagnosed with subjective symptoms was prevalent when noise exposure levels exceed 40dB, suggesting that WTN disturbed sleep among residents in WT site. No evidence was obtained concerning adverse effect of WTN on physical/mental health in terms of subjective (self-reported) symptoms. Insomnia and these symptoms also seemed to be affected by personal, complaining-prone features, which were presented by noise-sensitivity and feeling visual annoyance for wind turbines. These non-acoustic variables should be considered in future field studies on WTN.

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