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# Road traffic noise can explain higher morbidity in wind power areas more than wind turbine noise

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## ABSTRACT

This cross-sectional case-control study examined how the exposure to wind turbine noise and road traffic noise were related to the self-reported prevalence of chronic diseases and symptoms near three wind power areas, where the wind turbine noise levels agreed with Finnish regulations. 558 questionnaires were received from people living within 2.8 km from the nearest wind turbine. 121 questionnaires were received from control area not exposed to wind turbines. As everywhere, people were also exposed to road traffic noise. Therefore, both exposures were modelled outside residents' dwellings to gain a better understanding from public health point of view. The maximum wind turbine noise level was 39 dBA, while it was 64 dBA for road traffic noise. Higher wind turbine noise level was related to an increased probability of wind turbine noise annoyance, but not to the prevalence of any symptom or chronic disease. Instead, higher road traffic noise level was related to an increased probability of road traffic noise annoyance, heart disease, migraine, impaired hearing, blocked ears, and tachycardia. At the investigated sound levels, wind turbine noise was not related to increased prevalence of chronic diseases or symptoms, but road traffic noise was. The finding has importance for public health assessment because the sound levels of the study areas represent well the typical levels among the residents living close to wind farms.

Keywords: Wind turbine noise, Road traffic noise, Exposure, Health effects

## INTRODUCTION

Many residential surveys investigating the effects of wind turbine noise have been conducted in wind power areas where a notable proportion of residents close to the WTs were exposed to A-weighted sound pressure levels (SPLs) higher than commonly regulated nowadays (e.g., >40 dB $L_{Aeq}$) (1,2). For example, in Finland WT noise regulations were published 2015 and they give the upper limit 45 dB $L_{Aeq,07\text{–}22}$ of A-weighted SPLs during daytime and lower limit of

40 dB $L_{Aeq,07–22}$ of nighttime SPL (3). In practice, the nighttime regulation is applied also during daytime since energy companies do not want to invest on WTs which cannot produce full power during the nighttime. Therefore, there is a clear politically justified need for an examination of possible adverse health effects in WT areas fulfilling the regulations.

Most studies related to WT noise effects only take the WT noise exposure into account. From public health point of view, this is narrow sighted. WTs are usually erected close to main roads because of logistic reasons (transport, electric lines). Therefore, WT noise is not the only form of environmental noise exposure in on-shore WT areas. Previous studies have shown an association between WT SPL and WT noise annoyance (1,4), The relation with other self-reported health effects is non-existing or less clear (1,2). Instead, several different health effects have been found to be associated with road traffic (RT) noise (5). From public health point of view, it is relevant to investigate the health effects of both WT and RT noise in parallel to provide a holistic understanding of the health effects of environmental noise in the living environment. Focusing solely on the health effects of WT noise is not reasonable, if it is self-evident that the residents are also exposed to other forms of environmental noise. There are very few studies which have investigated the health effects of both WT and RT noise in parallel in the same area.

Our purpose was to determine, how the SPL of RT and WT noise are associated with noise annoyance, symptoms, stress, and diseases. The full study has been published (6) and this article gives a summary of it.

## MATERIALS AND METHODS

### *Study Design*

This was a case-control study, with three independent WT areas close to each other and a control area further from the WTs. As these three WT areas reside close to each other, together they could be seen to form a single WT area of this study. The independent objectively measurable exposure variables were the SPLs of RT noise and WT noise in the yard and the dependent response variables were the subjective responses to the questionnaire. The study was accepted by the ethics committee of Turku University of Applied Sciences.

### *Study Areas and Sample*

We selected WT areas that are located near population and that would fulfill Finnish WT noise regulations (3). The best choice in Finland was Hamina city (South-East Finland), which has three WT areas:

- Harbor involves two 3 MW WTs erected in 2015 (Eastmost)
- Summa involves three 3 MW WTs erected in 2010
- Mäkelänkangas involves four 2 MW WTs erected in 2012 (Westmost).

The control area was a suburb in Kotka city 6.8–8.0 km west from the eastmost WT of Mäkelänkangas. The control area resembled Hamina w.r.t. building base, socioeconomics, and seaside environment. The map of these areas is presented in Figure 1.

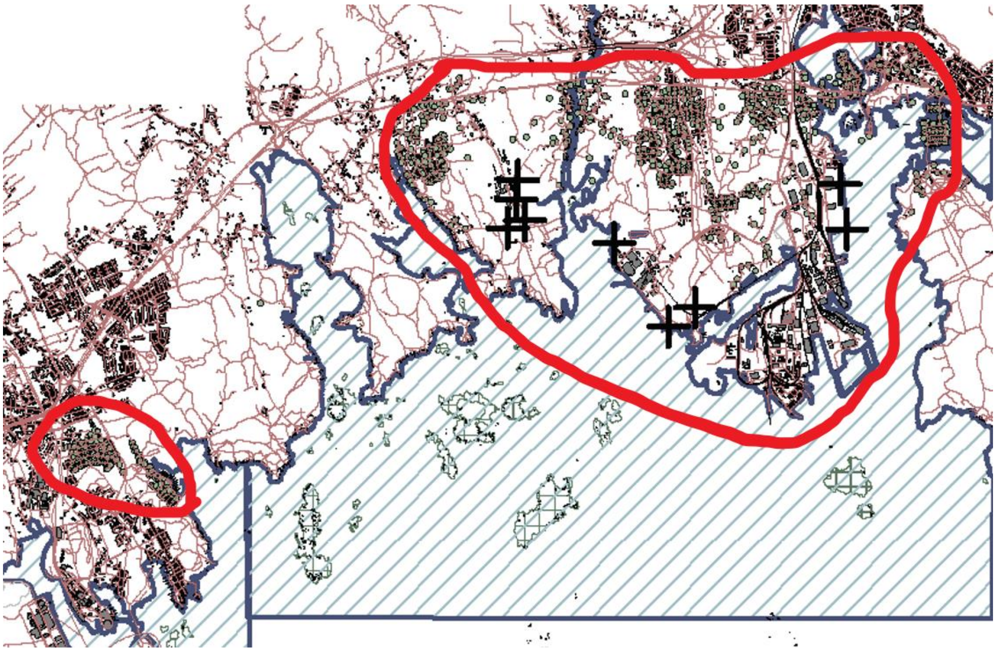

Figure 1. The circled area on the right represents the WT area. In this area, the households are within 2.8 km from the nearest WT. WTs are marked with black crosses. The circled area on the left is the control area.

The permanent residential houses were identified with map services. Their building IDs were used to obtain the basic information of residents. We asked individual address of a single adult from each household. In the case of two or more adults in the same address, randomization was made w.r.t. age and gender.

All households locating closer than 2,8 km from the WTs were invited to respond. The living environment questionnaire was mailed to 2560 households in the WT area and 498 households in the control area, altogether to 3058 households.

***Noise Modelling (independent variables)***

The following independent variables were determined for each yard:

- distance to the nearest WT (0.9–2.8 km),
- A-weighted equivalent SPL, when all WTs are producing maximum electricity ($L_{\mathrm{Aeq,WT}}$), and
- A-weighted equivalent SPL of RT noise during daytime hours 07–22 ($L_{\mathrm{Aeq,07\text{-}22,RT}}$).

The variables related to WTs were determined only for the households in the WT area, whereas the RT SPL was determined for all households. Both $L_{\mathrm{Aeq}}$'s were determined in the household's yard at 4 m height.

It should be noted that $L_{\mathrm{Aeq,07\text{-}22,RT}}$ represents well the RT noise exposure every day throughout the year. On the other hand, $L_{\mathrm{Aeq,WT}}$ is only reached during very windy conditions (wind speed larger than 12 m/s at hub height). Such conditions occur less than 10% of the year. Because such definition is used in legislation, we adopted it and we did not conduct our analyses using the annual WT noise level. Annual level would probably be more than 5 dB smaller.

SPLs in the yards were simulated using CadnaA -software using the national topographic maps. $L_{Aeq,WT}$ was determined using a national method (7). The prediction accuracy of this method has been found to be very good (4). Because the WTs were not new and the noise emission data was vague, we measured the sound power level of the WTs in each three WT area using another national method (8), which is principally in agreement with IEC 61400-11. $L_{Aeq,07\text{-}22,RT}$ was determined using Nordic model (9). It considers the traffic amount, share of heavy vehicles, road surface type, and traffic speed. Traffic numbers were obtained from a national authority.

### *Questionnaire (dependent variables)*

Questionnaires were sent in autumn 2018. Response time was 4 weeks after which a reminder was sent to all households. We received 684 responses, 563 from the WT area and 121 from the control area. Response rate was 22.4%. Questionnaire was mailed in paper form. Web answering option was available in Finnish, Swedish, and English. Low response rate could be explained by the length of the questionnaire and the fact that the filled questionnaire had to be returned to the nearest ordinary mailbox if not answering online.

As the response rate was quite low, we examined the difference between 1997 non-respondents and 563 respondents in the WT area. Respondents and non-respondents did not differ from each other with respect to WT sound level, distance to the nearest WT, nor RT sound level. Respondents were older (mean age 63 y) than non-respondents (mean age 56 y). We do not have reasons to believe that the results would not apply to the whole population in the studied WT area.

The purpose of our questionnaire was masked: it was not possible to see that the focus was to study WT and RT noise effects on human. Here, we focus on a minor proportion of the questionnaire items:

- WT noise (WTN) and RT noise (RTN) annoyance. Noise annoyance was measured using an 11-step response scale (0 Not at all, 10 Extremely). The responses were dichotomized so that people who responded 5 or more were rated to be annoyed. The annoyance ratings were asked both for indoors and outdoors.
- Prevalence of non-specific symptoms during last 12 months (migraine or headache including nausea, vomiting, and sensitivity to light and sound; dizziness; ringing, whistling or other sounds in your ears that have no actual source, e.g., tinnitus; impaired hearing; blocked ears or a sense of pressure in your ears; rash or itchy skin; back pain or backache; regular stomach problems; blurred vision; tachycardia or heart palpitations; problems in concentrating or remembering things; panic attacks or similar sensations)
- Prevalence of diseases during last 12 months (chronic pain; asthma; joint inflammation; cancer; depression; elevated blood pressure; bronchitis, pulmonary emphysema, or chronic obstructive pulmonary disease; diabetes; heart disease; sleep problems, including sleep apnea and insomnia; restless legs syndrome).

### *Analyses*

For analysis, the respondents were divided to four WT noise level categories (groups) having approximately similar sizes: group 17–25 dB (122 respondents), group 25–30 dB (282 respondents), group 30–40 dB (159 respondents) and control group with no audible WT noise exposure (121 respondents) and five noise categories according to their RT noise exposure: 32–40 dB, 40–45 dB, 45–50 dB, 50–55 dB and 55–64 dB.

Method 1. These groups were used in the examination of the relationship between annoyance and noise level related to different sound sources.
Method 2. The prevalence of symptoms, and diseases in the three first groups locating in the WT area were compared to the control group using binary logistic regression. The model involved also age, gender, and RT noise level ($L_{Aeq,07\text{-}22,RT}$).
Method 3. This method did not use the groups, but continuous noise levels and the focus was only in the WT area (excluding the control area). The association of continuous sounds levels ($L_{Aeq,07\text{-}22,RT}$ and $L_{Aeq,WT}$) and prevalence of symptoms, and diseases was analyzed using binary logistic regression.

The results of logistic regression are presented with the exponentiated logistic coefficient Exp(B) that reflects the changes in odds when the independent variable changes one unit. In Method 2 this unit is a comparison between groups and in Method 2 this is a change of 1 dB. A 95% confidence interval (CI) reflects the statistical significance of this relationship. If Exp(B) is above 1.00 and CI's lower value is also above 1.00, the relationship is positive, i.e., the increase in independent variable increases the odds of belonging to the predicted group of the dependent variable. If Exp(B) is below 1.00 and the higher value of CI is also below 1.00, the relationship is negative, i.e., the increase in independent variable decreases the odds of belonging to the predicted group of dependent variable. In other cases, the relationship is not significant.

## RESULTS

### *Method 1*

The relationship between annoyance and SPL groups related to different WTN and RTN is shown in Figure 2.

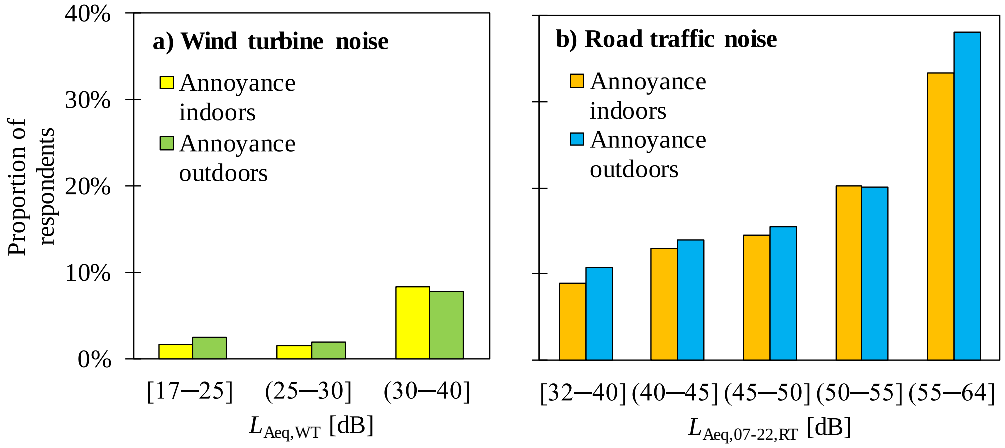


Figure 2. The proportion of respondents annoyed indoors and outdoors by WT and RT noise is presented for RT and WT SPL groups.

***Method 2***

Three groups locating in the WT area with different WT SPLs were compared to the control group using binary logistic regression. The model involved also age, gender, and RTN level ($L_{Aeq,07-22,RT}$). The outcome of the analysis was that no significant differences were observed between the control group and three other groups w.r.t. the prevalence symptoms, nor diseases ($p>0.05$), except for annoyance, which results are presented in Table 1. In conclusion, compared to residents in the control area, the residents in WT area did not have a higher prevalence of symptoms, or diseases, except for WTN annoyance that had higher prevalence both indoors and outdoors with residents in the area (30–40] dB.

Table 1. The association between noise annoyance variables and WT noise level categories (groups). The control area was the reference. Significant associations ($p<0.05$) are marked with bold.

| Variable | Comparison | Exp(B) | CI |
|---|---|---|---|
| *WTN annoyance indoors* | Control area vs. [17–25] dB | 2.03 | (0.18, 23.20) |
| | Control area vs. (25–30] dB | 1.80 | (0.20, 16.49) |
| | **Control area vs. (30–40] dB** | **11.06** | **(1.42, 86.48)** |
| *WTN annoyance outdoors* | Control area vs. [17–25] dB | 3.13 | (0.31, 31.19) |
| | Control area vs. (25–30] dB | 2.27 | (0.26, 19.89) |
| | **Control area vs. (30–40] dB** | **10.09** | **(1.29, 79.13)** |
| *RTN annoyance indoors* | **Control area vs. [17–25] dB** | **2.06** | **(1.02, 4.15)** |
| | Control area vs. (25–30] dB | 0.94 | (0.49, 1.80) |
| | Control area vs. (30–40] dB | 0.94 | (0.45, 1.95) |
| *RTN annoyance outdoors* | Control area vs. [17–25] dB | 1.96 | (0.96, 4.02) |
| | Control area vs. (25–30] dB | 1.24 | (0.64, 2.39) |
| | Control area vs. (30–40] dB | 1.21 | (0.58, 2.49) |

Controlled for age, gender, and $L_{Aeq,07-22,RT}$

***Method 3***

The association of continuous sounds levels ($L_{Aeq,07-22,RT}$ and $L_{Aeq,WT}$) and prevalence of symptoms, and diseases was analyzed using binary logistic regression (Tables 2 and 3). WTN level, $L_{Aeq,WT}$, was not associated with the prevalence of symptoms, nor diseases except for annoyance. Higher WTN level, $L_{Aeq,WT}$, was associated with higher WTN annoyance indoors and outdoors and lower RTN annoyance indoors and outdoors. Instead, higher RTN level, $L_{Aeq,07-22,RT}$, was significantly associated with higher prevalence of heart disease, and five symptoms.

Table 2. The association between the prevalence of symptoms and continuous sound level variables $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$. Significant associations ($p < 0.05$) are marked with bold.

| *Symptoms* | $L_{Aeq,WT}$ | | $L_{Aeq,07\text{-}22,RT}$ | |
|---|---|---|---|---|
| | Exp(B) | CI | Exp(B) | CI |
| WTN annoyance indoors | **1.21** | **(1.04, 1.4)** | 0.97 | (0.90, 1.06) |
| WTN annoyance outdoors | **1.16** | **(1.01, 1.33)** | 0.98 | (0.91, 1.06) |
| RTN annoyance indoors | **0.86** | **(0.81, 0.93)** | **1.07** | **(1.03, 1.11)** |
| RTN annoyance outdoors | **0.87** | **(0.82, 0.94)** | **1.07** | **(1.03, 1.11)** |
| Migraine or headache including nausea, vomiting, and sensitivity to light and sound | 1.06 | (0.96, 1.18) | **1.12** | **(1.06, 1.18)** |
| Dizziness | 0.97 | (0.89, 1.06) | **1.06** | **(1.01, 1.11)** |
| Ringing, whistling or other sounds in your ears that have no actual source (e.g., tinnitus) | 0.97 | (0.91, 1.03) | 1.01 | (0.97, 1.04) |
| Impaired hearing | 0.94 | (0.88, 1.00) | **1.04** | **(1.00, 1.08)** |
| Blocked ears or a sense of pressure in your ears | 1.04 | (0.95, 1.14) | **1.05** | **(1.01, 1.10)** |
| Rash or itchy skin | 0.97 | (0.91, 1.03) | 0.99 | (0.95, 1.02) |
| Back pain or backache | 1.01 | (0.96, 1.06) | 1.02 | (0.99, 1.05) |
| Regular stomach problems | 0.97 | (0.91, 1.03) | 1.01 | (0.97, 1.04) |
| Blurred vision | 0.92 | (0.84, 1.01) | 1.02 | (0.97, 1.07) |
| Tachycardia or heart palpitations | 0.99 | (0.92, 1.06) | **1.04** | **(1.00, 1.08)** |
| Problems in concentrating or remembering things | 1.06 | (1.00, 1.13) | 1.01 | (0.98, 1.05) |
| Panic attacks or similar sensations | 0.98 | (0.85, 1.12) | 1.07 | (1.00, 1.14) |

Controlled for *age* and *gender*.

Table 3. The association between the prevalence of diseases and continuous sound level variables $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$. Significant associations ($p < 0.05$) are marked with bold.

| *Diseases* | $L_{Aeq,WT}$ | | $L_{Aeq,07\text{-}22,RT}$ | |
|---|---|---|---|---|
| | Exp(B) | CI | Exp(B) | CI |
| Chronic pain | 0.99 | (0.94, 1.04) | 1.00 | (0.97, 1.03) |
| Asthma | 0.99 | (0.92, 1.06) | 1.01 | (0.97, 1.06) |
| Joint inflammation | 0.99 | (0.94, 1.05) | 1.00 | (0.97, 1.03) |
| Cancer | 0.93 | (0.84, 1.03) | 0.97 | (0.91, 1.03) |
| Depression | 0.99 | (0.92, 1.06) | 1.03 | (0.99, 1.07) |
| Elevated blood pressure | 0.98 | (0.93, 1.03) | 1.01 | (0.98, 1.04) |
| Bronchitis, pulmonary emphysema, or chronic obstructive pulmonary disease | 1.00 | (0.92, 1.08) | 0.97 | (0.93, 1.02) |
| Diabetes | 0.93 | (0.87, 1.00) | 0.97 | (0.93, 1.01) |
| Heart disease | 1.03 | (0.95, 1.12) | **1.05** | **(1.00, 1.09)** |
| Sleep problems, including sleep apnea and insomnia | 0.97 | (0.92, 1.02) | 0.99 | (0.96, 1.01) |
| Restless legs syndrome | 0.95 | (0.89, 1.00) | 1.00 | (0.97, 1.03) |

Controlled for *age* and *gender*.

## DISCUSSION

Higher wind turbine noise was not related to any other self-reported health effect, except for WT noise annoyance. Road traffic noise, on the other hand, was related to increased odds for road traffic noise annoyance, migraine or headache, dizziness, impaired hearing, pressure in ears, tachycardia or heart palpitations, and heart disease. In our sample, the wind turbine noise emission was in accordance with Finnish noise regulations, but road traffic noise exceeded current regulations (55 dB daytime ($L_{\mathrm{Aeq,07\text{-}22,RT}}$). To our view this is a common state near many wind turbine areas as they are built close to roads.

Our results on the association between WT sound level and health effects is in line with epidemiological studies, which conclude that the only clear relation is found between annoyance, while the relation with other self-reported health effects is non-existing or less clear (1,2). Based on our result, it is improbable that WT noise exposure under 40 dB would cause elevated prevalence of symptoms, or diseases in any WT area.

Even though the RT sound levels were not excessively high in any yard (32-64 dB), the probability of reporting heart disease and tachycardia or heart palpitations rose when $L_{\mathrm{Aeq,07\text{-}22,RT}}$ increased. This is in line with road traffic sound level's association with the increased risk of ischemic heart disease (5) and cardiovascular disease in general (10). However, the lack of association with self-reported hypertension and $L_{\mathrm{Aeq,07\text{-}22,RT}}$ was surprising. Hypertension is a cardiovascular disease and an association between road traffic sound level and hypertension has been suggested in many studies (5). Perhaps our question of hypertension was not specific enough, as it can be kept under control with medicine, which we did not inquire.

Results related to WT and RT noise annoyance showed an expected result that annoyance increased with increasing sound level. This agrees with previous literature (4,11,12). An important new finding was that the proportion of annoyed respondents was approximately the same both for RT noise and WT noise, when the RT sound level and WT sound level was within 30–40 dB. This disagrees with Janssen et al. (12) suggesting that the annoyance due to WT noise at this sound level range was much larger than annoyance due to RT noise. Janssen et al. collected the exposure–response relationships of different environmental noise types from different studies. Such comparisons are biased because annoyance depends on the study area (11) and annoyance reporting also depends on the precise question as well as response scale used. We measured both WT noise annoyance and RT noise annoyance in the same area using identical subjective metrics.

## CONCLUSION

Our study has large value from public health perspective, because the study was conducted in a WT area, where the regulated SPL of WT noise (40 dB) was not exceeded in any yard. This justifies the assessment of the operability of the WT noise regulation (3). Based on our survey, there is no health-based reason to tighten the current Finnish WT noise regulations (3). In addition, further research is needed about the comparison of exposure–response relationships between different environmental noise types. Because all health effects were associated with RT noise, it is more relevant to focus on RT noise control in the future.

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***Conflict of interest***

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. None of the funders except TUAS had any impact on the selection of wind power areas or the control area, study design, survey time, research questions, methods, analysis, and formulation of results. The WT operators (Puhuri Ltd., Haminan Energia Ltd.) are acknowledged for provision of the electricity production data during SWL measurements.

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