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Associations of insomnia with noise annoyance and neighborhood environments: A nationwide cross-sectional study in Japan

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ABSTRACT

Despite the increasing knowledge on the association between neighborhood and health, few studies have investigated sleep disorders in Japan, particularly the impact of neighborhood noise on sleep. Thus, this study aimed to investigate the associations between insomnia symptoms and annoyance because of traffic and neighborhood noise in Japan, which has different neighborhood conditions compared with those of the western societies. Neighborhood built and socioeconomic environments roles were also examined. We used nationwide cross-sectional data collected through a 2015 online survey of Japanese adults aged 20–64 years (n = 4,243). Adjusted prevalence ratios for insomnia according to the exposures were estimated using the multilevel Poisson regression models. The results showed that having insomnia was significantly associated with experiencing neighborhood and traffic-noise annoyance. Neighborhood noise had a stronger and independent association with insomnia. However, the neighborhood environmental variables, including population density, deprivation index, and access to commercial areas, were not associated with insomnia. In conclusion, noise annoyance, particularly that sourced from neighbors, is an important factor in relation to sleep health. Health and urban-planning policymakers should consider neighborhood noise, in addition to traffic noise, as health-related issues in residential neighborhoods.

1. Introduction

In the last few decades, health geography research has investigated the associations between neighborhood environment and health behaviors, including smoking, drinking, and physical inactivity as well as morbidity and mortality (Arcaya et al., 2016; Diez Roux and Mair, 2010). Previously, the epidemiological neighborhood studies were not focused on sleep (Riedel et al., 2012). However, the number of such studies has grown substantially since 2010, and many have reported that the sleep quantity and quality levels were lower in disadvantaged neighborhoods (Hale et al., 2015; Hunter and Hayden, 2018). For example, neighborhood deprivation or socioeconomic conditions have often been associated with sleep (Bagley et al., 2018; Xiao and Hale, 2018; Riedel et al., 2012; Troxel et al., 2017). In addition, physical and social disorders, lack of social cohesion, social fragmentation, and feeling unsafe have also been reported to be associated with sleep, including insomnia symptoms, shorter sleep duration, and later sleep timing (Hill et al., 2016; Chen-Edinboro et al., 2014; DeSantis et al., 2013; Johnson et al., 2016, 2017; Troxel et al., 2017; Pabayo et al., 2014). Chen-Edinboro et al. (2014) evaluated a nationally representative sample of adults from the United States (US) aged > 50 years. They reported that neighborhood-level factors of physical disorder and social cohesion are associated with insomnia symptoms in middle-aged and older adults.

However, despite the increasing knowledge, the role of neighborhood noise remains unclear. Noise pollution is thought to increase the health risks by causing psychological stress and sleep disturbance. The latter is considered the most deleterious non-auditory effect of environmental noise exposure (Basner et al., 2014); interestingly, strong evidence supports the association between environmental noise and negative sleep outcomes (Hunter and Hayden, 2018). However, most studies on environmental noise and health have focused on traffic or

Abbreviations: ADI, Areal Deprivation Index; CIs, confidence intervals; GIS, geographic information systems; PRs, prevalence ratios.

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aircraft noise rather than on various neighborhood noises (Jensen et al., 2018; Omlin et al., 2011). Thus, more studies are needed to examine the relationship between sleep health and neighborhood noise (e.g., talking voice, call of pet, footstep in the room, and sound coming from audio equipment).

In addition, further studies should be conducted in different countries and regions because neighborhood environments and their perceptions may differ by country/region. For example, residential density, which is strongly related to noise occurrence in neighborhoods, is generally higher in East Asian cities than those in the US, Australia, and European countries. However, previous studies in Japan only relied on perceived measures for neighborhood social and physical environments (Watanabe et al., 2020; Win et al., 2018). No studies have focused on objectively assessing the built and socioeconomic environment and their associations with sleep.

Therefore, this study aimed to investigate the associations between insomnia symptoms and annoyance because of neighborhood noise. Additionally, we explored the role of neighborhood built and socioeconomic environments, objectively measured by geographic information systems (GIS), as possible determinants of sleep health.

2. Material and methods

2.1. Data

Nationwide cross-sectional data were collected through an online survey conducted between September 25 and October 8, 2015. Details concerning the survey have been described elsewhere (Koohsari et al., 2017). Briefly, an invitation was sent to Japanese adults aged 20–64 years across the country who were registered as panel members of the survey company (Nippon Research Center, Ltd., Tokyo, Japan). Older people aged $\geq$ 65 years were excluded because of a very low registration rate on the survey platform. For this survey, the first invitation emails were sent to the 201,219 members. Of those, 25,315 participated in a screening survey, and in total, 5,002 respondents completed the survey (response rate not calculable). The quota sampling design was applied to the online survey to ensure a representative distribution in age, sex, geographical region, and population size of municipality (city, ward, town, and village).

In this study, the participants were restricted to those who provided residential addresses and were successfully geocoded on a sufficiently detailed level (*Chocho-moku*) (n = 4,726). Those who were receiving sleep medication (n = 466), had missing data on education (n = 9), size of households (n = 4), and housing (n = 4) were excluded from the analysis. In total, 4,243 respondents residing in 1,025 municipalities were eligible. Moreover, 112 respondents were further excluded from the analysis because of missing data on the Areal Deprivation Index (ADI).

This study was approved by the Research Ethics Committee of Chukyo University (2015-004).

2.2. Insomnia symptoms

Self-reported measures of insomnia symptoms (difficulty falling asleep, night awakenings, waking up too early, and not feeling well-rested) were used as outcomes. The respondents were asked whether they experienced each of the insomnia symptoms during the past month, with four possible responses: frequently, sometimes, occasionally, or never. Insomnia was defined as an answer of "frequently" to at least one symptom.

2.3. Noise annoyance

The respondents were asked regarding their perception of the noise from around their homes. The question inquired, "How noisy do you feel the sound coming from around your home (apartment room above and below, home or house next door, and neighborhood) during the past 1 month?" A 5-point Likert scale was used for each type of noise, with the responses being as follows: extremely noisy, very noisy, moderately noisy, slightly noisy, and not noisy at all. Noise annoyance was defined as a rating of "extremely noisy," "very noisy," or "moderately noisy." Two types of noise sources were distinguished: (a) traffic noise, including car or train sound during running, aircraft sound, and car or motorbike sound during revving or its horn sound; and (b) neighborhood noise, including sounds of banging or voices, child voice or cry, cry or call from pet, footsteps in the stairs or room inside, sound of the doors and windows opening and closing, sound of water supply and drainage from the bath and toilet, sound coming from washing machine, vacuum, and outdoor unit of air conditioner, sound coming from audio equipment such as television and stereo, and instrumental sounds such as from the piano.

2.4. Neighborhood environment variables

Population density and ADI were defined at *the chocho-aza* (i.e., neighborhood) level and derived from the 2010 Population Census of Japan. These variables represent the demographic and socioeconomic characteristics of the neighborhoods that could potentially relate to sleep conditions and noise occurrence because of, for example, crowded housing. ADI is a composite indicator that comprises weighted sums of several poverty-related census variables, such as the unemployment rate. A larger ADI means that there are more deprived conditions in the neighborhood. More details of the ADI were described in a previous work (Nakaya et al., 2014). We also used access to commercial areas, as they may be related to insomnia because of noise occurrence and artificial light generation. Straight distance from home to the nearest boundary of a commercial area was measured using GIS. Retail area data for 2011, which was developed by Akiyama et al. (2013) and released by Zenrin Co. Ltd. (Kitakyushu, Fukuoka, Japan), were used. A commercial area was defined as a cluster of $\geq$ 10 retail stores using a buffering technique for GIS.

2.5. Confounders

As possible confounders, age, sex, marital status, size of households, educational attainment ("high school" including junior high school and high school, "junior college" including junior (technical) college and vocational school, "university" including university and graduate school), annual household income before tax, employment status, and type of housing were used as indicators of the demographic and socioeconomic status. Current smoking (sometimes/every day vs. nonsmoker), daily drinking (every day vs. less than daily), and physical inactivity (rarely engaged in exercise or sports regularly vs. more frequent physical activity) were also used as variables of health-related behaviors. In addition, the K6 Psychological Distress Scale was used to adjust for mental distress ($\leq$4, 5–12, and $\geq$ 13 points).

2.6. Statistical analysis

A series of multilevel Poisson regression models with robust error variance using insomnia as a dependent variable was performed to estimate the prevalence ratios (PRs) and 95% confidence intervals (CIs). Model 1 included neighborhood- and traffic-noise annoyance separately adjusted for age and sex. Model 2 added marital status, size of households, education, household income, working status, housing, smoking, drinking, and physical activity. Model 3 further adjusted for mental distress (K6) and Model 4 included both noise annoyance variables simultaneously. The same models using the three neighborhood environment variables were also analyzed. Municipality was used as a group variable of multilevel models for adjusting unknown spatial clustering. All statistical analyses were performed using STATA 14 (StataCorp, College Station, TX, USA).

3. Results

Among the 4,243 respondents, approximately one-third had one or more insomnia symptoms. Almost half of the respondents reported that they experienced neighborhood- and traffic-noise annoyance. The basic characteristics of the respondents are presented in Table 1. Table 2 shows the results of the multilevel Poisson regression model using insomnia symptoms as a dependent variable. Covariates results are presented in Appendix A. In Model 1, neighborhood- and traffic-noise annoyances were significantly associated with insomnia [PRs = 1.43 (95% CI = 1.31–1.56) and 1.23 (1.13–1.34), respectively]. The results were almost unchanged when other covariates were added in Model 2. Similarly, Model 3 showed reduced but still significant PRs for both neighborhood- and traffic-noise annoyances [PRs = 1.24 (1.14–1.36) and 1.11 (1.03–1.21), respectively]. In Model 4, which simultaneously included both noise annoyance variables, only neighborhood-noise annoyance [PR = 1.23 (1.11–1.35)] retained a significant association with insomnia: those annoyed by neighborhood noise were 23% more likely to have insomnia symptoms, while traffic-noise annoyance presented no significant association [PR = 1.05 (0.96–1.14)]. Unlike noise annoyance, none of the indices of neighborhood built and socioeconomic environment showed significant associations with insomnia, except for the "High" category of ADI in Model 1 (Table 3).

Table 1
Participant characteristics, Japan, 2015.

	n	% / Mean (SD)
Total	4,243	100.0
Insomnia	1,398	32.9
Difficulty falling asleep	459	10.8
Night awakenings	790	18.6
Waking up too early	370	8.7
Not feeling well-rested	909	21.4
Types of noise		
Neighborhood noise annoyance	1,868	44.0
Traffic noise annoyance	2,088	49.2
Population density (people per km^2)		
Lowest (≤2,767)	1,061	25.0
Low (2,768–6,706)	1,061	25.0
High (6,707–12,369)	1,062	25.0
Highest (≥12,370)	1,059	25.0
Area Deprivation Index		
Lowest (≤4.90)	1,033	25.0
Low (4.91–5.46)	1,033	25.0
High (5.47–6.09)	1,033	25.0
Highest (≥6.10)	1,032	25.0
Distance to commercial area (m)		
Shortest (≤111)	1,061	25.0
Short (112–322)	1,061	25.0
Long (323–753)	1,061	25.0
Longest (≥754)	1,060	25.0
Age, years		
20–29	766	18.1
30–39	947	22.3
40–49	1,091	25.7
50–59	910	21.4
60–64	529	12.5
Sex		
Male	2,125	50.1
Female	2,118	49.9
Marital status		
Married	2,526	59.5
Never married	1,435	33.8
Divorced/separated	282	6.6
Size of household (Cont.)	4,243	2.88 (1.37)
Education		
High school	1,098	25.9
Junior college	1,052	24.8
University	2,093	49.3
Household income (yen)		
<3 million	747	17.6
3–7 million	1,776	41.9
≥7 million	1,079	25.4
Unreported	641	15.1
Working status		
Full time	2,320	54.7
Part time	762	18.0
Not working	1,161	27.4
Housing		
Single-family dwelling	2,299	54.2
Multi-family dwelling	1,944	45.8
Currently smoking	832	19.6
Daily drinking	591	13.9
Physical inactivity	2,089	49.2
Mental distress: K6		
≤4 points	2,639	62.2
5–12 points	1,301	30.7
≥13 points	303	7.1

SD, standard deviation.

4. Discussion

To the best of our knowledge, this is the first study to investigate the role of neighborhood noise and neighborhood built and socioeconomic environments in the development of insomnia symptoms in Japan, which has different neighborhood conditions compared to those of the western societies. This study showed that insomnia is associated with neighborhood and traffic-noise annoyance: however, the former showed a stronger association. The neighborhood environmental variables of density, deprivation, and commercial areas showed no significant associations with insomnia. Therefore, our findings suggested that neighborhood noise, in addition to traffic noise, should be considered in health and urban policy planning.

Previous studies have focused on traffic noise rather than on neighborhood noise (Jensen et al., 2018; Omlin et al., 2011). This study showed that both were related to insomnia: however, neighborhood-noise annoyance presented a stronger association. This result could be partly explained by the very high residential density in Japan, especially in urban areas. In a crowded residential environment, people may experience more noise annoyance from the neighborhood rather than from traffic. Respondents were more likely to report neighborhood noise annoyance when they lived in highly populated areas (results not shown). Although traffic-noise annoyance was not associated with insomnia independently from neighborhood-noise annoyance (Model 4), this could be attributed to noise sensitivity rather than to environmental factors: those who were hypersensitive to noise could have been annoyed by neighborhood and traffic noises. Indeed, the tetrachoric correlation coefficient between neighborhood- and traffic-noise annoyance was 0.50. This could have resulted in insomnia being independently associated only with neighborhood-noise annoyance.

However, no direct associations between neighborhood environments and insomnia were observed. Although the reason was unclear, there could be a conflicting pathway. For example, as population density and access to commercial areas are also used as indices of walkability, residents in highly populated areas closer to commercial areas tend to walk and have more social interaction with their neighbors, which results in lower psychological stress and better sleep health. Unlike many previous studies that found associations between neighborhood deprivation or socioeconomic conditions and sleep (Bagley et al., 2018; Xiao and Hale, 2018; Riedel et al., 2012; Troxel et al., 2017), this study found no such relationships. This could be attributed to the fact that most neighborhoods in Japan are generally safer, even in highly deprived areas, compared to those in other countries.

There were several limitations to this study. First, this was a cross-sectional study and, thus, causality between insomnia and noise annoyance cannot be determined. Second, the data used in this study were not randomly sampled; therefore, the findings may not be generalizable to the entire population. Third, although the current study only focused on the direct associations, further studies should examine the mediating role of neighborhood-noise annoyance in the relationships between insomnia and neighborhood built and socioeconomic

Table 2
Prevalence ratios for insomnia according to traffic and neighborhood noise annoyance estimated by Poisson regression models with robust error variance, Japan, 2015.

	Model 1[a]			Model 2[b]			Model 3[c]			Model 4[d]		
	PRs		95%CIs	PRs		95%CIs	PRs		95%CIs	PRs		95%CIs
Neighborhood noise annoyance	1.43	***	(1.31–1.56)	1.41	***	(1.29–1.54)	1.24	***	(1.14–1.36)	1.23	***	(1.11–1.35)
Traffic noise annoyance	1.23	***	(1.13–1.34)	1.22	***	(1.13–1.33)	1.11	**	(1.03–1.21)	1.05		(0.96–1.14)

PR, prevalence ratio; CI, confidence interval.
***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, +: $p < 0.1$ (not all symbols are used in this table).
[a] Adjusted for age and sex. Neighborhood and traffic noise annoyance were included separately.

[b] Adjusted for age, sex, marital status, size of households, education, household income, working status, housing, smoking, drinking, and physical activity. Neighborhood and traffic noise annoyance were included separately.

[c] Adjusted for age, sex, marital status, size of households, education, household income, working status, housing, smoking, drinking, physical activity, and mental distress (K6). Neighborhood and traffic noise annoyance were included separately.

[d] Adjusted for age, sex, marital status, size of households, education, household income, working status, housing, smoking, drinking, physical activity, and mental distress (K6). Neighborhood and traffic noise annoyance were included simultaneously.

Table 3
Prevalence ratios for insomnia according to neighborhood built and socioeconomic environment variables estimated by Poisson regression models with robust error variance, Japan, 2015.

	Model 1[a]			Model 2[b]			Model 3[c]		Model 4[d]	
	PRs		95%CIs	PRs		95%CIs	PRs	95%CIs	PRs	95%CIs
Population density (ref. Lowest)										
Low	0.89	+	(0.79–1.01)	0.92		(0.81–1.03)	0.97	(0.86–1.08)	0.96	(0.85–1.10)
High	1.00		(0.89–1.12)	1.02		(0.91–1.15)	1.05	(0.95–1.18)	1.04	(0.92–1.19)
Highest	0.96		(0.85–1.08)	0.99		(0.87–1.13)	1.04	(0.92–1.18)	1.03	(0.89–1.19)
Areal deprivation index (ref. Lowest)										
Low	1.04		(0.92–1.17)	1.02		(0.90–1.15)	0.97	(0.86–1.09)	0.97	(0.86–1.10)
High	1.16	*	(1.03–1.31)	1.12	+	(0.99–1.27)	1.05	(0.94–1.18)	1.06	(0.94–1.20)
Highest	1.08		(0.96–1.22)	1.02		(0.90–1.15)	0.97	(0.86–1.09)	0.98	(0.87–1.11)
Distance to commercial area (ref. Shortest)										
Short	0.96		(0.85–1.09)	0.97		(0.85–1.09)	0.95	(0.85–1.07)	0.96	(0.85–1.08)
Long	1.02		(0.90–1.14)	1.02		(0.91–1.15)	0.99	(0.88–1.11)	1.00	(0.89–1.13)
Longest	0.98		(0.87–1.10)	0.96		(0.85–1.09)	0.95	(0.84–1.07)	0.97	(0.84–1.12)

PR, prevalence ratio; CI, confidence interval.
***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, +: $p < 0.1$ (not all symbols are used in this table).
[a] Adjusted for age and sex. Neighborhood environment variables were included separately.

[b] Adjusted for age, sex, marital status, size of households, education, household income, working status, housing, smoking, drinking, and physical activity. Neighborhood environment variables were included separately.

[c] Adjusted for age, sex, marital status, size of households, education, household income, working status, housing, smoking, drinking, physical activity, and mental distress (K6). Neighborhood environment variables were included separately.

[d] Adjusted for age, sex, marital status, size of households, education, household income, working status, housing, smoking, drinking, physical activity, and mental distress (K6). Neighborhood environment variables were included simultaneously.

environments. Fourth, although the neighborhood noise in this study included both sounds coming from the neighborhood indoors (i.e., surrounding homes in the same buildings) and outdoors, further studies are needed to distinguish the different types of noise and the time of noise within a day. Fifth, although this study excluded those on sleep medication, individuals with pre-existing conditions that may affect sleep and those with hearing impairment were not excluded because of a lack of this information. Finally, insomnia symptoms were defined based on the respondents' self-reports. Further studies are needed to objectively examine the quality and quantity of sleep and their associations with noise and neighborhood environment.

In conclusion, neighborhood noise annoyance is an important factor associated with sleep health. Health and urban planning policymakers should consider neighborhood noise, in addition to traffic noise, as health-related problems in residential neighborhoods.

CRediT authorship contribution statement

Tomoya Hanibuchi: Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing - original draft. **Tomoki Nakaya:** Methodology, Supervision, Writing - review & editing. **Tsuyoshi Kitajima:** Conceptualization, Writing - review & editing. **Hiroshi Yatsuya:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. . Prevalence ratios for insomnia according to individual characteristics (confounders), Japan, 2015[a]

	PRs		95%CIs
Age (Ref. 20–29 years)			
30–39 years	1.05		(0.93–1.20)
40–49 years	0.96		(0.84–1.10)
50–59 years	0.95		(0.81–1.11)
60–64 years	0.96		(0.80–1.14)
Women	1.12	*	(1.03–1.23)
Marital status (Ref. Married)			
Never married	0.96		(0.86–1.07)
Divorced/Separated	1.25	**	(1.08–1.44)
Size of households (Cont.)	1.02		(0.99–1.06)
Education (Ref. High school)			
Junior college	0.90	*	(0.81–1.00)
University	0.83	***	(0.75–0.92)
Household income (Ref. < 3 million yen)			
3–7 million yen	0.98		(0.87–1.10)
≥7 million yen	1.03		(0.89–1.18)
Unreported	0.95		(0.84–1.08)
Working status (Ref. Full-time)			
Part-time	0.94		(0.84–1.06)
Not working	1.04		(0.94–1.15)
Current smoking	1.07		(0.96–1.18)
Daily drinking	1.16	*	(1.03–1.30)
Physical inactivity	1.04		(0.96–1.14)
Multi-family dwelling	1.04		(0.95–1.14)
Mental distress: K6 (Ref. ≤ 4 points)			
5–12 points	1.82	***	(1.65–2.01)
≥13 points	2.85	***	(2.57–3.17)
Constant	0.19	***	(0.15–0.25)

PR, prevalence ratio; CI, confidence interval

[a]The table shows the PRs for individual characteristics (confounders) estimated in Model 4 of Table 2.

***: $p < 0.001$, **: $p < 0.01$, *: $p < 0.05$, +: $p < 0.1$ (not all symbols are used in this table).

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