Noise Sensitivity Associated with Nonrestorative Sleep in Chinese Adults: A cross-sectional Study

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Abstract

Background: Nonrestorative sleep (NRS) is associated with various psychological and physical health issues. Noise exposure and noise sensitivity have been proposed to contribute to NRS. This study aimed to examine the relationship between noise, noise sensitivity, NRS, and physiological sleep parameters among Chinese adults.

Methods: A cross-sectional household study was conducted with Chinese adults in Hong Kong. We administered a battery of questionnaires, including the Nonrestorative Sleep Scale and the Weinstein Noise Sensitivity Scale for assessing NRS and noise sensitivity, respectively, as well as other instruments for assessing sociodemographics, lifestyle factors, social support, somatic symptoms, stress, anxiety, and depression. Nocturnal noise level was measured for one week by a noise dosimeter. Physiological sleep parameters were also measured by actigraphy during the night-time for a week.

Results: A total of 500 (66.4% female) adults with an average age of 39 years participated in this study. There was no significant association between nocturnal noise and NRS ($b = -0.09$, 95% CI: $-0.28, 0.10$). However, one unit increase of noise sensitivity was associated with 0.08 increase in NRS (95% confidence interval [CI]: $0.01, 0.15$), both on a 0–100 scale, after adjusting for sociodemographics, lifestyle factors, nocturnal noise, social support, somatic symptoms, stress, anxiety, and depression. This relationship remained after adjusting for sleep parameters. Nevertheless, nocturnal noise was significantly negatively associated with total time in bed ($b = -1.46$, 95% CI: $-2.51, -0.40$), and total sleep time ($b = -1.26$, 95% CI: $-2.18, -0.34$). None of the obtained physiological sleep parameters were associated with NRS.

Conclusions: NRS was associated with noise sensitivity while physiological sleep parameters were influenced by nocturnal noise level.

1. Background

Nonrestorative sleep (NRS) refers to the feeling of being unrefreshed and restless upon waking up [1] and was listed as a symptom of primary insomnia. However, NRS can occur without other insomnia symptoms. In the Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition (DSM-V), individuals could be diagnosed as “other specified insomnia disorder” or “unspecified insomnia disorder” when they report NRS without any other sleep disorders [2]. The prevalence of NRS among the general adult population varies from 1.4–35% [1]. In Hong Kong, the prevalence and persistence of NRS in adults was reported to be 8% and 31.9%, respectively, which was determined based on a single question about NRS [3]. This unrefreshed feeling may cause fatigue and reduced physical capacity during the day, which may hinder work performance and even occupational injury [4]. Individuals with NRS also experience reduced psychological well-being and even suicidal ideation [5]. Moreover, several chronic diseases were demonstrated to be highly associated with NRS [6]. Therefore, NRS has gained increasing attention as a potential target of treatment intervention. Personal factors such as age, stress, anxiety and depression, lack of regular exercise, and long working hours have been reported to be associated with the

development of NRS [7]. However, the cause and mechanism of NRS is still unclear. Furthermore, the impact of environmental factors such as noise on NRS, the interaction of noise with personal factors, and the relationship between physiological sleep parameters and NRS still remain to be studied.

Noise exposure from transportation, construction, community, or social sources poses a serious burden to humans. Noise pollution is ranked one of the world's largest environmental problems, second only to air pollution [8]. In Hong Kong, it is one of the most complained about environmental issues. The negative health effects induced by noise, such as hearing loss, hypertension, and cognitive impairment have been well studied, with a growing number of noise-related additional health problems and diseases. The hypothesized link between the physical, auditory stimulus of noise and non-auditory, physiological health effects has been based on the general stress model. Specifically, noise may induce annoyance that results in the release of stress-related cortisol, leading to various adverse physiological changes [9]. This link also applies to sleep [10]. Interruption of sleep and the adverse physiological changes would make a vicious cycle which cause different health problems of humans [11].

Moreover, people who were more sensitive to noise might be more vulnerable to the impact of noise when exposed to the same noise level as others with less sensitivity, reflected by increases in annoyance, and physical and mental health problems. Noise sensitivity refers to the increased reactivity to noise in general [12]. In the general population, it was estimated that 20–40% of individuals were sensitive to noise, and 12% were highly sensitive to noise [12]. A previous study suggested that it was the subjective response to noise, such as noise annoyance or noise sensitivity, that explained the association of sleep quality complaints after excess noise exposure [13]. Furthermore, people who were more tolerant of noise experienced less NRS [14]. The mechanism underlying the potential effect of noise sensitivity on NRS remains unclear. There could be a direct influence of noise sensitivity on NRS, or it may be that one is more reactive to noise during the night. The latter would be consistent with the stress model for the non-auditory impact of noise. However, one may not experience emotional responses when asleep [15]. Therefore, we hypothesized there was a direct association between noise sensitivity and NRS.

To the best of our knowledge, no study had controlled for factors such as nocturnal noise, stress, depression, and physiological sleep parameters before assessing the association between noise sensitivity and NRS. Moreover, previous studies only used a single question rather than a validated scale to assess noise sensitivity and/or NRS, which may have resulted in low measurement sensitivity and reliability. Hence, this study aimed to examine the association of noise, noise sensitivity with NRS and physiological sleep parameters, and the moderating effect of noise sensitivity, among Chinese adults in Hong Kong. We hypothesized that higher noise exposure and noise sensitivity would be associated with higher NRS and physiological sleep parameters, and an interaction effect between noise and noise sensitivity.

2. Methods

2.1. Study design and participants

This was a population-based cross-sectional household survey of individuals aged 18 years and older, conducted in Hong Kong from February 2018 to September 2019. We excluded those who were deaf, needed hearing aids, had psychiatric illness, took pills or other medical treatments for sleep, were pregnant, had children under 2 years of age, were unwilling or unable to wear an ActiGraph Link, or were unwilling or unable to assess nocturnal noise exposure.

Sample size calculation was first based on the assessment of an estimated 30 factors associated with NRS or noise sensitivity and, using the usual rule of thumb of 10 participants per one independent variable, we would need at least 300 participants in total. Second, to assess the moderating effect of noise sensitivity, we considered a conservative error of 0.1 on the standardized interaction effect, which, using a 95% confidence interval (CI), indicated a minimum sample size of 396. Hence, we planned to recruit 500 participants after considering the possibility of participant drop out.

Ethics approval of this study was obtained from the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (Ref no.: UW17-011).

2.2. Procedures

The household sampling began by first obtaining a sample list based on the frame of quarters maintained by the Hong Kong Census and Statistics Department, which is the most complete, up-to-date, and authoritative sampling frame available in Hong Kong. Records of household addresses were organized in quarters and stratified by geographical districts and types of quarters. A systematic sampling design with fixed sampling intervals and non-repetitive random numbers was then applied to obtain a random sample of quarters. For the quarters selected, all households residing in the quarters were included in the survey.

Before household visits took place, notification letters outlining the study details, planned visit times, and interviewer identities were mailed to all targeted households. During the household visits, the eligibility criteria were assessed and written informed consent obtained before taking study measurements.

After providing consent, each participant completed a battery of self-report questionnaires and wore an ActiGraph Link (ActiGraph, US) on their non-dominant wrist for a week. A research assistant then calibrated a noise dosimeter (Spark 706RC, Larson Davis Inc, US, or NSRT Mk2, Convergence Instruments, Canada) using a CAL150 (Larson Davis Inc, US) at 94dB and placed the dosimeter beside the bed, close to ear level during sleep. After a week, another household visit was made to collect the devices and to distribute shopping coupons valued at HK\$300 (around US\$40).

2.3. Measurements

2.3.1. Objective measurements

2.3.1.1. Nocturnal noise exposure

A noise dosimeter, Spark 706RC or the NSRT Mk2, both meeting the American National Standards Institute (ANSI) S1.4, was used to record nocturnal noise exposure for seven consecutive days. It was placed on a stable surface within 2 meters from where a participant slept and recorded A-weighted energy equivalence levels, set at 1-min intervals. Nocturnal noise exposure was calculated as the average daily equivalent continuous sound pressure level from 12:00am to 8:00am ($L_{Aeq,Bh}$).

2.3.1.2. Actigraphy

Objective physiological sleep parameters, including sleep latency, sleep efficiency, time in bed (TIB), total sleep time (TST), wake after sleep onset (WASO), and awakenings and average awakenings, were measured by ActiGraph Link, and calculated by ActiLife (ActiGraph, US) using the Cole-Kripke algorithm, which has been validated among adults [16, 17]. The results of Actigraphy have been demonstrated to be consistent with those of polysomnography [17]. Participants were required to wear an ActiGraph Link strapped securely to the non-dominant wrist for seven consecutive days. A valid record required recording from at least four weekdays and one weekend day. Data obtained from the ActiGraph Link were corroborated by a sleep diary where participants recorded the time they went to bed and the time they woke up every day. Sleep latency was the duration between time in bed and the first minute that the algorithm scored “asleep” [16, 17]. TIB was calculated as the duration between time in bed and time out of bed, and TST refers to the total duration scored as “asleep” [16]. Sleep efficiency was the TST divided by the TIB [16]. WASO was the total time that the participants were awake after sleep onset and awakenings were the number of awakening episodes during the night, while average awakenings refers to the average duration of all awakening episodes [16].

2.3.2. Subjective measurements

2.3.2.1. Nonrestorative Sleep Scale (NRSS)

The Chinese version of the NRSS which includes four domains, namely, refreshment from sleep, the physical/medical symptoms of NRS, daytime functioning, and the affective symptoms of NRS, has been demonstrated to be a valid and reliable instrument for measuring NRS [18]. NRSS scores were standardized on a 0–100 scale, with higher scores indicating less NRS (i.e., better restorative sleep).

2.3.2.2. Weinstein Noise Sensitivity Scale (WNSS)

The WNSS was developed to assess noise sensitivity. The traditional 18-item Chinese version of WNSS has been verified to be a reliable and valid scale to assess noise sensitivity [19]. Each item was rated on a 6-point Likert scale with a total score ranging from 18–108. This score was then standardized to a 0–100 scale. A higher total score indicates more sensitivity toward noise.

2.3.2.3. ENRICHD Social Support Instrument (ESSI)

Social support was assessed via the ESSI. The 6-item Chinese version of the ESSI has a global score of 6–30, with higher scores indicating a higher level of social support [20]. The Cronbach’s alpha of the Chinese version scale was 0.79. The internal consistency of the sample in this study was 0.87.

2.3.2.4. Patient Health Questionnaire (PHQ-15)

Psychosomatic symptoms were assessed using the Chinese version of the PHQ-15, which has been validated in a Chinese population [21]. It comprises 15 somatic symptoms, each assigned a score ranging from 0 (not bothered at all) to 2 (bothered a lot). The items cover the most prevalent DSM-IV somatization disorder somatic symptoms.

2.3.2.5. Perceived Stress Scale (PSS)

The Chinese 10-item PSS was adopted to assess the level of stress in participants. The 10-item version has been demonstrated to have better validity and reliability than the 14-item and 4-item scales. Positive items were reversed-scored before computing the total score. Higher total scores indicate higher stress level [22].

2.3.2.6. Hospital Anxiety and Depression Scale (HADS)

The Chinese version of the HADS was adopted to assess anxiety and depression symptoms of participants. HADS includes 14 items, seven of which measure anxiety and seven measure depression. The subscales were scored independently with each subscale score ranging between 0–21, with higher total scores indicating more severe anxiety/depressive symptoms [23].

2.3.2.7. STOP-BANG questionnaire

The Chinese version of STOP-BANG questionnaire, which was modified from the STOP questionnaire, has been validated in Chinese adults in Hong Kong with high sensitivity, and is an appropriate screening instrument for obstructive sleep apnea (OSA) [24]. Individuals are categorized as having high risk of OSA when they score “Yes” on three or more items.

2.3.2.8. Sociodemographics and lifestyle

Sociodemographic data gathered from participants were age, gender, education level, marital status, occupation, family income, exercise, smoking, as well as consumption of alcohol, cola, soda, coffee, and tea.

2.4. Statistical analysis

A structured multiphase regression analysis was conducted to assess the impact of nocturnal noise, noise sensitivity, and other variables on NRS and physiological sleep parameters. It accounts for the possible causal relationship among the variables by first grouping them into sequential clusters [25]. Specifically, we defined four clusters such that variables in Cluster 1 could affect variables in Clusters 2, 3, and 4, but not vice versa. Similarly, Cluster 2 variables may affect variables in Cluster 3 and 4, but not vice versa, and so on. Cluster 1 included sociodemographic variables, i.e., age, educational level, marital status, occupation and family income. Cluster 2 included lifestyle factors, i.e., exercise, smoking, alcohol, cola, soda, coffee, tea, social support, and nocturnal noise level. Cluster 3 included somatic symptoms, stress, anxiety, and depression levels. Cluster 4 included noise sensitivity and physiological sleep

parameters. The structured multiphase regression analysis was then performed in four phases (i.e., forward stepwise regression). In Phase 1, a regression was conducted on all variables in Cluster 1. In Phase 2, a regression was conducted on all Cluster 2 variables adjusting for Cluster 1 variables that were significant in Phase 1. In Phase 3, a regression was conducted on all Cluster 3 variables with adjustment of Cluster 1 variables that were significant in Phase 1 and Cluster 2 variables that were significant in Phase 2. A similar regression was conducted in Phase 4. The effect of a variable in Cluster 1 was taken as that estimated in Phase 1, while the effect of a variable in Cluster 2 was taken as that estimated in Phase 2, and so on. In addition, we also assessed the interaction between noise sensitivity and nocturnal noise.

All collected data were entered into SPSS version 23 (Armonk, NY: IBM Corp.) and cleaned by cross-checking with the original paper records. The significance level was set at 5%, and all estimates are accompanied with 95% CIs where appropriate. Regression was conducted with RStudio-1.2.1335. Adequacy of the regression models was assessed by examining the studentized residuals. The presence of multicollinearity was assessed by the variance inflation factor (VIF) with the “car” package under RStudio-1.2.1335 [26].

3. Results

3.1. Social-demographic characteristics and NRS status of participants

A total of 1625 individuals were approached. We excluded 584 individuals due to ineligibility. Moreover, 227 refused to participate and 314 were not at home during household visits for more than 5 times. Finally, a total of 500 individuals completed this study. The average age was 39 years old (standard deviation [SD]: 12; range: 18–80). Table 1 shows the sociodemographic and lifestyle characteristics of the participants. All participants completed the 12-item NRSS without any missing values. Table 2 shows the summary of nocturnal noise, noise sensitivity, NRS, physiological sleep variables, social support, somatic symptoms, stress, anxiety, and depression.

Table 1
Social-demographic characteristics of the 500 adults

Characteristics	Mean $\pm$ SD/n	%
Mean age $\pm$ SD	39 $\pm$ 12	
Gender	168	34%
Male	332	66%
Female		
Marital status	171	34.4%
Single	307	61.2%
Married/Cohabited	22	4.4%
Separated/Divorced/Widowed		
Educational level (1 missing)	24	5%
Primary school or below	251	50%
Secondary	224	45%
Bachelor or above		

SD: Standard Deviation

Characteristics	Mean $\pm$ SD/n	%
Occupation	370	74%
Working	73	14%
Not working	15	3%
Retired	42	8%
Students	10	2%
Family income (10 missing)	7	1.4%
< 5,000	17	3.4%
5,000-9999	29	5.8%
10000-14999	46	9.2%
15000-19999	53	10.6%
20000-24999	68	13.6%
25000-29999	37	7.4%
30000-34999	55	11.0%
35000-39999	37	7.4%
40000-44999	131	26.2%
45000-49999		
> 50000		
Aerobic exercise per week	170	34%
No	116	23%
1 hour	88	18%
2 hours	61	12%
3 hours	28	6%
4 hours	37	7%
5 hours or more		
Smoking	404	81%
Never	38	7%
Quit	58	12%
Yes		
SD: Standard Deviation		

Characteristics	Mean $\pm$ SD/n	%
Alcohol	270	54%
Never	36	7%
Quit	194	39%
Yes		
Cola	15	3%
Every day	130	26%
Every week	170	34%
Every month	68	14%
Every year	117	23%
Never		
Soda	10	2%
Every day	78	16%
Every week	139	28%
Every month	57	11%
Every year	216	43%
Never		
Coffee	102	20%
Every day	104	21%
Every week	62	12%
Every month	19	4%
Every year	213	43%
Never		
Tea	108	22%
Every day	198	39%
Every week	81	16%
Every month	14	3%
Every year	99	20%
Never		
SD: Standard Deviation		

Table 2

Summary of noise, WNSS, NRSS, physiological sleep parameters, ESSI, PHQ, PSS, and HADS (n = 500)

	Mean	SD	95%CI
Nocturnal noise level (dBA)	51.32	5.61	50.82, 51.82
WNSS (0-100)	60.44	12.09	59.38, 61.50
NRSS (0-100)	64.77	12.75	63.65, 65.89
Refreshment from sleep	59.16	16.99	57.67, 60.66
Physical/medical symptoms of NRS	68.60	18.39	66.98, 70.22
Daytime functioning	63.01	15.47	61.65, 64.37
Affective symptoms of NRS	65.65	21.30	63.78, 67.52
Physiological sleep parameters	7.13	6.95	6.52, 7.74
Latency (min)	78.34	7.74	77.66, 79.02
Efficiency (%)	441.10	65.17	441.60, 444.09
Time in bed (min)	345.07	57.38	345.22, 345.84
Total sleep time (min)	88.78	37.40	85.50, 92.07
Wake after sleep onset (min)	25.84	7.91	25.14, 26.53
Awakenings (n)	3.48	1.33	3.37, 3.60
Average awakenings (min)	21.39	4.76	20.98, 21.81
ESSI	3.93	3.88	3.58, 4.30
PHQ	15.60	5.31	15.12, 16.10
PSS	4.43	3.47	4.13, 4.75
Anxiety	5.15	3.44	4.83, 5.48
Depression			
SD: Standard Deviation; CI: Confidence Interval; WNSS: Weinstein Noise Sensitivity Scale; NRSS: Nonrestorative Sleep Scale; ESSI: ENRICH Social Support Instrument; PHQ: Physical Health Questionnaire; PSS: Perceived Stress Scale			

3.2. Associations among nocturnal noise, noise sensitivity, NRS, and physiological sleep parameters

Table 3 shows the associations between nocturnal noise, noise sensitivity, NRSS (four subscales), and the physiological sleep parameters. Nocturnal noise was significantly associated with only the physical/medical symptoms subscale of NRSS ($r = 0.09$, $p < 0.05$), and with TIB ($r = -0.15$, $p < 0.01$) and

TST ($r = -0.13$, $p < 0.01$). Noise sensitivity was statistically significantly associated with NRSS ($r = -0.26$, $p < 0.01$), as well as its four subscales, but not with any physiological sleep parameters.

Table 3

Spearman rank correlation between noise sensitivity, noise, NRSS, and physiological sleep parameters (n=500)

	Nocturnal noise	WNSS	NRSS	1	2	3	4	5	6	7	8	9	10	11
Nocturnal noise	1													
WNSS	-0.07	1												
NRSS	-0.05	-0.26**	1											
1. Refreshment from sleep	-0.04	-0.29**	0.71**	1										
2. Physical/medical symptoms of NRS	-0.06	-0.09*	0.77**	0.30**	1									
3. Daytime functioning	0.09*	-0.13**	0.66**	0.48**	0.27**	1								
4. Affective symptoms of NRS	0.05	-0.27**	0.67**	0.33**	0.54**	0.26**	1							
5. Latency	-0.03	-0.05	-0.08	-0.09	-0.08	-0.03	-0.05	1						
6. Efficiency	-0.01	0.02	0.07	0.04	0.13**	-0.02	0.05	-0.34**	1					
7. Time in bed	-0.15**	0.01	0.06	0.16**	-0.03	0.10*	0.01	0.16**	-0.16**	1				
8. Total sleep time	-0.13**	0.01	0.09	0.15**	0.04	0.06	0.04	-0.07	0.44**	0.78**	1			
9. Wake after sleep onset	-0.04	0.02	-0.03	0.04	-0.10*	0.06	-0.05	0.22**	-0.91**	0.48**	-0.10*	1		
10. Awakenings	-0.09	0.06	-0.10*	-0.02	-0.14**	0.04	-0.12**	0.20**	-0.58**	0.49**	0.11*	0.71**	1	
11. Average awakenings	0.01	-0.02	0.06	0.07	0.00	0.05	0.04	0.10**	-0.65**	0.16**	-0.25*	0.64**	-0.02	1

WNSS: Weinstein Noise Sensitivity Scale; NRSS: Nonrestorative Sleep Scale; NRS: Nonrestorative Sleep

*: p-value <0.05; **: p-value <0.01

3.3. Effects of noise sensitivity and nocturnal noise on sleep

Table 4 shows the effects of the different variables on the NRSS global scale. The VIF ranged from 1.03 to 1.56. People who had less family income, exercised less, had less social support, and had more somatic symptoms, stress, anxiety, depression, and noise sensitivity were more vulnerable to NRS, while marriage and cohabitation acted as a protective factor. Nocturnal noise level showed no significant association with the NRSS global scale. However, one unit increase in noise sensitivity was associated with a -0.08 (95% CI: -0.15, -0.01) change in the NRSS global scale. After excluding eighty individuals who were indicated as at high risk of OSA on the STOP-BANG, the effect for noise sensitivity on global scale remained significant (-0.09 [95% CI: -0.17, -0.02]).

Table 4
Structured multiphase regression of NRSS in Chinese adults (n=489)

Variable	Estimate	95% CI	P-value
Phase 1 ($R^2 = 5.0\%$, adjusted $R^2 = 3.6\%$)			
Age	0.01	-0.12, 0.13	0.908
Gender (Ref: Male)			
Female	-1.48	-3.95, 0.98	0.237
Marital status (Ref: Single)			
Married/Cohabited	3.52	0.61, 6.42	0.018*
Separated/Divorced/Widowed	5.89	-0.48, 12.26	0.070
Educational level (Ref: Primary school or below)			
Secondary	-1.55	-6.88, 3.79	0.570
Bachelor or above	-3.45	-9.02, 2.12	0.225
Occupation (Ref: Working)			
Not working	-2.16	-5.88, 1.56	0.255
Retired	-5.03	-10.82, -0.76	0.088
Students	-1.21	-5.86, 3.44	0.610
Family income	0.53	0.08, 0.98	0.021*
Phase 2 ($R^2 = 17.6\%$, adjusted $R^2 = 13.9\%$)			
Exercise	1.13	0.42, 1.83	0.002**
Smoking (Ref: Never smoking)			
Quitted smoking	-2.75	-6.93, 1.43	0.197
Current smoking	-2.19	-5.67, 1.29	0.217
Alcohol (Ref: Never alcohol)			
Quitted alcohol	-3.30	-7.69, 1.08	0.140
Current alcohol	-1.51	-3.91, 0.89	0.217
Cola	0.08	-0.99, 1.15	0.887
Soda	0.47	-0.53, 1.47	0.356
Coffee	0.37	-0.30, 1.03	0.278
Tea	0.17	-0.64, 0.97	0.687

ESSI	0.76	0.52, 0.99	<0.001**
Nocturnal Noise	-0.09	-0.28, 0.10	0.345
Phase 3 ($R^2 = 54.4\%$, adjusted $R^2 = 52.0\%$)			
PHQ	-0.95	-1.21, -0.68	<0.001**
PSS	-0.74	-0.95, -0.53	<0.001**
Anxiety	-0.35	-0.70, -0.00	0.049*
Depression	-0.60	-0.90, -0.31	<0.001**
Phase 4 ($R^2 = 56.0\%$, adjusted $R^2 = 52.8\%$)			
WNSS	-0.08	-0.15, -0.01	0.022*
CI: Confidence Interval; NRSS: Nonrestorative Sleep Scale; ESSI: ENRICH Social Support Instrument; PHQ: Patient Health Questionnaire; PSS: Perceived Stress Scale; WNSS: Weinstein Noise Sensitivity Scale;			
*: p-value <0.05; **: p-value <0.01			

Analyses were conducted on the four NRSS subscales. Nocturnal noise level was not significantly associated with the four subscales of the NRSS: -0.10 (95% CI: -0.34, 0.15), -0.1 (95% CI: -0.33, 0.14), -0.10 (95% CI: -0.33, 0.13) and 0.32 (95% CI: 0.04, 0.60). For every unit increase in noise sensitivity, there was a -0.24 (95% CI: -0.35, -0.12; $p < 0.001$), 0.11 (95% CI: 0.00, 0.22; $p = 0.059$), -0.07 (95% CI: -0.18, 0.03; $p = 0.178$) and -0.22 (95% CI: -0.36, -0.09; $p = 0.027$) change in the refreshment from sleep, physical/medical symptoms of NRS, daytime function, and affective symptoms, respectively, after adjusting for the above-mentioned confounders.

Table 5 shows the impact of nocturnal noise and noise sensitivity on the physiological sleep parameters after adjusting for sociodemographic, lifestyle characteristics, social support, somatic symptoms, stress, anxiety, and depression. The VIF ranged from 1.03 to 1.56 for TIB and TST. Nocturnal noise reduced TIB ($b = -1.46$, 95% CI: -2.51, -0.40) and TST ($b = -1.26$, 95% CI: -2.18, -0.34). However, noise sensitivity did not show any significant changes with TIB ($b = 0.12$, 95% CI: -0.39, 0.62), and TST ($b = 0.04$, 95% CI: -0.39, 0.49).

Table 5
Effects of nocturnal noise and noise sensitivity on physiological sleep parameters (n = 489)

Nocturnal noise				WNSS		
Variables	Estimate	95% CI	p-value	Estimate	95% CI	p-value
Latency	-0.04	(-0.15, 0.07)	0.431	-0.04	(-0.09, 0.01)	0.119
Efficiency	-0.03	(-0.15, 0.10)	0.692	-0.01	(-0.07, 0.05)	0.793
TIB	-1.46	(-2.51, -0.40)	0.007**	0.12	(-0.39, 0.62)	0.652
TST	-1.26	(-2.18, -0.34)	0.007**	0.04	(-0.39, 0.49)	0.872
WASO	-0.13	(-0.73, 0.48)	0.684	0.11	(-0.18, 0.40)	0.457
Awakenings	-0.11	(-0.24, 0.02)	0.085	0.04	(-0.02, 0.11)	0.159
Average Awakenings	0.01	(-0.01, 0.03)	0.382	0.00	(-0.01, 0.01)	0.790
CI: Confidence Interval; WNSS: Weinstein Noise Sensitivity Scale; TIB: total time in bed; TST: total sleep time; WASO: wake after sleep onset;						
**: p-value < 0.01						

For both NRS and physiological sleep parameters, there was no significant interaction between nocturnal noise and noise sensitivity ($p \geq 0.165$).

3.4 Additional analysis

We also fitted a model with all the physiological sleep parameters included as the independent variables in Phase 4 along with noise sensitivity in the regression model for NRS. However, none of the sleep parameters were associated with NRS after adjusting for the above-mentioned variables while noise sensitivity remains significantly associated with NRS (-0.08, 95% CI: -0.15, -0.01).

4. Discussion

This was the first study that assessed the association between nocturnal noise, noise sensitivity, and NRS by using standardized scales and adjusting for relevant confounders. The average NRS level of Chinese adults in Hong Kong was 64.77 ± 12.75 . The results revealed that noise sensitivity, as well as lifestyle, sociodemographic attributes, physical and psychosocial health were associated with NRS.

The average nocturnal noise level in the participants' bedrooms was 51.32 ± 5.61 dBA, which was beyond the suggested level of 30–40dBA at night [27]. NRS was independent of nocturnal noise level while TIB and TST were shown to be negatively associated with noise in this study. This was consistent with a previous study that revealed the relationships of noise, noise annoyance, and objective and subjective sleep parameters [28]. People who live in noisy areas may be more easily influenced by noise, and tend to have less TIB [29]. Furthermore, noise has been shown to fragment sleep, reduce sleep continuity and

TST, and increase awakenings and shifts between stages of sleep [30]. These factors may result in less “asleep” time of the individuals.

Consistent with our hypothesis, there was a direct association between noise sensitivity and NRS during the night-time. We found that every unit increase of WNSS (0–100) resulted in a 0.08 unit decrease of NRSS (0–100), but was not significantly associated with changes in physiological sleep parameters after adjusting for nocturnal noise, sociodemographics, lifestyle factors, physical and psychosocial health. It is unlikely that people who are more noise sensitive would have substantially more emotional responses to noise when they are asleep, as they should then also have more changes in their physiological sleep levels under the general stress model. Alternatively, the potential influence of noise sensitivity on NRS may be attributed to the higher vulnerability of noise sensitive people to day-time noise exposure whose stress-related responses have not recovered by the time they go to sleep. Further studies that incorporate day-time noise measurements will be necessary to confirm this hypothesis. In addition to the global scale of the NRSS, higher noise sensitivity was also associated with the less refreshment from sleep and more affective symptoms scales. The refreshment from sleep scale shares similar interpretation as the global scale. For affective symptoms, they have been shown to be influenced by introversion and extroversion [31], which are two personality traits that have also been shown to be associated with noise sensitivity [12].

Individuals who had higher family income had less NRS in this study. Previous study indicated that sleep quality declined with decreasing income [32]. Individuals with higher family income may have less living stress which may help decrease NRS level.

In this study, people who exercised more were less vulnerable to NRS. Previous studies showed that a combined unhealthy lifestyle, which included low or no exercise, would lead to NRS [7], whereas higher intensity exercise was associated with shorter sleep latency and fewer awakenings [33]. Exercise could shorten the N1 stage of non-rapid-eye-movement sleep, which is the stage of very light sleep, while increasing rapid-eye-movement (REM) sleep, sleep continuity, and sleep efficiency [34]. Therefore, exercise could be beneficial for relieving NRS.

Married or cohabited people suffered less NRS when compared with people who were single. A previous study also showed that married adults had better sleep characteristics measured by ActiGraph, such as total sleep time and wake after sleep onset [35]. This may due to the supportive relationship that helps improve sleep quality [36]. Indeed, our study also indicated that people with higher social support had less NRS. Adequate social support is a stress reliever, and it can strengthen individual resilience to stress [37].

This study showed that PHQ was associated with NRS. NRS was suggested to be associated with chronic medical disorders [3]. For example, NRS is common in patients with fibromyalgia syndrome [38]. Individuals who suffer from somatic symptoms like pain may have difficulty falling asleep and more awakenings after sleep onset, which can then increase the risk of poor sleep and NRS.

This study also demonstrated that stress, anxiety, and depression were associated with increased NRS as reported by previous study. Stressful events and psychosocial stressors might induce increased sleep latency and awakenings, and reduced slow wave sleep (SWS) and sleep efficiency [39]. Anxious individuals were reported to have longer sleep latency, a smaller percentage of SWS, more early microarousals, and a lower REM sleep density compared with those with lower levels of anxiety [40]. Lastly, depressive individuals were characterized by a decrease of SWS and sleep efficiency in addition to an increase of the percentage and density of REM [41]. Conclusively, people who are anxious, depressive, and experiencing stressful events may be more vulnerable to NRS.

Lastly, this study indicated that none of the obtained physiological sleep parameters in this study were associated with NRS. Scholars proposed a possible association between alpha activity and NRS among people with chronic fatigue syndrome. However, the fact that people without such symptoms also had NRS caused doubt on this link [1]. As there remains a lack of study on the relationship between objective physiological sleep parameters and NRS, a more precise and functional device which can reveal more sleep parameters is worthy of research to test the relationship between specific physiological sleep parameters and NRS.

Daytime noise, which may also influence NRS and physiological sleep parameters, was not investigated in this study. This would require the assessment of personal noise exposure by asking the participants to carry a noise dosimeter all day. However, this can be highly demanding to the participants and innovation in assessing personal noise exposure would be helpful in this regard. In addition, despite controlling a number of covariates, factors like light were not investigated in this study; further study could be conducted to fill this gap. Moreover, the mechanism underlying why noise sensitive people were more vulnerable to NRS is worth studying since people are considered to be less reactive to the outside environment when sleeping.

5. Conclusions

In conclusion, there was a significant association of noise sensitivity with NRS and nocturnal noise levels did impact physiological sleep parameters. The results indicate that practitioners should assess noise sensitivity in patients with NRS. Interventions targeting reducing noise sensitivity and controlling noise level are necessary for improving subjective and objective sleep conditions.

Abbreviations

CI, confidence interval; ESSI, ENRICH Social Support Instrument; HADS, Hospital Anxiety and Depression Scale; NRS, nonrestorative sleep; NRSS, Nonrestorative Sleep Scale; OSA, obstructive sleep apnea; PHQ, Patient Health Questionnaire; PSS, Perceived Stress Scale; REM, rapid-eye-movement; SD, standard deviation; SWS, slow wave sleep; TIB, time in bed; TST, total sleep time; VIF, variance inflation factor; WASO, wake after sleep onset; WNSS, Weinstein Noise Sensitivity Scale

Declarations

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Authors' contributions

SL involved in the data collection, analyzed and interpreted the data, drafted and revised the manuscript. DYTF designed the study and revised the manuscript critically for important intellectual content. All authors made important contributions to the revision of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality.

Ethics approval and consent to participate

Ethics approval of this study was obtained from the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (Ref no.: UW17-011). The written informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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