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## Neighbour noise in multi-storey housing – Annoyance and potential health effects

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### ABSTRACT

Neighbour and traffic noise annoyance questions have been included in the Danish Health and Morbidity Surveys since year 2000. Noise annoyance was assessed by asking the respondents about noise annoyance from neighbours and traffic, respectively, in their home during the past two weeks. For people in multi-storey housing, neighbour noise annoyance was significantly higher than annoyance from traffic. The latest survey was performed in 2017; 3893 respondents living in multi-storey houses completed the self-administered questionnaire, 36% reported being very/slightly bothered by neighbour noise and 22% by traffic noise.

Additional studies were carried out aiming at analyzing associations between neighbour noise annoyance and physical/mental health symptoms such as pain in various body parts, headache, fatigue, depression and anxiety and furthermore with getting enough sleep to feel rested. Noise annoyance from neighbours was strongly associated with all these health/sleep outcomes. Similar associations were observed for traffic noise. Although causality cannot be established in this cross-sectional study, it is concluded that neighbour noise annoyance is strongly associated with various physical/mental health symptoms and with not getting enough sleep to feel rested. The results highlight that health effects of neighbour noise might be as serious as for traffic noise and should have more attention.

### 1. INTRODUCTION

Neighbour noise and related complaints are quite old topics and the main reason for introducing sound insulation requirements in building regulations aiming at protecting citizens from neighbour noises intruding everyday life and, thus, improve quality of life. In spite of the extent of neighbour noise annoyance in housing and implications for privacy in homes, health authorities like WHO and EAA do not at all or only very little deal with the adverse effects of neighbour noise. In contrast, the health implications of traffic noise has been quite thoroughly investigated for decades, see e.g. [1], [2], [3], [4] supported by the Environmental Noise Directive [5]. Seemingly, only [6] and [7] deal with neighbour noise, based on a survey carried out more than 15 years ago.

Only few national surveys include questions on neighbour noise. The Danish Health and Morbidity Surveys include simple questions on noise annoyance from both neighbours and traffic at home, see

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[8] and Section 3. In UK, much more extensive studies including neighbour noise have been carried out, see e.g. [9] and [10]. In [2], based on traffic noise research, it is stated that sleep disturbance is one of the most serious effects of environmental noise. Nevertheless, sleep disturbances and other activity disturbances by neighbours may be unhealthier than those caused by traffic, since the information contents in neighbour noise is high, implying a high annoyance potential. In Table 1, based on [9], [10] and national input in Denmark, examples are listed on disturbing/annoying neighbour sounds and own activities being disturbed. Results for neighbour noise health implications based on analysis of the Danish surveys are found in [11], [12], [13]. This paper focuses on the health issue “getting enough sleep to feel rested”, which is used as a proxy for sleep quality.

Table 1 – Examples of disturbing/annoying neighbour sounds and own activities being disturbed.

Disturbing/annoying neighbour noises		Own activities disturbed
♦ Neighbours’ footsteps	♦ Parties	♦ Sleeping
♦ Children jumping/playing	♦ Neighbours’ DIY	♦ Using every room in the house
♦ Voices/shouting/arguments	♦ Doors banging	♦ Listening to TV, radio, music
♦ Dogs	♦ Various “toilet sounds”	♦ Quiet activities: Reading, resting
♦ Radio, TV, music	♦ Washing machines etc.	♦ Having a conversation

## 2. MULTI-STOREY HOUSING IN DK: CONSTRUCTIONS AND ACOUSTIC REGULATIONS

The housing stock in Denmark consists of about 2.7 million dwellings in total, of these almost 1.1 million in multi-storey (MS) housing. In Figure 1 is found an overview of the multi-storey housing stock in Denmark with number of dwellings and construction types in various time periods. Due to different building regulations and construction characteristics, information about estimated sound insulation performance has been added. More details are found in [14] and [15] and in references in those publications. The building types are, cf. Figure 1, denoted E1, E2, E3 and NEW, and number of dwellings are, based on data from in [16] ~ 500,000, up to 100,000, ~ 400,000 and ~ 65,000 (incl. estimate for 2019). Figure 1 also includes small sketches of the four building types and expected acoustic classes F, E, D and C according to [17]. The current Danish building regulations are found in [18], which refers to class C in [17] as minimum acoustic performance. Acoustic requirements for other countries are found in e.g. [19], [20] and [15].


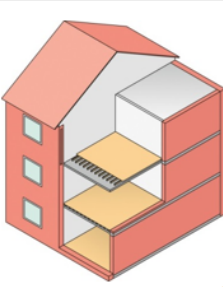
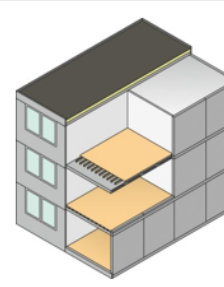
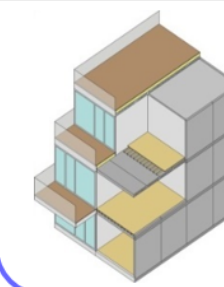
Building type E1 Old brick-built buildings with timber floor constructions Period: ~ 1850 to 1930/1950 ~ 500.000 dwellings	Building type E2 Brick-built buildings with thin in-situ concrete slabs and wooden floors Period: ~ 1930 to 1960 Up to 100.000 dwellings	Building type E3 Concrete elements with wooden floors Period: ~ 1960 to 2009 ~ 400.000 dwellings	Building type NEW Concrete elements with wooden floors Period: From ~ 2010 ~ 65.000 dwellings (incl. 2019)
			
Regulations: None	Regulations: None	Regulations: BR1961-BR1995	Regulations: From BR2008
Estimated performance: $R'_{w} \sim 42-50$ dB $L'_{n,w} \sim 63-75$ dB	Estimated performance: $R'_{w} \sim 45-53$ dB $L'_{n,w} \sim 58-67$ dB	Estimated performance: $R'_{w} \geq 52-53$ dB $L'_{n,w} \leq 58$ dB	Estimated performance: $R'_{w} \geq 55$ dB $L'_{n,w} \leq 53$ dB
Acoustic classification DS 490:2007: None DS 490:2018: Class F	Acoustic classification DS 490:2007: None DS 490:2018: Class E	Acoustic classification DS 490:2007: Class D DS 490:2018: Class D	Acoustic classification DS 490:2007: Class C DS 490:2018: Class C

Figure 1 – Overview multi-storey housing stock in Denmark, number of dwellings and construction types in various time periods Building regulations, estimated acoustic performance and expected acoustic classes indicated.

### 3. SURVEY METHODOLOGY AND STATISTICAL ANALYSIS

Data derives from the Danish Health and Morbidity Survey in 2017 [21]. The main purpose of these surveys is to describe the status and trends in health and morbidity in the adult Danish population and the factors that may influence health status. A nationally representative random sample of 25,000 adults (16 years or older) was drawn from the Danish Civil Registration System [22]. The register contains information on matters such as sex, birthdate, address, marital status and place of birth.

An invitation letter was sent to all selected subjects. The letter briefly described the purpose and content of the survey and it was emphasized that participation in the study was voluntary. The invitation letters were distributed digitally by the secure electronic mail service, Digital Post. In Denmark, all adults are registered to use Digital Post; however, a smaller proportion of the population (<10%) had actively deregistered from the service. This group of individuals was sent an introduction letter by regular postal service. Up to four reminders were sent to non-responders. A concurrent mixed-mode approach was used to collect the survey data, allowing for the invited individuals to complete either an online questionnaire or to fill out an identical enclosed paper questionnaire. In all, 14,022 individuals completed the questionnaire which corresponds to a response rate of 56%.

The use of the personal identification number made it possible to link all subjects at an individual level to the Building and Housing Register [23]. Hence, it was possible to obtain information on the type of dwelling for each respondent at the time of the survey. In all, 7,871 of the respondents lived in one-family houses, 1,855 lived in row and double houses, 3,966 lived in multi-storey housing and 285 lived in other types of dwellings. Information on type of dwelling was not available for 45 respondents. The Building and Housing Register was also used to obtain information on owner/tenant status.

Noise and traffic annoyance were assessed by asking the respondent whether they had been annoyed by noise from neighbours and traffic, respectively, in their home during the past two weeks. The possible answer categories were: 'Yes, very annoyed', 'yes, slightly annoyed', and 'no'. The following question was used to assess subjective sleep quality: 'Do you feel you get enough sleep to feel rested?' The possible answer categories were: 'Yes, usually', 'yes, but not often enough' and 'No, never (hardly ever)'. The presence of pain or discomfort was assessed by asking the respondent whether he or she during the past two weeks had been bothered by eight different symptoms covering both physical and mental domains: 'Pain or discomfort in the shoulder or neck', 'Pain or discomfort in the arms, hands, legs, knees, hips, or joints', 'Pain or discomfort in the back or lower back', 'Fatigue', 'Headache', 'Sleeping problems or insomnia', 'Melancholy, depression, or unhappiness', and 'Anxiety, nervousness, restlessness, or apprehension'. There were three answer categories for each symptom: 'Yes, very bothered', 'yes, slightly bothered', and 'no'.

The variables used as possible confounding factors in the present study were: sex, age, marital status, highest completed education level, ethnic background, degree of urbanization and owner/tenant status. Information on sex, age, marital status, and country of origin was obtained from the Danish Civil Registration System. Country of origin was classified according to information on the respondents' birthplace and citizenship and parental birthplaces. The subjects were categorized into three broad groups: Danish background, other Western background, and non-Western background. Information on the highest completed education level was based on self-reported information from the questionnaire 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' [24].

#### *Statistical analysis*

Descriptive statistics were used to determine percentages. Multiple logistic regression models were used to investigate the associations between never or not often enough getting enough sleep to feel rested and noise annoyance from neighbours and traffic, respectively, within the past two weeks among individuals living in multi-storey houses. Furthermore, multiple logistic regression models were also used to investigate the association between very bothering pain or discomforts and noise annoyance from neighbours and traffic, respectively, within the past two weeks among individuals

living in multi-storey houses. The models were adjusted for sex, age, marital status, highest completed education level, degree of urbanization, owner/tenant status and country of origin. Results are presented as odds ratios (OR) with 95% confidence intervals (CI). An odds ratio is a measure of effect size, measuring the strength of association between two variables [25]. An OR greater than 1 indicates that the group of interest has a higher odds of experiencing the event (e.g. headache) relative to the reference group and an OR less than 1 indicates that the group of interest has a lower odds of experiencing the event relative to the reference group. Thus, an odds of 1 means there is no association between the group of interest and the reference group.

Calibration weighting was applied in order to reduce the possible impact of non-response bias in the present study [26]. The weights were computed by Statistics Denmark based on information such as sex, age, marital status, highest completed education level, income, employment status, country of origin and healthcare utilization. Statistical analyses were performed using SAS version 9.4.

#### 4. RESULTS

Figure 2 shows that 14.9% of the subjects who lived in multi-storey houses, reported that they never (hardly ever) get enough sleep to feel rested. The corresponding proportions among individuals living in one-family houses or row and double houses were 11.8% and 15.6%, respectively.

Rather few of those that lived in other types of dwellings than multi-storey houses were annoyed by noise from neighbours and traffic. Hence, the following analyses were restricted to subjects living in multi-storey houses, cf. [13]. In all, 25.1% (~ 53 respondents) of those who had been very annoyed by noise from neighbours never (hardly ever) get enough sleep to feel rested compared to 11.6% among those who had not been annoyed by noise from neighbours, see Figure 3. The corresponding proportions for annoyance from traffic was 24.1% (~ 24 respondents) and 13.6%, respectively.

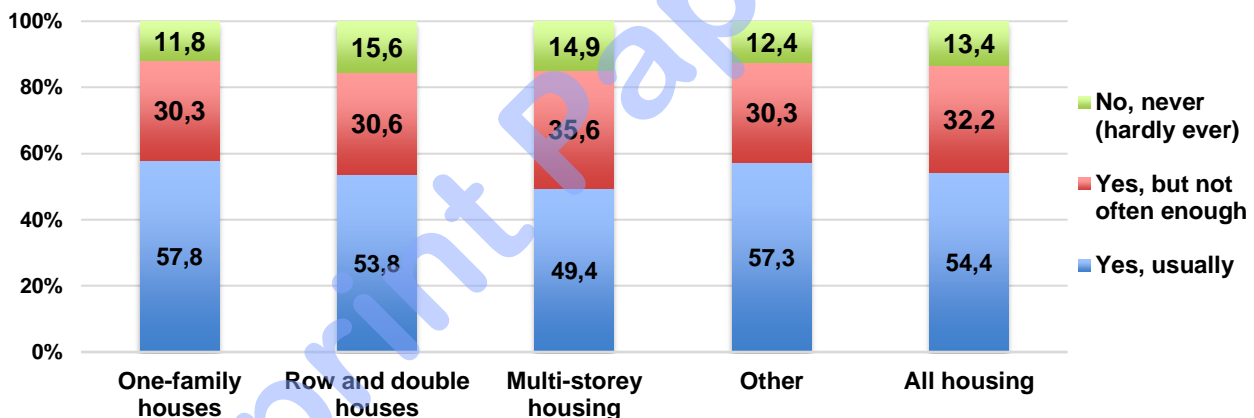


Figure 2 – Percentage who feel that they get enough sleep to feel rested by type of dwelling (for various reasons, incl. noise).

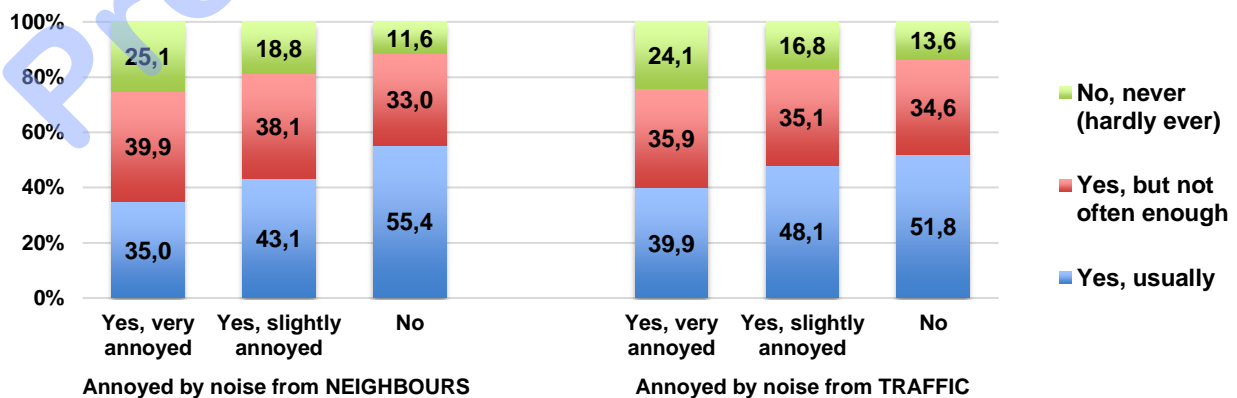


Figure 3 – Percentage who feel that they get enough sleep to feel rested by noise annoyance from neighbours and traffic, respectively, within the past two weeks (among individuals living in multi-storey housing).

From Figure 2 can be seen that percentages are similar for all types of dwellings. The potential reasons are not studied further for this paper, but it should be observed that *all* causes are included, also from inside the dwellings, and not only noise. - For results in Figure 3, the percentages are similar for neighbour noise and traffic noise, but it should be noted that the basis is a much higher number of people being annoyed by neighbour noise (36%) than for traffic noise (22%), cf. [13] and example above Figure 2.

Results from multiple logistic regression analysis, revealed that individuals who had been very annoyed by noise from neighbours during the past two weeks had 2.49 (95% CI: 1.79-3.46) times higher odds of never or not often enough getting enough sleep to feel rested than those who had not been annoyed by noise from neighbours (data not shown). The corresponding odds ratio for those who had been slightly annoyed by noise from neighbours was 1.62 (95% CI: 1.31-2.00). Furthermore, individuals who had been very or slightly annoyed by noise from traffic during the past two weeks had 1.84 (95% CI: 1.15-2.95) and 1.27 (95% CI: 1.00-1.61), respectively, times higher odds of never or not often enough getting enough sleep to feel rested than those who had not been annoyed by noise from traffic (data not shown).

Tables 2 and 3 show that both neighbour and traffic noise annoyance were associated with all the included indicators of pain and discomfort symptoms among subjects living in multi-storey houses (all P-values <0.05). For example, the prevalence of being very bothered by fatigue during the past two weeks was 33.0% among those who had been very annoyed by noise from neighbours, but only 20.4% among those who had not been annoyed by noise from neighbours. Adjustment for the possible confounding factors did not alter these findings (Table 4). However, the associations between noise annoyance from traffic and pain or discomfort in the back or lower back and headache, respectively, were no longer statistically significant after adjustment for sex, age, marital status, highest completed education level, degree of urbanization, owner/tenant status and country of origin.

*Table 2 – Prevalence of bothering pain or discomforts within the past two weeks by noise annoyance from neighbours within the past two weeks (among individuals living in multi storey housing in 2017). Percentages.*

		Annoyed by noise from NEIGHBOURS			
		Yes, very annoyed	Yes, slightly annoyed	No	
Pain or discomfort in the shoulder or neck	Yes, very bothered	24.1	16.7	13.8	**
	Yes, slightly bothered	38.4	41.6	34.4	
	No	37.5	41.7	51.8	
Pain or discomfort in the arms, hands, legs, knees, hips or joints	Yes, very bothered	24.4	15.4	15.1	*
	Yes, slightly bothered	32.1	36.9	35.0	
	No	43.5	47.7	49.9	
Pain or discomfort in the back or lower back	Yes, very bothered	25.6	15.6	14.5	**
	Yes, slightly bothered	37.3	40.6	34.1	
	No	37.1	43.8	51.4	
Fatigue	Yes, very bothered	33.0	20.4	13.9	**
	Yes, slightly bothered	45.5	53.7	45.3	
	No	21.5	25.9	40.8	
Headache	Yes, very bothered	15.5	8.9	7.0	**
	Yes, slightly bothered	35.0	37.0	26.4	
	No	49.5	54.1	66.6	
Sleeping problems or insomnia	Yes, very bothered	24.5	15.5	10.9	**
	Yes, slightly bothered	39.3	36.6	27.2	
	No	36.2	47.9	61.9	
Melancholy, depression or unhappiness	Yes, very bothered	16.4	9.7	7.2	**
	Yes, slightly bothered	34.7	31.1	24.6	
	No	48.9	59.2	68.1	
Anxiety, nervousness, restlessness or apprehension	Yes, very bothered	16.4	10.1	6.9	**
	Yes, slightly bothered	37.7	31.7	23.3	
	No	45.9	58.2	69.8	

\*=P-value<0.05, \*\*=P-value<0.01

Table 3 – Prevalence of bothering pain or discomforts within the past two weeks by noise annoyance from traffic within the past two weeks (among individuals living in multi-storey housing in 2017). Percentages.

		Annoyed by noise from TRAFFIC			
		Yes, very annoyed	Yes, slightly annoyed	No	
Pain or discomfort in the shoulder or neck	Yes, very bothered	23.1	16.6	14.5	**
	Yes, slightly bothered	39.8	41.5	35.6	
	No	37.1	41.9	49.9	
Pain or discomfort in the arms, hands, legs, knees, hips or joints	Yes, very bothered	17.1	16.9	15.3	**
	Yes, slightly bothered	45.0	36.4	34.7	
	No	37.9	46.7	50.1	
Pain or discomfort in the back or lower back	Yes, very bothered	22.2	16.8	14.8	*
	Yes, slightly bothered	34.1	37.5	35.9	
	No	43.7	45.7	49.3	
Fatigue	Yes, very bothered	30.5	19.5	15.8	**
	Yes, slightly bothered	42.7	52.3	46.8	
	No	26.9	28.2	37.4	
Headache	Yes, very bothered	15.3	8.2	7.9	**
	Yes, slightly bothered	36.5	33.9	28.8	
	No	48.2	57.9	63.3	
Sleeping problems or insomnia	Yes, very bothered	22.6	15.8	11.8	**
	Yes, slightly bothered	34.4	35.6	29.4	
	No	43.0	48.6	58.8	
Melancholy, depression or unhappiness	Yes, very bothered	17.1	10.5	7.8	**
	Yes, slightly bothered	37.2	30.4	26.1	
	No	45.7	59.1	66.1	
Anxiety, nervousness, restlessness or apprehension	Yes, very bothered	18.2	11.1	7.4	**
	Yes, slightly bothered	37.2	29.8	25.3	
	No	44.6	59.1	67.3	

\*=P-value<0.05, \*\*=P-value<0.01

Table 4 – Adjusted odds ratios<sup>1</sup> (and 95% confidence intervals) of very bothering pain or discomforts within the past two weeks by noise annoyance from neighbours and traffic, respectively, within the past two weeks (among individuals living in multi-storey housing in 2017).

	Annoyed by noise from NEIGHBOURS			Annoyed by noise from TRAFFIC		
	Yes, very annoyed	Yes, slightly annoyed	No	Yes, very annoyed	Yes, slightly annoyed	No
Pain or discomfort in the shoulder or neck	1.73 (1.22-2.45)	1.32 (1.06-1.65)	1 **	1.95 (1.21-3.14)	1.37 (1.07-1.74)	1 **
Pain or discomfort in the arms, hands, legs, knees, hips or joints	2.23 (1.57-3.17)	1.29 (1.03-1.61)	1 **	1.49 (0.89-2.52)	1.34 (1.05-1.72)	1 *
Pain or discomfort in the back or lower back	3.32 (2.15-5.13)	1.57 (1.15-2.14)	1 **	1.71 (0.86-3.38)	1.37 (0.98-1.92)	1
Fatigue	2.91 (2.14-3.98)	1.46 (1.18-1.79)	1 **	2.12 (1.36-3.31)	1.34 (1.07-1.69)	1 **
Headache	1.82 (1.19-2.78)	1.16 (0.87-1.54)	1 *	1.86 (1.03-3.38)	1.66 (0.76-1.47)	1
Sleeping problems or insomnia	2.62 (1.86-3.69)	1.46 (1.16-1.84)	1 **	2.04 (1.26-3.32)	1.38 (1.07-1.78)	1 **
Melancholy, depression or unhappiness	2.10 (1.39-3.18)	1.46 (1.11-1.92)	1 **	2.03 (1.17-3.53)	1.44 (1.07-1.95)	1 **
Anxiety, nervousness, restlessness or apprehension	2.60 (1.73-3.91)	1.58 (1.20-2.09)	1 **	2.60 (1.54-4.39)	1.60 (1.19-2.16)	1 **

<sup>1</sup>Adjusted for sex, age, marital status, education, degree of urbanisation, owner/tenant status and country of origin

\*=P-value<0.05, \*\*=P-value<0.01

## 5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

### *WHO and EAA studies about health effects of noise*

In [27], WHO has defined health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”. Based on this definition, noise effects on health should not simply be understood as the adverse physical effects due to noise exposure, but also as disturbance of well-being, i.e. psychological effects of noise, which in the long term may also lead to adverse physical effects. WHO identified a considerable number of specific adverse health effects caused by environmental noise. These effects can be medical conditions, but can also include sleep disturbance, psychophysiological stress or negative effects on the learning capabilities of children.

Many publications highlight sleep as a necessity for good health, and not least in a number of WHO and EEA reports, see e.g. [1], [2], [3], [4], the restorative and consolidating effects of sleep are explained as necessary. In the WHO-report *Night noise guidelines for Europe* [2], the health risks due to sleep disturbance are emphasized: “Sleep disturbance is one of the most serious effects of environmental noise, causing both immediate effects and next-day and long-term effects on mental and cardiovascular health”. Thus, it seems obvious that when a resident almost every day is woken up several times during evening, night and morning due to e.g. ordinary footsteps from neighbours, the resident becomes “unhealthy”, because the building is not “healthy” enough to protect the resident.

The above-mentioned reports [1], [2], [3], [4] deal with health effects of traffic noise and include explanations of human health reactions as consequences of traffic noise, see especially [1] with the well-known noise-effect-pyramid with indications of discomfort, disturbances, sleep disturbances as the effect of noise at the first step and stress indicators at the next step. After that, the pyramid’s next steps are about other risk factors (like e.g. high blood pressure), diseases, and morbidity. The first effects of neighbour noise are exactly the same as for traffic noise, and it seems justified as a first hypothesis to consider neighbour noise to have the same or a similar noise-effect-pyramid.

The WHO Noise Guidelines [3] from 2018 includes revised recommendations for noise limits for road traffic, railways and air traffic, but – in addition to transportation noise as before – it includes also recommendations for wind turbine noise and leisure noise. However, neighbour noise is not dealt with in the guidelines, not even in the review papers prepared as basis for the guidelines.



### ***Neighbour noise in Danish Health and Morbidity Surveys***

A strong association was revealed between self-reported noise annoyance from neighbours and various types of pain, sleep quality and stress and mental health related questions. In fact, the association was stronger than the corresponding association observed between annoyance from traffic and the same health outcomes. Studies examining the association between noise annoyance from neighbours those outcomes are scarce and more research is needed in this field.

An important strength of the study is that the sample is based on a representative random sample of adults, which allows us to generalise the findings to the entire adult population. In addition, due to the Danish building and housing register [23], restricting our analyses to only those living in multi-storey housing is a major strength of the study, as the study population then is relatively homogenous in relation to housing conditions (i.e. how close they live to their neighbours). This means that the associations between neighbour noise annoyance and the health outcomes are not likely to be confounded by a substantial variation in the type of housing among the respondents. Some limitations with the present study should be mentioned. For example, it is a cross-sectional study, and, therefore, we cannot determine a causative relationship between noise annoyance and the health outcomes. Furthermore, the response rate was slightly lower among individuals living in multi-storey housing than among individuals living in other types of housing.

The recent Danish studies [11], [12], [13] and the current study show that the prevalence of annoyance depends on the type of exposure and housing. For example, as expected, noise annoyance from neighbours were most prevalent among individuals living in multi-storey housing.

The strong associations between neighbour noise annoyance and various types of pain, sleep quality and stress and mental health related questions, see Section 3, among individuals living in multi-storey housing in Denmark seems reasonable due to the unpredictable nature of noise from neighbours (often with a very high informational content) and/or loud noises like e.g. neighbours' footsteps, playing/running children, barking dogs, loud discussions, banging doors.

These findings show strong associations between neighbour noise annoyance and fatigue and sleeping problems, poor mental health, perceived stress and not getting enough sleep to feel rested.

The studies highlight the importance of studying the association between neighbour noise annoyance and the health outcomes indicated. However, future prospective studies are needed to determine the direction of causality, since it's not possible in a cross-sectional study to determine, whether people with the indicated health outcomes are more annoyed by noise, or opposite, if the annoyance leads to such problems. However, either way is relevant for evaluation of the health situation of the population and the quality of life.

### ***Neighbour noise annoyance in multi-storey housing and potential health effects: Conclusions***

The analysis of SUSY-surveys show that for occupants in multi-storey housing, there is a strong association between self-reported neighbour noise annoyance and:

- perceived stress
- poor mental health
- fatigue
- sleeping problems
- sleep quality (getting enough sleep to feel rested).

The new Danish research results can contribute to highlight the potential adverse health effects of neighbour noise and point out that neighbour noise is a real nuisance in housing with poor sound insulation and for that reason, acoustic renovation major parts of such housing.

### ***Recommendations for future studies***

For future research, the following studies are recommended:

- Cross-sectional studies to investigate direction of causality for the health outcomes described above.
- Studies on serious effects of neighbour noise causing both immediate effects, next-day and long-term effects on health and diseases, e.g. cardiovascular diseases.
- Longitudinal studies quantifying number people actually moving to other housing due to neighbour noise
- Identifying actual restrictions in own activities in everyday life to avoid complaints from neighbours
- Implications on lack of own privacy due to the fact that sounds and noises are transmitted both ways between neighbour dwellings.

## 6. ACKNOWLEDGEMENTS

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