

# BMJ Open Effect of noise tolerance on non-restorative sleep: a population-based study in Hong Kong

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## ABSTRACT

**Objective** The aim of this study was to assess the impact of auditory noise tolerance on non-restorative sleep using an objective audiometric test in a representative sample.

**Design** A total of 202 Chinese individuals aged 15 years and above were recruited from a population-based household survey. Their non-restorative sleep was assessed by a single item, the degree of feeling refreshed on waking up, on a 0–10 scale, while noise tolerance was measured by the most comfortable level expressed in A-weighted decibels.

**Results** The 202 individuals (106 women) had a mean degree of feeling refreshed on waking up of 6.5 on the 0–10 scale and a mean maximum comfortable sound level of 69.2 dB. A multivariable analysis showed that a 1 dB increase in noise tolerance was associated with a 0.1-unit increase in the degree of feeling refreshed after adjusting for age, education, marital status, occupation, exercise, smoking, alcohol consumption, household noise level, stress, anxiety and depression. Moreover, housewives, non-smokers and individuals who were less anxious or stressed felt significantly more refreshed on waking up.

**Conclusion** People with higher levels of noise tolerance experienced more refreshing sleep. Additional clinical consideration of enhancing noise tolerance in patients with sleep complaints is needed.

## INTRODUCTION

Non-restorative sleep (NRS) is defined as feeling unrefreshed on waking up, and it has been found to affect approximately 4.7%–44% of the general adult population.<sup>1–6</sup> NRS has been listed in the International Classification of Sleep Disorders, third edition, as a defining symptom of insomnia, obstructive sleep apnea, fibromyalgia and some other sleep disorders.<sup>7</sup> However, it may not necessarily coexpress with other insomnia symptoms such as difficulty falling and staying asleep.<sup>8</sup> NRS may cause feelings of fatigue during the day; hinder work performance; reduce physical capacity; and cause other chronic illnesses, occupational injuries, impaired psychological well-being and even suicidal ideation.<sup>3 8–11</sup> NRS is a manifestation of sleep problems or disorders that may be caused by intrinsic factors, including age,

## Strengths and limitations of this study

- The main strength of this study is the assessment of the association between noise tolerance and non-restorative sleep in the largest study to date with the additional adjustment of potential confounding effects of anxiety and depression.
- Our study is limited to the lack of nocturnal noise assessment which may have moderated the identified association.
- We use maximum comfortable level which is preferred to assess the impact of auditory tolerance to noise on non-restorative sleep.

obesity, smoking, a lack of regular exercise, stress, anxiety and depression, and extrinsic factors, such as long working hours and environmental noise.<sup>4 5 12–14</sup> Hence, there has been an increase in attention on NRS as a target for treatment.<sup>8</sup>

Noise tolerance refers to the vulnerability of an individual to noise.<sup>15</sup> People with reduced noise tolerance may not tolerate sounds at intensity levels considered comfortable by most other people. Reduced noise tolerance may be caused by ageing, injury or prolonged exposure to loud sounds and is frequently observed in patients suffering from tinnitus. Functional MRI studies have shown that reduced noise tolerance is associated with elevated auditory activity in the midbrain.<sup>15</sup> Therefore, such central auditory gain has been a physiological target of sound-enrichment therapies for improving noise tolerance and tinnitus.<sup>16 17</sup> Hence, noise tolerance can be a modifiable factor in the disorders it causes.

Reduced noise tolerance, measured as a personality trait, has been previously shown to be associated with health problems.<sup>18</sup> In particular, people who are less noise tolerant have been shown to experience various sleep disturbances, including NRS and poor sleep quality.<sup>19 20</sup> One may hypothesise the adverse influence of noise tolerance on health by the



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general stress model.<sup>21</sup> Under the model, people who are less noise tolerant are more easily annoyed by noise that induces stress-related cortisol, leading to different health problems. However, a study of 1495 Finnish adults showed that noise tolerance, measured as a personality trait, was not significantly associated with annoyance to noise during daytime or night-time.<sup>22</sup> Hence, there has been a conjecture of a direct influence of noise tolerance on subjective evaluation of sleep quality without having the noise-induced annoying feeling at night.<sup>19</sup> However, most previous studies used small sample sizes (fewer than 100 subjects), and the observed associations may be confounded by known prognostic factors such as anxiety and stress. In addition, while noise tolerance was assessed using well-validated self-report questionnaires, physiological measures, such as the maximum comfortable level, are preferred to assess the impact of auditory tolerance to noise on NRS.

Therefore, this study aimed to assess the impact of reduced noise tolerance on NRS using an objective audiometric test in a larger representative sample from a household survey.

## METHODS

### Design

This was a population-based household study performed in Hong Kong. The study protocol and informed consent form were approved by the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster.

### Participants and sampling

We planned to recruit 200 individuals aged 15 years and older in Hong Kong. Those who were deaf or unable to read and communicate in Chinese were excluded. The sample size was large enough to examine 20 factors in a regression analysis using the usual rule of thumb of 10 participants per factor.<sup>23</sup>

Recruitment was performed in households by trained research assistants. Based on a representative sampling frame of residential addresses obtained from the Hong Kong Census & Statistics Department, a random sample of addresses was drawn after stratifying by geographical districts and types of dwellings. Before household visits took place, notification letters were mailed that described the study details, planned visit times and identities of the interviewers. During each household visit, the eligibility criteria were assessed and written informed consent was obtained before the study measures were taken.

### Measures

#### Non-restorative sleep

NRS was assessed using a single item, 'How refreshed did you feel on waking up over the past month?' Responses were made on a 0–10 scale, where 0=not at all and 10=fully refreshed. The same item was adopted in a

large cross-sectional survey, except that we used a 0–10 measurement scale rather than a yes/no answer.<sup>5</sup>

### Anxiety and depression

The 14-item Hospital Anxiety and Depression Scale (HADS), made up of anxiety (HADS-A) and depression (HADS-D) scales, was used to assess anxiety and depression. The Chinese version has been validated with good psychometric properties found for it.<sup>24</sup> All items were rated on a 4-point Likert scale with the total score of each scale ranging between 0 and 21 after reverse coding. A higher score indicated a higher level of anxiety or depression.

### Stress

Perceived stress was assessed using the 14-item Perceived Stress Scale (PSS).<sup>25</sup> It has been translated and validated in the Chinese population.<sup>26</sup> Each item was rated on a 5-point Likert scale. The total score, after reverse coding some items, ranged from 14 to 40, with a higher score indicating a higher perceived stress level.

### Noise tolerance

Noise tolerance was assessed by obtaining the subject's most comfortable level (MCL) of hearing. Specifically, each participant was asked to listen to a highly repetitive locomotive soundtrack in earphones connected to a portable digital sound player (Creative MuVo T200) with 25-vol levels. The soundtrack was played at the lowest volume level for 5 s and was increased by one level at a time until the subject indicated that it was too loud. The volume level before which the participant indicated that it was too loud was considered to be the MCL.

Each volume level was mapped into A-weighted decibel (dBA) units using an IEC651 Type 2 and ANSI S1.4 Type 2 compliant digital sound level meter (SL-5868P) with a resolution of 0.1 dBA. Specifically, for each volume level, three 30s A-weighted equivalent sound pressure levels were measured and their average was taken as the sound level of the volume level in dBA. The mapped volume levels ranged from 48.9 to 82.3 dBA. The three repeated measurements had SDs ranging from 0.06 to 0.6 dBA and an intraclass correlation of 1.0 based on a one-way random effects model.

### Household noise level

The noise level at the interview area was assessed by using the sound level meter (SL-5868P) with the microphone placed at least 1 m from any surface. A 1 min A-weighted equivalent sound pressure level was measured.

### Statistical analysis

We performed univariable and multivariable linear mixed effects regressions of the degree of feeling refreshed after sleep on demographics, hours of aerobic exercise per week, smoking habits, alcohol consumption, household noise level, HADS-A, HADS-D, PSS and noise tolerance. Potential bias was minimised by considering more potential confounding variables than previous studies. The

linear mixed effects approach was adopted to account for the possibility of extra covariance among individuals in the same household. To alleviate the potential influence of deteriorated hearing ability among older people, the moderating effect of age was assessed. In addition, the analysis was repeated in individuals at most 40 years old.

The model's adequacy was assessed by examining the residuals. The presence of multicollinearity was also checked by obtaining the tolerance. Missing values were discarded as there were only a few. The nominal level of significance was taken as 5% and all statistical tests were two tailed. The analysis was performed using SAS V.9.2 software.

## RESULTS

A total of 202 Chinese individuals from 80 households were recruited in August and September of 2013. Their characteristics are summarised in table 1. The mean age was 32 years (range: 15–95 years). Most participants were married (64%) and had at least a secondary education level (82%). Only 14% were retired or seeking employment. Most individuals (54%) did not exercise regularly, 14% were current smokers and 23% were consumers of alcohol. The mean noise tolerance level was 69.2 dBA (SD=4.2 dBA, range=53.1–82.3 dBA) with a 95% CI of (68.6 to 69.8). Only seven participants (3.5%) tolerated the noise at the maximum volume level. The mean degree of feeling refreshed after sleep was 6.5 (range=0–10; 95% CI 6.2 to 6.8), with 1 (0.5%) participant stating that they did not feel at all refreshed after sleep and 8 (4%) participants stating that they felt fully refreshed after sleeping.

Table 2 displays the effects of factors on feeling refreshed after sleep in the univariable and multivariable analyses. Factors found to be significantly associated ( $P<0.05$ ) with lower degrees of feeling refreshed after sleep included not being a housewife, being a current smoker, being more anxious, having a higher level of perceived stress and being more tolerant to noise. These results were observed regardless of whether adjustments for other factors were made. The moderating effect of age on the effect of noise tolerance on the degree of feeling refreshed after sleep was insignificant ( $P=0.30$ ). In addition, among the 131 individuals of age at most 40 years, the estimated effect of noise tolerance on the degree of feeling refreshed after sleep was 0.14 (95% CI 0.08 to 0.21,  $P<0.01$ ).

In all of the models, residuals did not show severe departures from the normal distribution assumption. The tolerance ranged 0.51–0.93, indicating the absence of multicollinearity.

## DISCUSSION

This was the first study to assess to what extent feeling refreshed after sleep would be associated with noise tolerance using MCL measurements. After accounting for the potential confounding effects of demographics, exercise

**Table 1** Sample characteristics of 202 individuals

	Mean (SD) or n (%)
Age (years)	32.0 (13.1)
Gender	
Female	106 (52.5%)
Male	96 (47.5%)
Marital status (1 missing)	
Single	68 (33.8%)
Married	128 (63.7%)
Cohabiting	2 (1.0%)
Widowed	3 (1.5%)
Education level (1 missing)	
Primary or below	36 (17.9%)
Secondary/associate degree	119 (59.2%)
Tertiary degree or above	46 (22.9%)
Occupation (1 missing)	
Employed	120 (59.7%)
Self-employed	7 (3.5%)
Employer	4 (2.0%)
Housewife	24 (11.9%)
Seeking employment	9 (4.5%)
Student	15 (7.5%)
Retired	22 (10.9%)
Hours of aerobic exercise per week	
0	109 (54.0%)
1	23 (11.4%)
2	31 (15.3%)
3	6 (3.0%)
4	10 (5.0%)
≥5	23 (11.4%)
Smoking	
No	161 (79.7%)
Former smoker	13 (6.4%)
Yes	28 (13.9%)
Alcohol consumption	
No	140 (69.3%)
Former drinker	16 (7.9%)
Yes	46 (22.8%)
Household noise level (dBA)	64.0 (4.9)
HADS-A	6.2 (3.6)
HADS-D	7.9 (3.1)
Perceived Stress Scale (1 missing)	27.2 (4.6)
Noise tolerance (dBA)	69.2 (4.2)
Feeling refreshed after sleep (6 missing)	6.5 (1.8)

HADS-A, Hospital Anxiety and Depression Scale—Anxiety; HADS-D, Hospital Anxiety and Depression Scale—Depression.

habits, smoking, alcohol consumption, household noise level, anxiety, depression and stress, the ability to tolerate a noise level of 1 dBA higher was significantly associated

**Table 2** Factors associated with feeling refreshed after sleep

Factor (unit/plausible range)	Univariable analysis			Multivariable analysis		
	Coefficient	95% CI	P value	Coefficient	95% CI	P value
Age (years)	0.01	-0.004 to 0.03	0.136	0.0003	-0.02 to 0.02	0.980
Gender						
Female	0.26	-0.19 to 0.72	0.247	-0.06	-0.54 to 0.41	0.791
Male	0	-		0	-	
Marital status						
Married/cohabitating	0.47	-0.04 to 0.98	0.073	0.12	-0.49 to 0.73	0.697
Single/widowed	0	-		0	-	
Education level	-0.36	-0.73 to 0.003	0.052	-0.10	-0.57 to 0.38	0.704
Occupation			0.002			0.049
Housewife	1.52	0.79 to 2.24	<0.001	1.15	0.36 to 1.93	0.005
Seeking employment	0.53	-0.60 to 1.65	0.353	0.46	-0.60 to 1.53	0.388
Retired	0.58	-0.19 to 1.36	0.139	0.43	-0.51 to 1.36	0.367
Student	0.04	-0.89 to 0.96	0.937	0.42	-0.59 to 1.43	0.413
Employed/self-employed/employer	0	-		0	-	
Hours of aerobic exercise per week	-0.10	-0.24 to 0.05	0.196	0.01	-0.13 to 0.15	0.904
Smoking			0.008			0.008
Yes	-1.01	-1.67 to -0.36	0.003	-1.23	-2.00 to -0.46	0.002
Former smoker	0.28	-0.67 to 1.22	0.564	-0.15	-1.18 to 0.89	0.780
No	0	-		0	-	
Alcohol drinking			0.268			0.574
Yes	-0.49	-1.08 to 0.10	0.105	0.23	-0.39 to 0.84	0.463
Former drinker	-0.15	-1.07 to 0.77	0.742	0.47	-0.54 to 1.48	0.363
No	0	-		0	-	
Household noise level (dBA)	0.02	-0.05 to 0.08	0.573	0.0001	-0.06 to 0.06	0.997
HADS-A (0–21)	-0.18	-0.25 to -0.11	<0.001	-0.18	-0.26 to -0.10	<0.001
HADS-D (0–21)	0.004	-0.08 to 0.09	0.931	0.08	-0.01 to 0.17	0.070
Perceived Stress Scale <sup>14–40</sup>	-0.09	-0.14 to -0.04	0.001	-0.07	-0.12 to -0.01	0.024
Noise tolerance (dBA)	0.07	0.004 to 0.13	0.037	0.10	0.04 to 0.16	0.001

HADS-A, Hospital Anxiety and Depression Scale—Anxiety; HADS-D, Hospital Anxiety and Depression Scale—Depression.

with a 0.1-unit increase in feeling more refreshed after sleep on a 0–10 scale.

The noise tolerance in our sample, as measured by the MCL with earphones, ranged from 53 to 82 dBA, corresponding to the sound level of a quiet office up to that of city traffic.<sup>27</sup> Its mean level of 69 dBA corresponds to the sound intensity of a vacuum cleaner or hair dryer. This is slightly higher but comparable to a previously reported average MCL of 63 dBA in normal listeners in the United States, which was measured by levelling the loudness of taped speech noise in a cafeteria via earphones.<sup>28</sup> Noise tolerance in the Chinese population has received little attention. The observed difference could be due to the difference in measurement methods or ethnic differences. Caucasians, who generally have larger bodies than Chinese people, have been previously shown to have lower wideband energy reflectance at the lower sound

frequencies, where locomotive and speech noise occur. With lower wideband energy reflectance, more sound energy is absorbed by the middle ear and transferred to the cochlea; thus, less tolerance for noise is observed.<sup>29</sup> However, the role of wideband energy reflectance on ethnic differences in noise tolerance requires further investigation.

The mean degree of feeling refreshed on awakening in the Chinese population in Hong Kong was 6.2 out of a maximum of 10 points, which corresponds to feeling only 62% refreshed on waking up. This is very similar to results reported in Germany.<sup>19</sup> The degree of feeling refreshed has not often been reported in the literature. Rather, dichotomous responses of yes or no have generally been used, which is how prevalence estimates were obtained. While a dichotomous response choice is easier to obtain and interpret, a Likert scale with more response

choices or a continuous response scale will have a higher measurement hierarchy with a lower sample size requirement. They also allow for the assessment of improvements after treatment. Nevertheless, a threshold above which the degree the feeling refreshed on waking would be considered to be not refreshing can be determined for estimating the prevalence of individuals not feeling refreshed, by concurrently administering the dichotomous and Likert scales.

A 1 dBA increase in MCL was associated with feeling 1% more refreshed after a night of sleep independent of other known prognostic factors of NRS. An association between psychological noise tolerance and sleep quality has been previously reported.<sup>19 30</sup> However, in this study, auditory noise tolerance was assessed and expressed in dBA for the first time, which is more interpretable than a self-reported scale, and more factors prognostic to NRS were considered. Although, psychological noise tolerance, being a stable personality trait, may not necessarily correlate with auditory noise tolerance which may be also influenced by hearing loss, their associations with NRS have been observed. Noise-tolerant individuals are less reactive to noise. Their sleep quality would be less impaired by surrounding noise and, as a result, they would likely have higher quality sleep and feel more refreshed afterwards. People with reduced noise tolerance may suffer from hyperacusis and need to wear high-decibel noise-reduction ear plugs in order to reduce the adverse effects of environmental noise.

Our study shows that housewives report having more refreshing sleep than the working group, even after accounting for effects due to common prognostic factors of sleep quality, such as exercise, stress, anxiety and depression. A large national face-to-face household survey in the United States reported that non-working people had longer sleep durations than a group of people who worked.<sup>31</sup> Shorter sleep durations have been found to be associated with a higher risk of experiencing non-refreshing sleep.<sup>32</sup> Housewives could have more flexible hours in which they can obtain adequate sleep; thus, they feel more refreshed after sleep. Interestingly, that association is contrary to other studies that found that housewives were more prone to experiencing insomnia, chronic pain and fatigue.<sup>33 34</sup> However, these studies did not adjust for the effect of stress in addition to the influence of noise tolerance. Given that stress is known to be associated with disturbed sleep, it might have confounded the previously observed association between being a housewife and sleep quality.<sup>35</sup> Moreover, these were telephonic surveys through landline phones, which may have a limited reach of target individuals due to the increasing trend of exclusively using mobile phones.

The observed adverse influences of smoking, anxiety and stress in this study have also been previously reported.<sup>35–37</sup> However, we did not observe an association between depression and the degree of feeling refreshed on waking up despite the fact that depression has been known to be associated with insomnia.<sup>38</sup> Indeed, our study

showed that people with depression tended to feel more refreshed on wake up, although this trend was statistically insignificant. Depressed people would experience dysregulation of their hormonal systems; specifically, they would experience an increase in the production of corticotropin-releasing factor, enhancing the release of cortisol.<sup>39</sup> Therefore, depressed people may have heightened alertness, preventing them from falling and staying asleep. Hence, they may feel more refreshed when waking up, not because of adequate sleep but because of their level of alertness. However, there were few severely depressed individuals included in our sample, so a study with a larger cohort will be needed to assess the association between depression and NRS.

This study used a repetitive locomotive soundtrack to assess the MCL. The soundtrack was chosen to have a relatively stable acoustic characteristic throughout the play. However, other studies had used other soundtracks, such as normal speech, when assessing MCL.<sup>28</sup> Sounds of different acoustic characteristics at even the same loudness level may be reacted with different neural activities in humans that induces different emotional responses.<sup>40</sup> Although the use of different sound stimuli may not have profound impact on the association of MCL with other measures, it is desirable to standardise the assessment of MCL. The soundtrack used in this study would be available from the authors.

Although we carefully designed and conducted this study, several limitations worth noting remain. First, we assessed NRS using a single self-reported item, the degree of feeling refreshed on awakening. This may not fully capture all NRS symptoms experienced, for example, the night-time aspects of NRS. A systematic review found no well-validated self-reported scales for evaluating NRS<sup>8</sup>; until recently, the Non-restorative Sleep Scale (NRSS) was developed and validated for clinicians to use to identify and monitor the severity of NRS symptoms.<sup>41</sup> However, it is not available in Chinese, and further development of the tool for the Chinese population is necessary. Second, NRS was self-reported which may subject to recall bias or concern of low reliability. Objective measures of NRS have been proposed including electroencephalography (EEG) during sleep.<sup>42</sup> However, there had not been any objective measures with demonstrated diagnostic accuracy for NRS.<sup>42</sup> Third, we did not assess the participants' hearing ability. Older people are more prone to hearing problems which may confound or moderate the observed association of noise tolerance on NRS. However, our results showed no evidence that age moderated the association and the subgroup analysis of individuals of at most 40 years old resulted in similar results. Hence, our observed association may not have been substantially influenced by hearing ability despite further study would be desirable. Fourth, to ensure better study participation, the MCL assessment was conducted at subjects' households rather than in a laboratory setting where we can have more control of the surrounding sound level. With the use of the standard earphones supplied with

the digital sound player that may not be well protecting from external noise, the MCL may have been inflated in noisy households. This may increase the variation of MCL and reduce the power of identifying an association. However, given that we observed a highly significant association between noise tolerance and NRS, we should not have suffered from an inadequate power. Fifth, we did not assess the subjects' night-time indoor noise exposure, which is also a factor associated with NRS. The assessment of that would require setting up a reliable noise meter with continual recording of data throughout the night in each household. Such a set-up would be inconvenient for the households and would reduce their willingness to participate in our study, resulting in a limitation to the study's generalisability.

In conclusion, a 1 dBA increase in MCL was associated with feeling 1% more refreshed after sleep. This suggests a need for additional clinical consideration to clinicians of increasing the noise tolerance of patients with sleep complaints.

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