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Finnish study on the health effects of environmental noise among residents living close to a wind power area

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ABSTRACT

The aim was to determine how the sound levels of wind turbines and road traffic are associated with stress, diseases, and symptoms in a wind turbine area. Case-control design included a wind power area and a control area farther away not exposed to wind turbine noise nor visibility of turbines. Sound levels were modeled to the yard or all potential respondents. Road traffic and wind turbine sound level varied between 32–64 dB and 17–39 dB L_{Aeq}, respectively. Altogether 684 residents responded to a living environment questionnaire. No associations with wind turbine sound level were found for symptoms, diseases, nor stress. Unexpectedly, prevalence of several symptoms and prevalence of heart disease were higher if road traffic sound level was higher. Wind turbine sound level did not exceed the Finnish regulated value of 40 dB L_{Aeq} in any residential yard. Therefore, the findings can be applied to existing and future areas where the regulated value is applied. Our study emphasizes that road traffic noise can be a larger problem than wind turbine noise even in wind power areas, not to mention areas where the road traffic noise is higher than in our study.

1. INTRODUCTION

Most of the residential surveys investigating the effects of wind turbine (WT) noise until 2015 were conducted in wind power areas where a large proportion of residents close to the WTs were exposed to A-weighted sound pressure levels (SPLs) higher than 40 dB L_{Aeq} [1, 2]. Those studies were utilized as scientific evidence in the development of Finnish WT noise regulations which were published in 2015 [3]. These regulations give the upper limit of WT noise both for daytime ($L_{Aeq,07–22}$ =45 dB) and nighttime ($L_{Aeq,07–22}$ =40 dB). 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. It is highly relevant now to investigate the effects of WTs in areas, which fulfill the new regulation. This will provide evidence-based information about the health effects of WTs under current regulations. This is especially important in areas with large WTs, since they induce more concerns and fears than smaller WTs. The concern about the infrasound exposure is also an important driver to investigate the health status of residents living close to WT areas fulfilling regulations.

Because onshore WTs are usually erected close to main roads, WT noise is not the only form of environmental noise in WT areas. Previous studies have not shown any other health effects of WTs than noise annoyance. Instead, several different health effects have been found to be associated with road traffic (RT) noise [4]. 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

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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 RT and WT noise are associated with noise annoyance, symptoms, stress, and diseases. This study is a summary of Ref. [5].

2. MATERIALS AND METHODS

The study applied *case-control* design, where the exposure variables (independent, objectively measurable variable) were the SPLs of RT noise and WT noise in the yard and the response variables (dependent variables) were the subjective responses to the questionnaire. The study was accepted by the ethic committee of Turku University of Applied Sciences.
We wanted to WT areas, where the Finnish WT noise regulation [3] is fulfilled. The areas should also have sufficient population density. We could not apply random sampling over all Finnish WT areas since it was necessary to conduct the noise emission measurements of the WTs and they are very time-consuming. The best choice in Finland was Hamina city, which has three nearby WT areas:

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

The control area was a suburb in Kotka city 6.8–8.0 km west from Mäkelänkangas. The control area resembled Hamina with respect to building base, socioeconomics, and seaside environment.
The permanent residential houses were identified with map services. Their building IDs were used to obtain the basic information of residents from population registry. We asked them for individual address of a single adult from each household. In the case of two or more adults in the same address, randomization was made with respect to age and gender.
All households were invited to respond, which located closer than 2,8 km from the WTs. The living environment questionnaire was mailed to 2560 households in the WT area and 498 households in the control area, altogether to 3058 households.
Questionnaire survey was conducted in autumn 2018. Response time was 4 weeks after which a reminder was sent to all households. We received 684 responses, 563 from WT area and 121 from control area. Response rate was 22.4%. Questionnaire was mailed in paper form. Web option was available in Finnish, Swedish, and English.
The questionnaire was masked: it was not possible to see, that our purpose was to study WT and RT noise effects on human. In this paper, we focus on a very limited proportion of the questionnaire items focusing on annoyance, stress, symptoms, and diseases:

- Annoyance of WT and RT noise. Noise annoyance was measured using an 11-step response scale (0 Not at all, 10 Extremely) adopted from ISO/TS 15666. The responses were dichotomized so that people who responded 5 or more were rated to be annoyed (%A).
- Stress was measured using Cohen's 10-item perceived stress scale, which describes, e.g., life control, anger, and stress experienced during the past month.
- 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).

For each respondent, the following independent variables were determined:

- distance to the nearest WT (0.9–2.7 km),
- A-weighted equivalent SPL, when all WTs are producing maximum electricity ($L_{Aeq,WT}$) ja
- A-weighted equivalent SPL of RT noise during daytime hours 07–22 ($L_{Aeq,07\text{-}22,RT}$).

Both L_{Aeq}'s were simulated to the respondent's yard at 4 m height. It should be noted that $L_{Aeq,07\text{-}22,RT}$ represents well the RT noise exposure every day throughout the year while $L_{Aeq,WT}$ is only valid during a windy condition (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 had to adopt it and we did not conduct our analyses using the annual WT sound level. Annual level would probably be more than 5 dB smaller.

L_{Aeq}'s were simulated using CadnaA -software using the national topographic maps. $L_{Aeq,WT}$ was determined using a national method [6]. The prediction accuracy of this method has been found to be very good [1]. Because the WTs were not new and the noise emission data provided by manufacturers contained some uncertainties, we had to measure the sound power level (SWL) of the WT's in each three WT area. Measurements were conducted using national method [7], which follows IEC 61400-11 to large extent. $L_{Aeq,07\text{-}22,RT}$ was determined using Nordic model [8]. It accounts for the hourly vehicle counts, share of heavy vehicles, road surface type, and traffic speed. Vehicle counts were obtained from a national authority.

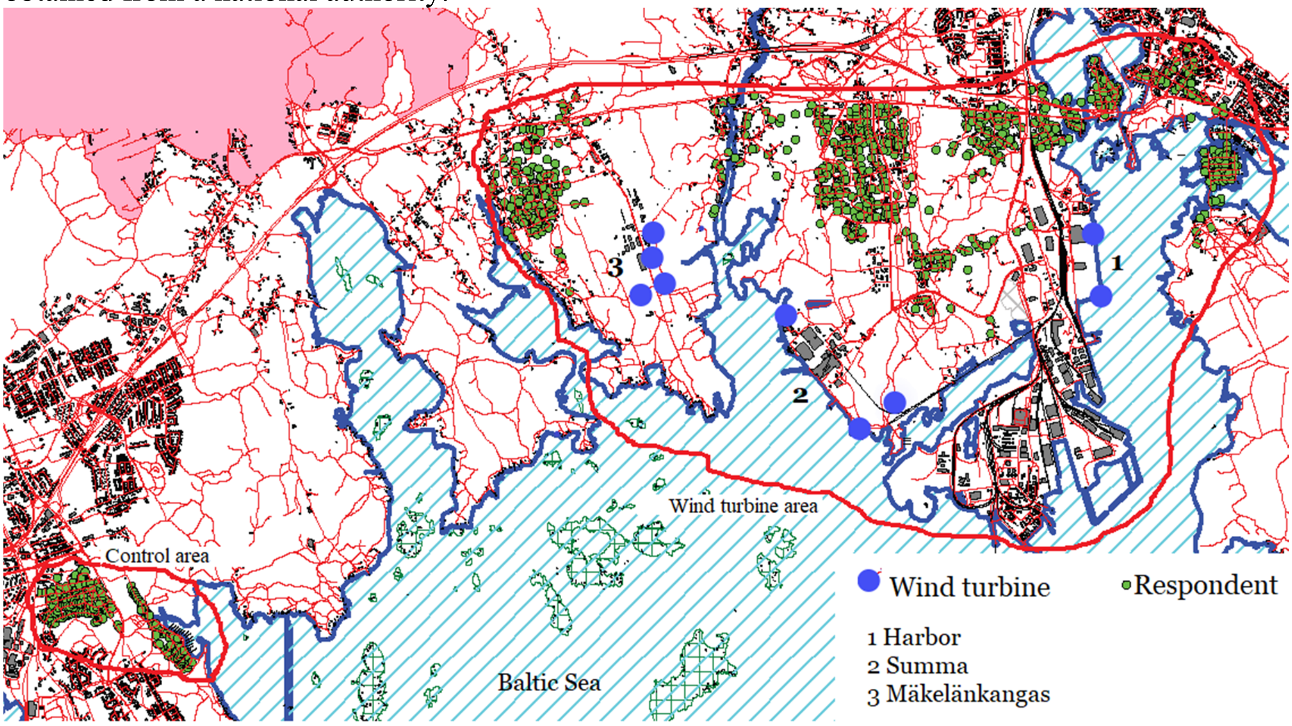

Figure 1: A map of the study areas. Control area is on the left and the three WT areas on the right. Both areas are surrounded by red line. Hamina city center locates in the right top corner.

3. RESULTS

Results were analyzed using three methods. Method 1 compared the prevalence of stress, symptoms, and diseases in WT area and the control group. Method 2 assessed the association of stress prevalence, symptom prevalence, and disease prevalence with WT and RT sound levels. Method 3 assessed the noise annoyance related to WTs and RT in different sound level categories.

Method 1. Respondents were divided to four WT sound 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). 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 sound level ($L_{Aeq,07\text{-}22,RT}$). The outcome of the analysis was that no significant differences were observed between the control group and three other groups with respect to the prevalence of stress, symptoms, nor diseases ($p>0.05$). In conclusion, exposure to WT noise within 17–40 dB $L_{Aeq,WT}$ was not associated with higher prevalence of stress, symptoms, or diseases.

Method 2. This method did not use the groups, but continuous sound levels and the focus was only in the WT area. The association of continuous sounds levels ($L_{Aeq,07\text{-}22,RT}$ and $L_{Aeq,WT}$) and prevalence of stress, symptoms, and diseases was analyzed using binary logistic regression. The model included also age and gender. WT sound level, $L_{Aeq,WT}$, was not associated with the prevalence of stress, symptoms, nor diseases. Instead, higher RT sound level, $L_{Aeq,07\text{-}22,RT}$, was significantly associated with higher prevalence of heart disease, and higher prevalence of five symptoms. Figure 2 reports the risk coefficients in percentages. Figure 3 clarifies the meaning of the risk coefficients.

Method 3. Respondents in the WT area were divided in the three noise categories (groups) according to their WT noise exposure as described above. All respondents were also grouped in five noise categories according to their RT noise exposure: 32–40 dB, 40–45 dB, 45–50 dB, 50–55 dB ja 55–64 dB. The relationship between the proportion of respondents being annoyed (%A) and sound level is show in Figure 4.

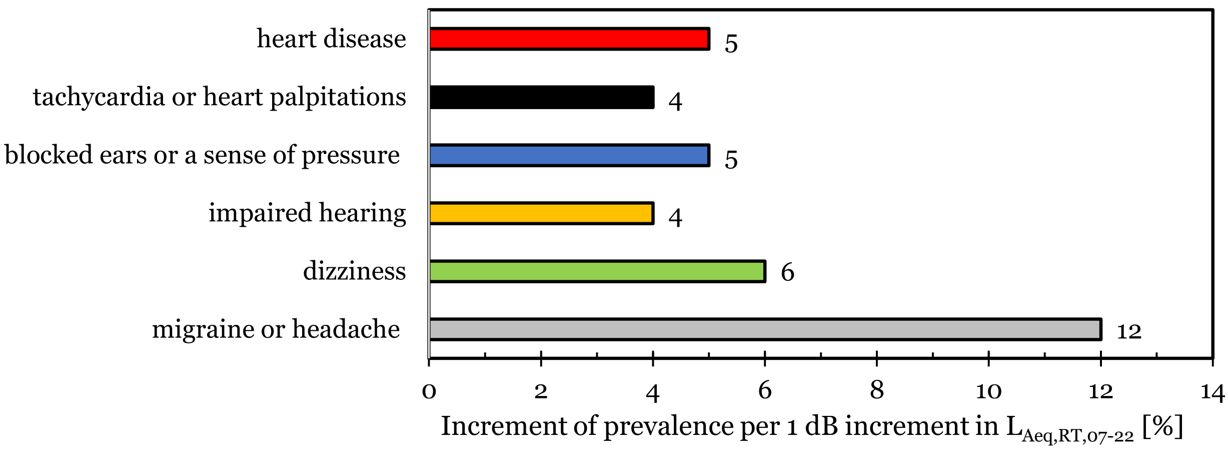

Figure 2: The increment of prevalence for heart disease and five symptoms per 1 dB increment in RT sound level, $L_{Aeq,07\text{-}22,RT}$. The x-axis corresponds to $100\cdot(\text{Exp}(B) - 1)$. $L_{Aeq,07\text{-}22,RT}$ represents the value in the respondents' yard.

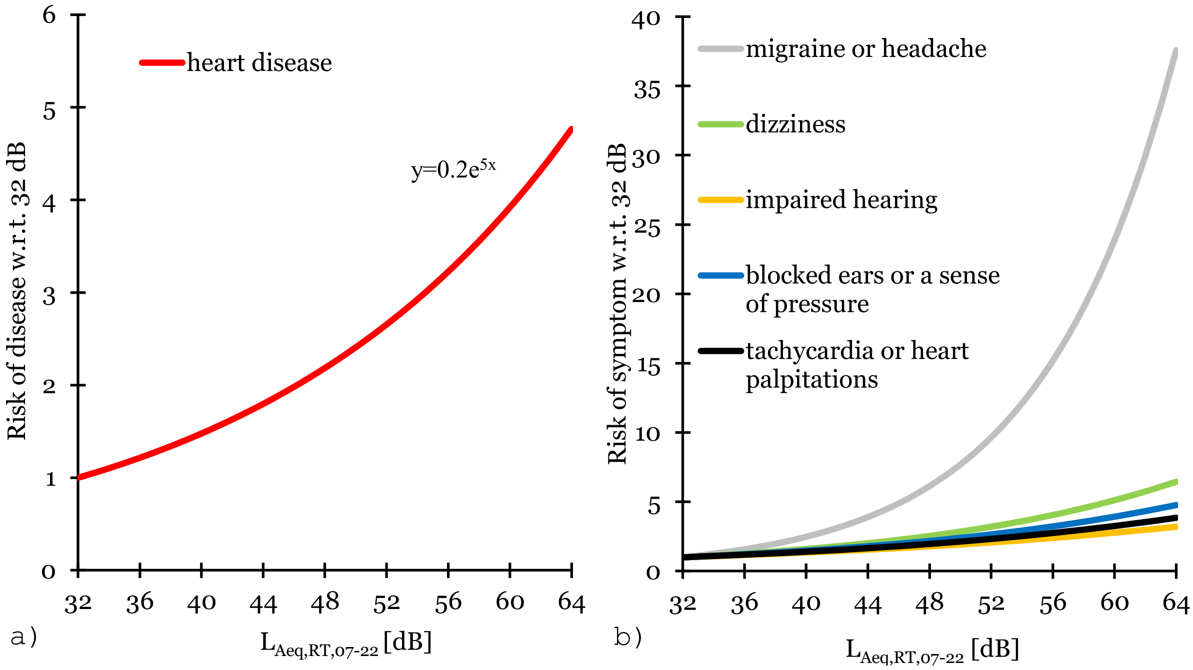

Figure 3: a) Prevalence of heart disease was significantly higher, when the A-weighted SPL of RT noise, $L_{Aeq,RT,07\text{–}22}$, was higher. Prevalence increased by 5 %, when the level increased by one dB. b) Prevalence of five non-specific symptoms was significantly higher, when $L_{Aeq,RT,07\text{–}22}$ was higher. $L_{Aeq,07\text{-}22,RT}$ represent the value in the respondents' yard.

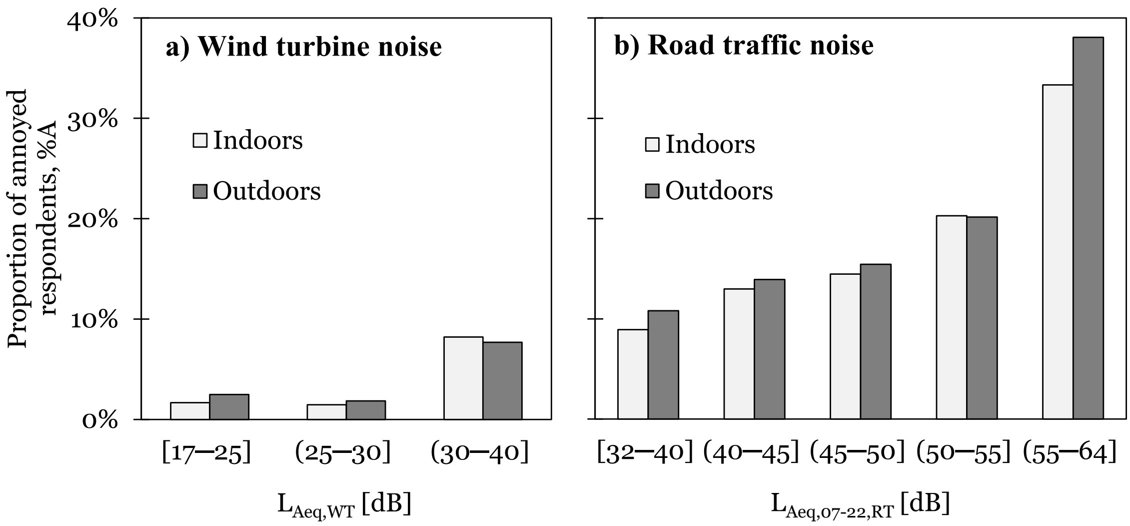

Figure 4: (a) Proportion of respondents reporting WT noise annoyance was higher when the WT sound level, $L_{Aeq,WT}$, was higher. (b) Proportion of respondents reporting RT noise annoyance was higher when the RT sound level, $L_{Aeq,RT,07\text{–}22}$, was higher. %A describes the probability, that the annoyance response in 11-step annoyance response scale from 0 to 10 was five or higher. Both $L_{Aeq,WT}$ and $L_{Aeq,07\text{-}22,RT}$ represent the sound level in the respondents' yard.

4. DISCUSSION

Altogether 2560 residents were invited to respond in the WT area but only 563 responded, giving a response rate of 22 %. Number of non-respondents was 1997. 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. We found that respondents were older (mean age 63 y) than non-respondents (56 y). We do not have reasons to believe that the results would not apply to the whole population in the studied WT area.

Results with method 1 agree with previous literature: the only undisputed health effect of WT noise under 40 dB is noise annoyance [1, 9]. Based on our result, it is improbable that WT noise exposure under 40 dB would cause elevated prevalence of stress, symptoms, or diseases in any WT area.

Results with method 2 agreed with the results obtained with method 1 regarding WT noise. Although the RT noise exposure was not very high in the studied areas, we found that higher RT sound level was associated with higher prevalence of five symptoms and heart disease, although the RT sound levels were not excessively high in any yard (32–64 dB). The finding related to heart disease agrees with previous literature [4]. The finding is very important from public health point of view: it suggests that RT noise was a larger problem in this WT area than WT noise. Because WT areas are erected close to roads, it is probable that similar findings would be made also in other WT areas where the RT sound levels reach 64 dB. Current Finnish WT noise regulation [3] seems to be sufficiently tight, because lawfully implemented WT areas do not affect residents' stress, symptoms, nor diseases. Instead, the regulation of RT noise [10] was violated in many yards of the WT area. It states that the RT sound level shall not exceed 55 dB daytime ($L_{Aeq,07\text{-}22,RT}$) and 50 dB nighttime ($L_{Aeq,22\text{–}07,RT}$). It is possible that our results would change, if we excluded yards, where 55 dB was exceeded.

Results with method 3 showed an expected result that annoyance increased with increasing sound level. The same finding was made for both investigated environmental noise types. This agrees with previous literature [1,11,12]. 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 subjective metrics (precise question, response scale). We measured both WT noise annoyance and RT noise annoyance in the same area using identical subjective metrics.

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]. Based on the results of Method 3, it is even possible to question why the noise regulations of WT noise [3] are tighter than the noise regulations of RT noise [10]. 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

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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