

# Neighbour and traffic noise annoyance: a nationwide study of associated mental health and perceived stress

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**Background:** Noise exposure is a well-known risk factor for multiple adverse health effects. Annoyance is the most prevalent response to environmental noise and may result in negative emotional responses, including poor mental health and high levels of perceived stress. The aim of this study was to investigate the association between neighbour and traffic noise annoyance, and mental health and perceived stress. **Methods:** Data were derived from the Danish Health and Morbidity surveys in 2010 and 2013. The study was based on a random sample of the adult population in Denmark living in multistorey housing ( $n = 7090$ ). Information on neighbour and traffic noise annoyance during the past 2 weeks, and mental health and perceived stress, using Short Form-12 and Perceived Stress Scale instruments, respectively, was obtained by means of self-administered questionnaires. Multiple logistic regression models were used to examine the associations between noise annoyance and poor mental health, and high perceived stress levels, respectively. **Results:** Those who reported being very annoyed by neighbour noise had 2.34 [95% confidence interval (CI): 1.83–2.99] times higher odds of having poor mental health and 2.78 (95% CI: 2.25–3.43) times higher odds to experience a high level of perceived stress than individuals not annoyed by noise from neighbours. Similar associations were observed with traffic noise annoyance. **Conclusion:** The results from this study indicate that there is a strong relationship between noise annoyance and poor mental health and high levels of perceived stress among individuals living in multistorey housing in Denmark. Future studies are needed to determine the direction of causality.

## Introduction

It is well-known that exposure to environmental stressors may have adverse effects on health.<sup>1,2</sup> Among such stressors, studies have found persistent or high levels of environmental noise, such as traffic noise, to negatively affect, e.g. sleep quality and cardiovascular health.<sup>1–7</sup>

Noise annoyance, which can be seen as a negative emotional and attitudinal reaction to noise,<sup>8</sup> is the most prevalent and immediate response in a population exposed to environmental noise and exposure may interfere with daily activities, feelings, thoughts, rest or sleep and may be accompanied by negative emotional responses such as irritability, distress, exhaustion and other stress-related symptoms.<sup>9</sup> Susceptibility or resistance to stressor-induced health effects depends on a complex interaction between stressor and coping strategies developed through previous experiences, psychological, biological and social factors as well as competing stressors and personality type.<sup>10</sup> Noise sensitivity is suggested to be one of the most important non-acoustic modifiers of the relationship between noise and subjective perception and reaction.<sup>5,11</sup> Thus, although people tend to gradually adapt to noise exposure, the degree of habituation differs substantially between individuals, i.e. according to their noise sensitivity.<sup>12,13</sup> Habituation is, however, rarely complete and after prolonged exposure adverse health effects may develop.<sup>9</sup>

Exposure to noise may affect health and well-being by activation of 'direct' and 'indirect' pathways of stress reactions, sleep-stage changes and other biological and biophysical effects.<sup>5</sup> This may in turn negatively affect various health risk factors such as blood pressure, potentially causing a relatively small proportion of the population to develop clinical symptoms of e.g. insomnia or cardiovascular disease. As a consequence, mortality risk is increased among individuals with such clinical presentations.

According to the World Health Organization, it is estimated that disability-adjusted life-years (DALYs) (i.e. the number of years lost because of disability or death, a measure that combines both morbidity and mortality) from environmental traffic noise are 61 000 years for ischaemic heart disease and 903 000 years for sleep disturbance in the European Union member states and other Western European countries.<sup>1</sup> Moreover, an additional 654 000 DALYs are lost from environmental traffic noise annoyance, thereby constituting the main burden of environmental noise along with sleep disturbances.<sup>1</sup>

Most studies investigating the impact of environmental noise on health outcomes use road traffic or aircraft noise as the environmental noise exposure, which can be objectively quantified by physical parameters.<sup>14</sup> However, other sources of noise exist, e.g. various neighbour noises that are more complex and generally not quantifiable.<sup>15</sup> Individual and subjective perceptions of noise are often assessed by means of survey questions targeting noise annoyance, and there are reasons to suspect that neighbour noise annoyance affects health,<sup>15</sup> e.g. because of its largely unpredictable nature and typically with a very high informational content, which may lead to conflict between neighbours.

Although convincing evidence exists that exposure to environmental noise affects physical health,<sup>1–6</sup> only few studies have assessed the impact of noise annoyance on mental health indicators, including stress. These studies consistently suggest mental health to be negatively associated with noise annoyance.<sup>9,15,16</sup> Interestingly, Hammersen et al.<sup>16</sup> found mental health to be more negatively affected by neighbour noise than by both traffic and aircraft noise, i.e. that neighbour noise induced more annoyance than other sources of environmental noise. This finding suggests that despite neighbour noise probably resulting in exposure to lower noise levels,<sup>17</sup> this source of noise annoyance may exceed those from road traffic and aircrafts in terms of adverse effects on mental health.

Mental health has become an area of increasing focus in public health research. However, the association between noise annoyance and mental health is still understudied. Thus, the aim of this study was to examine the association between neighbour and traffic noise annoyance and mental health and perceived stress, respectively, in the general adult population living in multistorey housing in Denmark.

## Methods

Data were derived from the Danish Health and Morbidity surveys in 2010 and 2013 (the national subsamples in the Danish National Health surveys).<sup>18,19</sup> The major aim of the surveys is to describe the status and trends in health and morbidity in the adult Danish population and the factors that influence health status. In 2010, a nationally representative random sample of 25 000 Danish adults (16 years or older) was drawn from the Danish Civil Registration System.<sup>20</sup> This register includes individual information on e.g. the unique personal identification number, name, sex, date of birth, marital status and address. A random subsample of 5517 individuals of the 25 000 invited to the survey in 2010 (and still alive and resident in Denmark) was re-invited to the survey in 2013. Thus, the survey in 2013 consisted of both randomly selected individuals from the sample in 2010 and a new nationally representative random sample of adult Danes. The total sample size in 2013 was also 25 000 individuals.

The invited individuals were sent a postal questionnaire and a letter of introduction, which briefly described the purpose and content of the survey. Individuals could choose either to complete the enclosed paper questionnaire or an identical web questionnaire. Thanks to the unique personal identification number, linkage at an individual level between survey data and administrative registers is possible in Denmark. Thus, information on type of housing (e.g. one-family houses, multistorey housing) was obtained from the Building and Housing Register.<sup>21</sup>

In all, 15 165 individuals completed the questionnaire in 2010 (response proportion: 61%) and 14 265 individuals in 2013 (57%). Individuals who participated in both surveys were omitted from the latter sample ( $n = 2593$ ). Hence, the pooled sample consisted of 26 837 individuals, out of which 7090 individuals lived in multistorey houses. This proportion is somewhat lower than in the entire Danish population (~34% of the adult population live in multistorey houses).<sup>22</sup> How the study population was derived is also described in a flow-chart in Supplementary figure S1.

Noise annoyance was assessed by asking the respondent whether they had been annoyed by noise from traffic or noise from neighbours, respectively, in their home during the past 2 weeks. The possible response categories were 'yes, very annoyed', 'yes, slightly annoyed' and 'no'. The two measures were also combined into a single measure (i.e. annoyed by noise from traffic and/or neighbours).

Poor mental health was assessed by using the Mental Component Summary (MCS) scores from Short Form-12 (SF-12 version 2).<sup>23</sup> SF-12 is a health survey with 12 questions designed to assess mental (and physical health). All questions use a reference period of 4 weeks. Lower scores on the MCS indicate worse mental health status. As no Danish norm data exist for the MCS summary score, the summary score was normed to the US population to ensure comparability across countries and studies. The 10th percentile in the pooled dataset (which is equivalent to a score of 32.78) was used as cut-off point to define poor mental health. The Perceived Stress Scale (PSS) was used to measure the perception of stress over the last 4 weeks.<sup>24</sup> The scale consists of 10 questions graded on a five-point Likert scale. A sum stress score was computed, with higher scores indicating greater stress. The scale has a possible total of 40 points and high perceived stress was defined as a PSS score at or above the 80th percentile in the pooled dataset (this threshold corresponds to a

score of 20 or higher). Several previous studies have used these cut-off points (see e.g.<sup>25</sup>).

The variables used as possible confounding factors were sex, age, education, marital status, degree of urbanisation and the Physical Component Summary (PCS) score from SF-12. Information on sex, age and marital status were obtained from the Danish Civil Registration System. Information on the highest completed level of education was based on self-reported information and categorised as: 'basic school', 'upper secondary or vocational education', 'higher education' or 'other or in school'. Eurostat's classification of urban and rural areas was used to divide the Danish municipalities into three types of areas: densely populated areas, intermediate populated areas and sparsely populated areas.<sup>26</sup>

## Statistical methods

Sex- and age-adjusted mean (MCS and PSS) scores with 95% confidence intervals (CIs) were calculated using the direct standardisation method. The adult population of Denmark in 2010 was chosen as the standard population. Multiple logistic regression models were used to examine the associations between noise annoyance and poor mental health and high perceived stress levels, respectively. The results are presented as odds ratios (ORs) with 95% CIs. The ORs are adjusted for sex, age, education, marital status and degree of urbanisation. Moreover, a dummy variable for survey year was included in all models. No statistically significant interactions between neither sex nor age, respectively, and noise annoyance in relation to the two outcome measures were observed. However, the analyses revealed a significant interaction between the highest completed level of education and traffic noise annoyance with regard to both poor mental health and high perceived stress levels. Calibration weighting was applied to reduce the possible impact of non-response bias on the estimates.<sup>27</sup> The weights were computed by Statistics Denmark based on information such as sex, age, highest completed level of education, income, employment status, marital status, country of origin, healthcare utilisation and research protection for all individuals who were invited. Statistical analyses were performed using SAS version 9.4.

## Results

The characteristics of the study population are displayed in table 1. In all, 2.7% of the respondents living in multistorey houses reported that they had been very annoyed by noise from traffic during the past 2 weeks. Furthermore, 13.9% had been slightly annoyed. The corresponding prevalence estimates for noise from neighbours were 6.7 and 26.7%, respectively. The item non-response rates were ~4% for both questions. Respondents with missing data were excluded from further analyses.

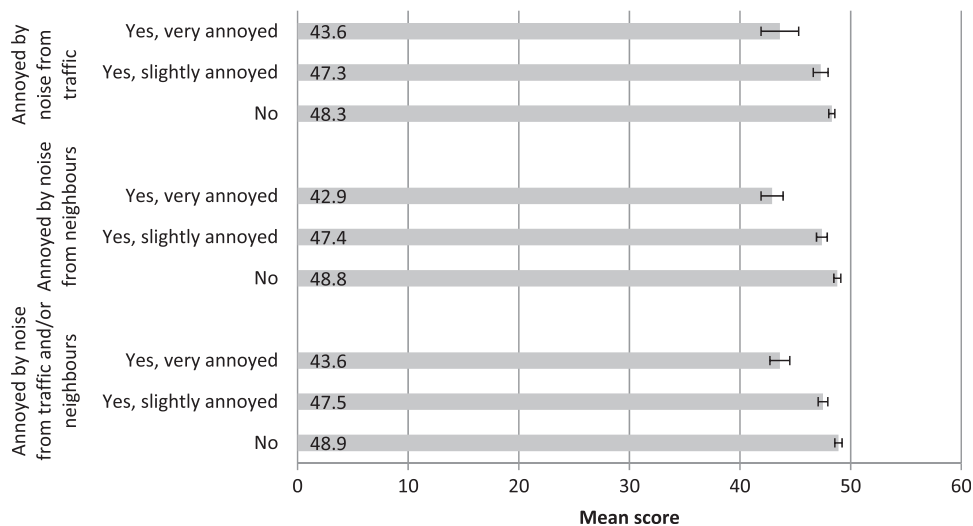
Both noise annoyance from traffic and neighbours were strongly associated with lower MCS scores ( $P$  values < 0.0001) (figure 1). Thus, individuals who had been very annoyed by noise from neighbours during the past 2 weeks reported lower (sex- and age-adjusted) scores (42.9) than individuals who had been slightly annoyed (47.4) or not at all annoyed (48.8) by noise from neighbours.

Figure 2 shows that individuals who had been very annoyed by noise from neighbours during the past 2 weeks had significantly ( $P$  values < 0.0001) higher mean levels of perceived stress (16.5) than individuals who had been slightly annoyed (13.9) or not at all annoyed (12.8) by noise from neighbours. The figure also indicated that noise annoyance from traffic was strongly associated with higher levels of perceived stress.

Table 2 shows the results of the multiple logistic regression analyses for both outcome measures. These analyses suggest that there are strong associations between noise annoyance, poor mental health and high perceived stress levels, even after adjustment for possible confounding factors (all  $P$  values < 0.0001). For example, individuals who had been very annoyed by noise from neighbours during the past

**Table 1** Characteristics of the study population

	2010		2013		Pooled dataset (2010 + 2013)	
	%	No. of respondents	%	No. of respondents	%	No. of respondents
Total		3989		3101		7090
Gender						
Men	46.8	1710	49.2	1371	47.9	3081
Women	53.2	2279	50.8	1730	52.1	4009
Age						
16–24 y.	17.7	620	18.4	535	18.0	1155
25–44 y.	37.9	1336	40.5	1075	39.1	2411
45–64 y.	24.6	1092	22.8	779	23.8	1871
≥65 y.	19.8	941	18.3	712	19.1	1653
Education						
Basic school	10.1	414	6.7	220	8.6	634
Upper secondary or vocational education	28.4	1143	27.3	872	27.9	2015
Higher education	38.3	1589	38.5	1245	38.4	2834
Other or in school	19.6	700	19.4	530	19.5	1230
No information	3.7	143	8.0	234	5.6	377
Marital status						
Married	28.3	1257	27.1	931	27.8	2188
Divorced	13.4	561	13.5	429	13.5	990
Widowed	8.6	356	7.1	236	8.0	592
Never married	49.6	1815	52.4	1505	50.8	3320
Degree of urbanisation						
Densely populated area	65.6	2643	66.4	2079	65.9	4722
Intermediate	15.4	608	16.6	496	15.9	1104
Thinly populated area	19.0	738	17.1	526	18.1	1264
Annoyed by noise from traffic						
Yes, very annoyed	3.1	105	2.2	60	2.7	165
Yes, slightly annoyed	14.8	577	12.8	395	13.9	972
No	79.1	3186	79.7	2504	79.4	5690
No information	3.0	121	5.0	142	4.1	263
Annoyed by noise from neighbours						
Yes, very annoyed	7.4	276	5.7	166	6.7	442
Yes, slightly annoyed	27.4	1070	25.8	785	26.7	1855
No	62.5	2536	63.4	2016	62.9	4552
No information	2.6	107	5.0	134	3.7	241
Annoyed by noise from traffic and/or neighbours						
Yes, very annoyed	9.3	345	7.0	203	8.3	548
Yes, slightly annoyed	33.5	1306	30.4	933	32.1	2239
No	54.8	2237	58.1	1845	56.2	4082
No information	2.5	101	4.5	120	3.4	221

**Figure 1** Sex- and age-adjusted mean SF-12 mental (MCS) health summary scores and 95% CIs by noise sources and noise annoyance levels

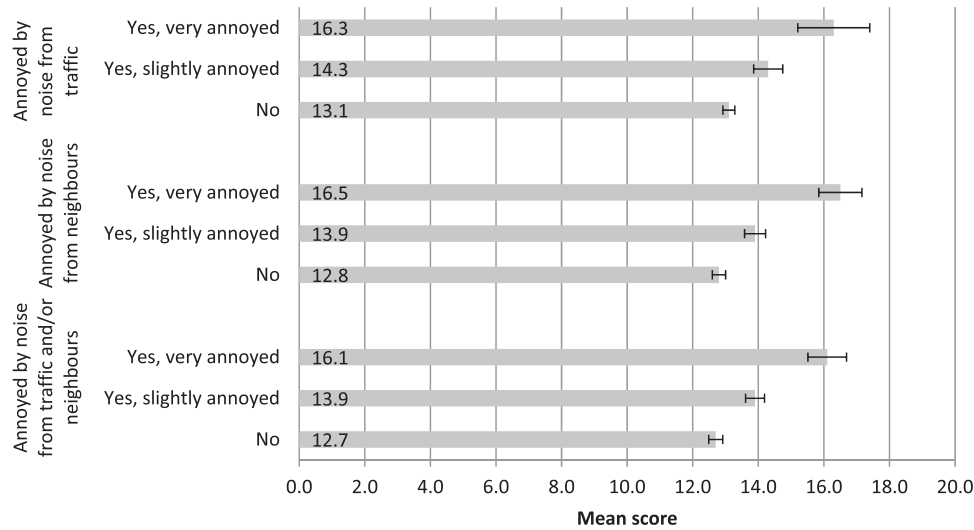


Figure 2 Sex- and age-adjusted mean PSS scores and 95% CIs by noise sources and noise annoyance levels

Table 2 Association between noise annoyance and poor mental health and high perceived stress levels, respectively

	Poor mental health					High perceived stress levels				
	%	OR <sup>a</sup>	95% CI	OR <sup>b</sup>	95% CI	%	OR <sup>a</sup>	95% CI	OR <sup>b</sup>	95% CI
Annoyed by noise from traffic				*		*			*	
Yes, very annoyed	23.7	3.12	(2.20–4.42)	3.03	(2.14–4.30)	37.2	2.59	(1.92–3.51)	2.41	(1.71–3.36)
Yes, slightly annoyed	11.5	1.23	(1.00–1.52)	1.22	(0.99–1.50)	23.4	1.34	(1.14–1.56)	1.25	(1.06–1.48)
No	9.0	1		1		18.4	1		1	
Annoyed by noise from neighbours				*		*			*	
Yes, very annoyed	19.5	2.41	(1.89–3.08)	2.34	(1.83–2.99)	37.4	2.86	(2.35–3.49)	2.78	(2.25–3.43)
Yes, slightly annoyed	10.3	1.17	(0.98–1.40)	1.16	(0.97–1.38)	21.2	1.33	(1.17–1.52)	1.25	(1.08–1.44)
No	8.5	1		1		17.3	1		1	
Annoyed by noise from traffic and/or neighbours				*		*			*	
Yes, very annoyed	18.9	2.42	(1.92–3.05)	2.35	(1.86–2.97)	35.2	2.64	(2.19–3.17)	2.54	(2.08–3.10)
Yes, slightly annoyed	10.0	1.16	(0.98–1.38)	1.15	(0.96–1.36)	20.5	1.28	(1.13–1.46)	1.20	(1.05–1.38)
No	8.3	1		1		17.0	1		1	

Percentages and adjusted odds ratios (OR).

a: Model 1: adjusted for sex, age, education, marital status, degree of urbanisation and survey year.

b: Model 2: adjusted for variables in model 1 + SF-12 physical component score.

\*: P value < 0.0001.

2 weeks had 2.34 (95% CI: 1.83–2.99) times higher odds of having poor mental health and 2.78 (95% CI: 2.25–3.43) times higher odds of high perceived stress levels than individuals who had not been annoyed by noise from neighbours. However, no significant differences were observed among individuals with a higher education (data not shown).

## Discussion

In this study, we investigated the association between neighbour and traffic noise annoyance and mental health and perceived stress in a nationwide sample of adult Danes living in multistorey housing. The results indicated a clear tendency towards a dose–response relationship between noise annoyance and mental health and stress, with people who reported a higher annoyance being more likely to have a poor mental health and experience high levels of stress. However, the associations between traffic noise annoyance and poor mental health and high perceived stress levels, respectively, were not observed in individuals with a higher education. The precise nature of these associations needs to be more carefully examined in future research but may e.g. be related to better housing conditions among individuals with a higher education.

Our results are in line with the results in other studies that have examined the association between noise annoyance and mental health, all indicating an adverse impact on mental health. Whereas the majority of these studies have examined the association between traffic noise annoyance and mental health, e.g.<sup>16,28–30</sup> less studies have considered the relationship to neighbour noise annoyance, e.g.<sup>16</sup>

For example, based on data from the German Health Update Study (GEDA) 2012, Hammersen et al.<sup>16</sup> found individuals highly annoyed by neighbour noise and road traffic noise to be at higher risk of reporting impaired mental health, assessed by a mental health five-item subscale of the SF-36 Short-Form Health Survey. No association was found with air traffic noise annoyance. Direct comparisons with the results from this study is somewhat compromised by analyses stratified by sex by Hammersen et al.<sup>16</sup> However, both studies exhibited similar patterns regarding the association between noise annoyance and poor mental health.

In a study from New Zealand from 2016 using postal survey data, in which the WHO short-form quality of life form (WHOQOL BREF) was included to assess quality of life in four different domains, Shepard et al.<sup>28</sup> found traffic noise annoyance to be inversely associated with psychological well-being. Oiamo et al.<sup>29</sup>

investigated the association between noise annoyance and mental health in a cross-sectional study from Canada. The SF-12 was used to assess mental health, and by using a structural equation model, traffic noise annoyance was found to negatively affect the mental composite score. Similarly, in a Swiss cohort study from 2010, Dratva et al.<sup>30</sup> found individuals highly annoyed by road traffic noise to report a significantly lower mean SF-36 mental health score as compared with those not annoyed.

This study revealed a clear association between noise annoyance and perceived stress. According to Munzel et al.,<sup>6</sup> chronic stress caused by annoyance may trigger the development of cardiovascular disease, indicating a serious impact of stress on health. To our knowledge, this study is the first to investigate the association between traffic or neighbour noise annoyance and perceived stress. Thus, direct comparisons to other studies are not possible.

Applying a more specific definition on mental health, Beutel et al.<sup>9</sup> found both moderate and extreme overall noise annoyance to increase the risk of depression and anxiety compared with no annoyance in a German population-based cross-sectional study from 2016. However, the analyses were not stratified by noise source, which compromises direct comparisons with our results along with the use of different indicators of mental health. Lastly, within the context of the WHO-LARES survey carried out in eight European cities from 2002 to 2003, Niemann et al.<sup>17</sup> found adults who indicated chronically severe annoyance by neighbourhood noise to be at increased risk of depression.

There are some potential limitations of this study. Due to the cross-sectional design of this study, we did not have the possibility to confirm causality, i.e. to determine whether environmental noise annoyance increases the risk of developing poor mental health and stress, or if individuals with poor mental health or a high level of stress are more vulnerable to noise, resulting in high levels of environmental noise annoyance. Furthermore, the proportion of individuals living in multistorey houses was somewhat lower in the study population than in the entire Danish population. Possible explanations for this discrepancy are (i) a lower response rate among individuals living in multistorey houses than among individuals living elsewhere and (ii) a higher proportion of individuals living in multistorey housing have sought research protection (i.e. individuals who have informed the authorities that they did not want to be contacted for research purposes). However, this discrepancy should not alter neither the results nor the conclusion of this study.

Assuming that exposure to noise increases the risk of poor mental health and perceived stress and not the opposite, potential biological explanations have been proposed for this direction of causality. These mechanisms include an activation of the hypothalamus–pituitary–adrenal axis and a subsequent release of cortisol,<sup>31,32</sup> the latter of which is considered a reliable biomarker of physiological stress in humans.<sup>33</sup> According to Miller et al.,<sup>34</sup> cortisol significantly impacts mood and cognitive processing, thereby indicating a relationship with mental health.<sup>35</sup> Biological stress mechanisms related to noise exposure, e.g. measured by saliva cortisol levels, have not yet been examined in relation to neighbour noise but only for occupational noise and traffic noise.<sup>31,36,37</sup> It is, however, reasonable to assume that these mechanisms are also adequate and valid to explain the relationship between neighbour noise annoyance and mental health and stress.

On the other hand, it is also possible that individuals with poor mental health or those experiencing stress are more easily annoyed by traffic and neighbour noise. Noise sensitivity has been found to increase noise annoyance independently of noise exposure.<sup>38</sup> According to Job,<sup>39</sup> noise sensitivity can be defined as ‘the internal states of an individual, which increase their degree of reactivity to noise in general’ and is affected by e.g. physiological, psychological and social factors. Thus, when individuals with poor mental health or stress are exposed to noise, it is plausible to assume that other underlying stressors may interact synergistically with noise, thereby resulting in an increased noise annoyance.<sup>40</sup>

A major strength of this study is that the analyses are restricted to individuals living in multistorey housing. Given that these people live rather close to each other, one must assume that the demonstrated associations between neighbour noise annoyance and both mental health and perceived stress are not blurred by a large variation in the type of housing. In the study by Hammersen et al.,<sup>16</sup> such variation is incorporated into the data. Although this does not compromise the validity of their results, the associations between neighbour noise annoyance and mental health and perceived stress may be underestimated among individuals living in multistorey housing. Another strength of this study is the use of a nationally representative sample, enabling us to draw conclusions relevant to the entire general population. A limitation of this study is related to different reference periods for the predictor (noise annoyance) and the outcome (mental health and perceived stress). Questions on the former included a reference period of 2 weeks, but a reference period of 4 weeks for the latter, which implies that the results should be interpreted with some caution. Moreover, a general limitation of only using self-reported measures is that the demonstrated associations rely on only the recall and assessment of the respondent and thus do not include objective measures. Another possible limitation is that we did not assess noise annoyance by an international standardised question such as ISO/TS 15666:2003 and, hence, switching to a new question in our health surveys would result in a break in our time series.

In conclusion, the results from this study indicate that there is a strong relationship between noise annoyance and poor mental health and high levels of perceived stress among individuals living in multistorey housing in Denmark. This study highlights the importance of focusing on environmental noise annoyance in relation to public health in general and more specifically in relation to mental health matters. Future studies are, however, needed to determine the direction of causality.

## Supplementary data

Supplementary data are available at *EURPUB* online.

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*Conflicts of interest:* None declared.

## Key points

- Neighbour and traffic noise annoyance are associated with an increased odds of reporting poor mental health and high levels of perceived stress.
- Future studies should aim at exploring the direction of causality.
- Public health policies should take into account the potential impact of noise annoyance on mental health e.g. by focusing on providing information to the public on noise levels in multistorey housing and by improving sound proofing in multistorey housing.

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