Annoyance due to industrial noise in a petrochemical industrial area

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ABSTRACT

Knowledge of how industrial noise affects health and well-being is very limited. We conducted a questionnaire study in three residential areas located near petrochemical industrial plants in Sweden. The questionnaire was sent to 358 randomly selected persons within these areas (52 % response rate). No estimation of noise levels from the industries was done at the time of the survey. However, a crude estimation of noise levels from road traffic and the industries was done in 2008 and this indicated levels about $L_{\text{night22-07}}$ 35–50 dB from the industries in the study area. General annoyance due to industrial noise ranged between 19 % and 32 % and up to 29 % reported disturbed sleep quality. Those who could see the petrochemical industry from their home were more annoyed by industrial noise. The survey results were complemented with interviews of 14 respondents.

INTRODUCTION

Inhabitants living near petrochemical industries commonly report disturbances as a result of environmental exposures to e.g. odor and noise (e.g. Taylor et al. 1997; Luginaah et al. 2002). In comparison to transportation noise, far fewer are exposed to industrial noise and there are also larger knowledge gaps about how industrial noise affects human health and well-being. There are some studies of annoyance due to noise from industrial sources (Häberle et al. 1984; Gyr & Grandjean 1984; Pierette et al. 2012). Miedema and Vos (2004) presented exposure-response functions relating annoyance to noise levels aggregated from industries producing chemicals, metal, paper, food, glass, and ammonium. Two shunting yards were also included, but were treated separately as they caused more noise annoyance than the other industries at the same sound levels. Using these exposure-response functions for industrial noise (excluding the shunting yards), Eriksson et al (2013) showed that industrial noise is similarly or slightly more annoying than road traffic noise at the same noise levels. However, additional studies are needed to confirm this result. Industrial noise is more difficult to study than, for example, road traffic noise. It varies greatly and is, in general, very complex depending on the existence both of many noise sources and different activities operating. This will influence the annoyance response. For example, industrial noise sources creating impulsive noise or noise with a tonal component cause substantially higher annoyance in comparison to noise from other sources (Berglund & Lindvall 1995; Berry & Porter 2004). Furthermore, non-acoustic factors influencing the annoyance reaction (e.g. noise sensitivity, attitudes towards and fear of the noise source, perceived control, coping resources, etc.) need to be taken into account (Guski 1999). The current project is a follow-up to previous surveys (Axelsson et al. 2013) in residential areas close to petrochemical industries. Using both questionnaires and interviews, it aims to increase the knowledge of what it means to live close to this type of industry. The focus of the present paper is on responses to industrial noise.

METHOD

Study Area and Selection of the Population

A large part of Sweden's petrochemical industry is located in the municipality of Stenungsund. The industry operates for 24 hours a day and many harmful substances are produced, used and transported. Five large flares are situated in the area and the burning of surplus gases occasionally causes a rumbling noise. Transportation to and from the industrial plants consists of heavy vehicles, trains, and ships. Industrial machinery, compressors and internal alarms are also sources of noise. Three residential areas located close to the petrochemical industries were included in the study (Figure 1A). Area 3 is located in the direction of the prevailing winds from the industrial plants and the black areas represent the location of these plants.

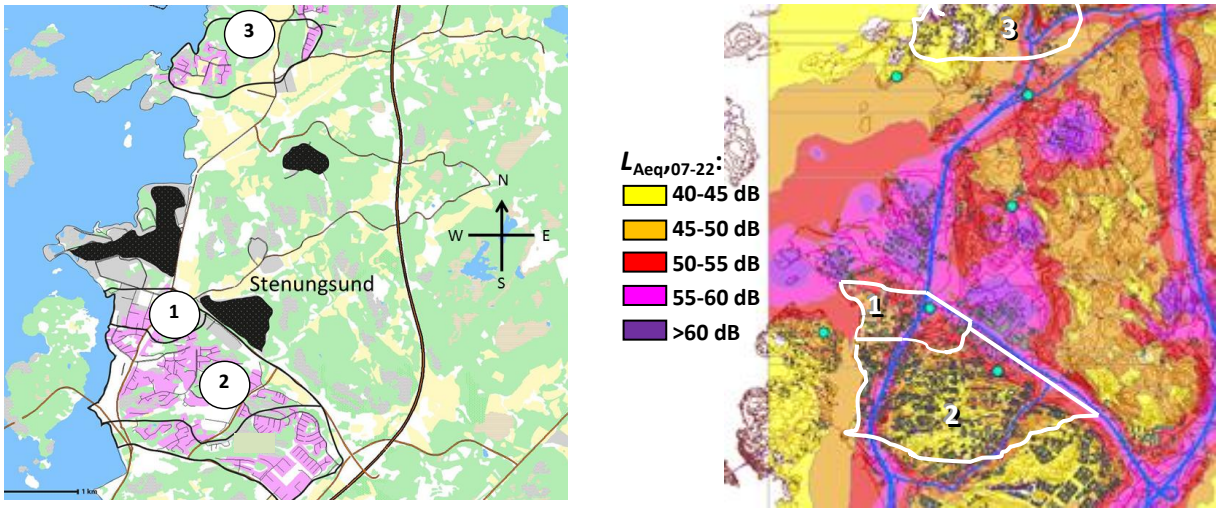

Figure 1A (left): The three residential areas (marked in pink) included in the study. The black areas represent the location of the petrochemical plants. **Figure 1B (right):** Calculated noise levels ($L_{Aeq,07-22}$) from road traffic and industries in the three areas.

The sample (stratified by age and gender) included 358 persons. If there were two or more persons aged 18-75 years in a household, only one person was randomly selected. 187 persons participated (52 % response rate). For the three study areas, the response rate was 47 % (N=55), 51 % (N=73), and 62 % (N=59) for Area 1, 2, and 3, respectively.

Noise Exposure

We had no estimation of noise levels from the petrochemical industries at the time of the study. However, an investigation of the noise situation was conducted during 2008 (Landström 2009) and the noise estimates were based on a common Nordic model for calculating external industrial noise (Kragh et al.1982). A topographic map of the site and immediate surroundings were used as basic data. All external noise sources were input as point sources. Sound reflections, shielding, ground attenuation, vegetation, buildings, etc. that affect the propagation of sound from each source were included. Figure 1B shows the estimated total noise levels ($L_{Aeq,07-22}$) from road traffic and the industrial plants. The difference between calculated road traffic noise levels during day and night at one of the major roads was about 9 dBA. This difference was generally used for all roads when estimating night noise levels. The industrial noise in the study areas was estimated to vary between about $L_{night,22-07}$ 35–50 dB. The episodes of noise from the burning of surplus gases were not taken into account in the noise calculations. As it was not possible to link noise levels to each participant's

home in the present study, it should be noted that the calculated noise levels from the petrochemical industries only give a crude and overall picture of the noise situation in the three studied areas.

Questionnaire

The questionnaire was sent by mail (April, 2012) to the selected persons along with a letter explaining the background and purpose of the study and that participation was anonymous and voluntary. The study was presented as a study on the living environment and human health and well-being. Two reminders were sent to those who did not respond. Questions were asked about the living environment and various sources of nuisance (industrial noise, road traffic noise, railway noise, noise, industrial odor, etc.) and were formulated according to the ISO specification of annoyance scales (ISO 2003): “Thinking about the last 12 months or so, when you are here at home, how much are you annoyed or disturbed by…”. Annoyance was evaluated with a 5-point category scale (“not at all”, “slightly”, “moderately”, “very”, and “extremely”). In the presentation of the results, the “annoyed” category consists of those who were moderately, very, or extremely annoyed on the 5-point category scale. Included were also questions about how noise from industry, road traffic, and railway traffic disturb relaxation and sleep with windows closed and open as well as disturb relaxation when being outdoors near the home and disturb the desire to stay outdoors. Each item was evaluated from two questions on how often (“never”=0, “sometimes”=1, and “often”=2) and to what degree (“not very”=2, “rather”=3 and “very”=4) the activities were disturbed by the various noise sources. A disturbance score ranging from 0 to 6 was constructed, where the value on frequency was added to the value on degree of disturbance.

Five questions were asked about worry regarding the risk of health effects due to air pollution from road traffic or from industry, and risk of accidents due to road traffic, railway traffic or from industrial activity. The questions were phrased as “How often (during the last 12 months) do you experience worry concerning yourself or your family about…”. Each item was evaluated similarly as the above mentioned disturbance questions. A worry score ranging from 0 to 6 was constructed, where the value on frequency was added to the value on degree of worry.

Interviews

An interview study was conducted in spring 2013. Fourteen respondents who participated in the questionnaire study were included based on their interests in being interviewed and their responses to questions on worries about the health impacts of industrial activity (minor worries/strong worries) and period of residence in the area (about 2-12 years/longer than 25 years). The main aim of the interviews was to gain knowledge of how environmental disturbances and worries of potential health effects are formed, expressed and handled by those who live in the vicinity of a petrochemical industry. However, in the present paper, and as a complement to the survey results, we only report briefly how the participants mainly perceived the noise from the petrochemical industry. A descriptive design was chosen to capture experiences of the topics selected for the study. We used semi-structured interviews based on a topic guide, which gave the participants opportunity to talk freely about their experiences related to perceptions of their living environment, annoyances and health concerns, security and risk issues, etc. The interviews were recorded with the permission of the participants who were guaranteed confidentiality.

Statistical Analyses

Differences in proportions for categorical variables were determined with the Chi-square test (χ^2) and the association between variables was determined with Spearman's rank correlation coefficient (r_S).

Population Characteristics

In all three study areas, the average age was about 55 years. Slightly more women than men participated. Most respondents were married or cohabiting; the largest proportion in Area 3. Twelve percent stated that they work in the petrochemical industry. The type of housing differed greatly between the three areas. In Area 1, around 40 % lived in either a condominium or a detached house. A majority in Area 3 lived in detached houses, while most respondents in Area 2 lived in rented accommodation (49 %) and about 20 % in either a townhouse or detached house. The average time living in the area was around 30 years and the average time in current residence was around 13 years (small differences between the areas). The amount who indicated that they perceive themselves as somewhat or very sensitive to sounds and noise were 22 %, 25 %, and 31 % in Areas 1, 2, and 3, respectively. A majority could see the petrochemical industry from their home (74 %, 53 %, and 59 % in Areas 1, 2, and 3, respectively).

RESULTS

Annoyance due to Industrial Noise, Road Traffic Noise, and Railway Noise

Figure 2 shows that industrial noise annoys more inhabitants than railway noise and road traffic noise in the three study areas. The prevalence of industrial noise annoyance is highest in Area 3 (32 %) and Area 1 (27 %). Inhabitants in Area 1 are more exposed to noise from road and railway traffic (see Fig. 1B) and are also annoyed to a greater extent by noise from these noise sources than in the other two areas. For the entire study population, there is no link between working in the petrochemical industry and reports of industrial noise annoyance. Noise sensitive respondents were significantly more annoyed by industrial noise than those not sensitive to noise (42 % vs. 20 %; $p<0.05$). Those who indicated that they can somewhat or very clearly see the industrial buildings of the petrochemical industry from their home or outdoors near their home were significantly more annoyed by industrial noise than those who cannot see the petrochemical industry (31 % vs. 18 %; $p<0.05$). Worry about health impact of industrial air pollution was moderately

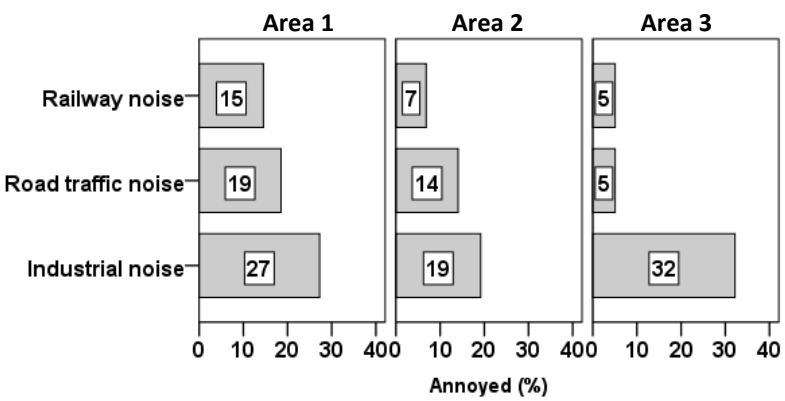

Figure 2: Percentage annoyed due to industrial noise, road traffic noise, and railway noise in the three study areas.

correlated with industrial noise annoyance (r_S=0.51) and also higher than the association between worry about health impact of vehicle exhaust and road traffic noise annoyance (r_S=0.26) and worry about health impact of railway accidents and railway noise annoyance (r_S=0.14).

Noise Disturbed Activities

Figures 3-5 present the percentage of respondents reporting disturbed activities due to industrial noise, road traffic noise, and railway noise with a score above three. This includes individuals who report that they are alternatively sometimes and rather disturbed (score 4), often and rather disturbed (score 5), or often and very disturbed (score 6). In all study areas, disturbed sleep quality due to industrial noise affects more inhabitants than noise from railway and road traffic. In the situation with closed window a fifth of the respondents in Area 3 report that industrial noise disturbs their sleep quality. This number is slightly lower in the two other areas. With open windows, the proportion with disturbed sleep quality increases in Area 1 from 17 % to 29 % while the number drops slightly in Area 3 (from 20 % to 15 %).

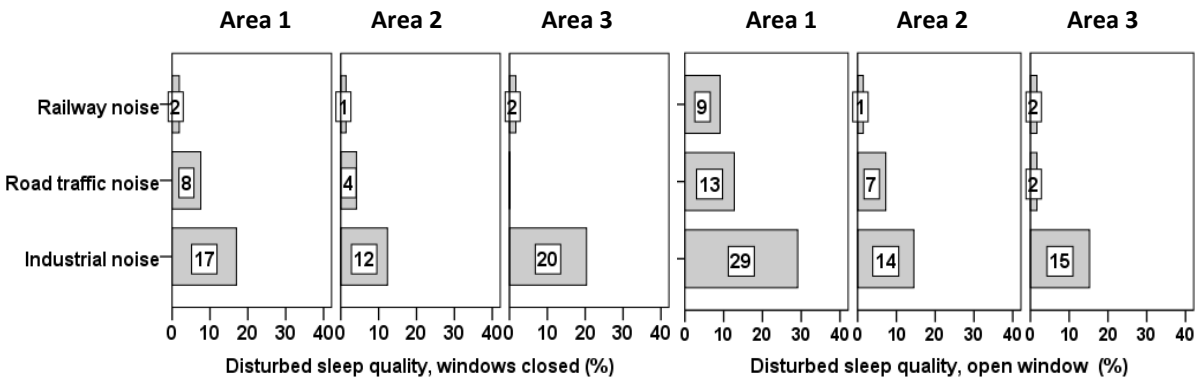

Figure 3: Percentage with disturbed sleep quality due to industrial noise, road traffic noise, and railway noise with closed (left) and open (right) window in the three study areas.

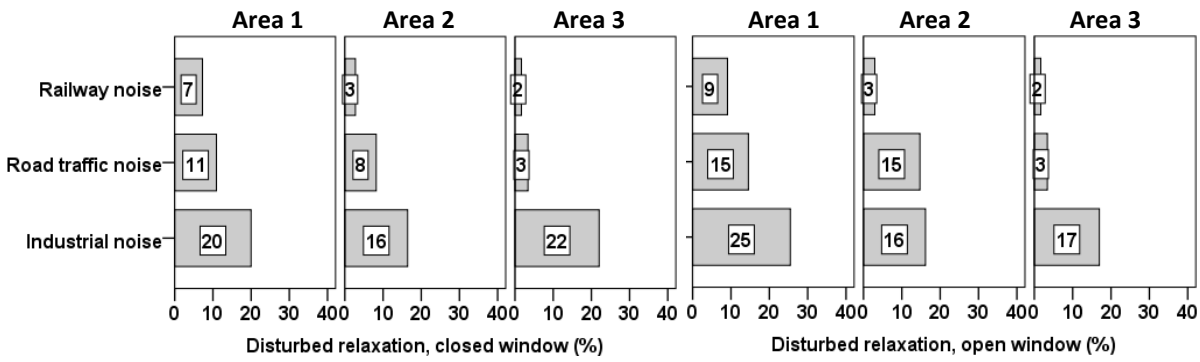

Figure 4: Percentage with disturbed relaxation indoors due to industrial noise, road traffic noise, and railway noise with closed (left) and open (right) window in the three study areas.

In all areas, industrial noise primarily interferes with relaxation indoors (16-25 %, Figure 4) as well as outdoors close to the home (Figure 5, left). There is no major difference in disturbed relaxation with closed respectively with open window. About 11 % report that they do not stay outdoors due to industrial noise. This number is less for road traffic noise and railway noise (Figure 5, right). Those who reported that they can somewhat or very clearly see the petrochemical industry from home or outdoors near the home, stated to a greater extent that they experienced disturbance due to industrial noise of the aforementioned activities.

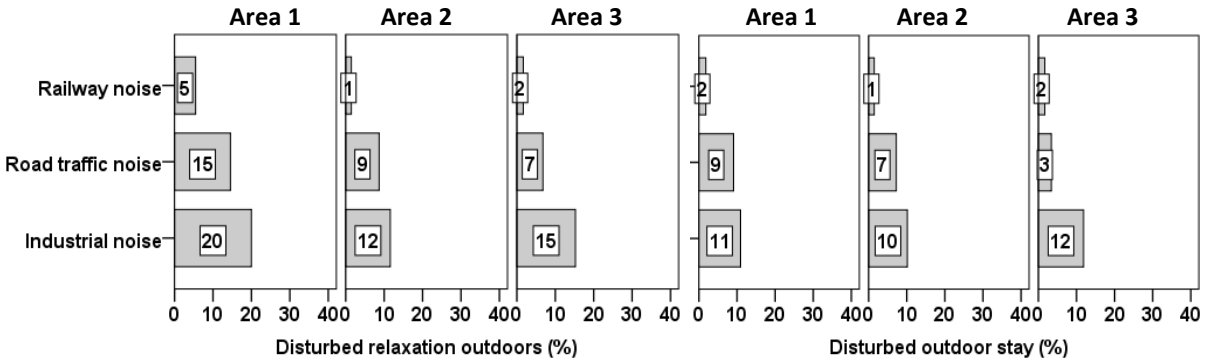

Figure 5: Percentage with disturbed relaxation outdoors (left) and disturbed outdoor stay (right) due to industrial noise, road traffic noise, and railway noise in the three study areas.

The Interviewees' Perceptions of the Noise from the Petrochemical Industry

By asking the interview participants how they notice the presence of the petrochemical industry, we got an indication of their perceptions of the petrochemical industry. What they primarily mentioned was the odor, the smoke, the fire from the flares, and the noise – particularly the episodes of rumbling noise from the largest of the five flares within the industry when burning off the surplus gases. For six of the fourteen interviewees, these perceptions represented something negative, while the others were more neutral or positive in their views. The negative perception of the noise from the petrochemical industry was expressed as follows: *"I live quite close, so of course I hear this sound and see the light* (from the flare) *that can last for several days and disrupt my sleep. I sleep much worse and the sound is scary"*;

"…when they fail (with the production)*, and the roar and the fire at the flare is 30 meters high and there's black smoke, then you know, of course, what it is, … but it's clear that if the flare didn't exist then the whole lot would have exploded instead, because it's a safety-valve".*

"it's pretty dull, it's pretty low, but it varies, it's a sound that goes up and down so that you thinks of it as well, a bit like a mill"

"…when it's summer, you would like to sleep with the window open, but then there's usually a humming sound all the time, a sound that makes you close the windows."

DISCUSSION

This study shows that annoyance due to industrial noise is quite extensive among the residents living in the vicinity of the petrochemical industry, although fewer are as annoyed as the last survey in 2006 (Axelsson et al. 2013). Industrial noise also annoys more people than noise from road and rail traffic and it impedes and disturbs many in their daily activities, such as during relaxation and sleep, which is in line with a study by Gyr and Granjean (1984). The highest number of annoyed residents are found in Area 1 located closest to the largest petrochemical industrial complex and in Area 3, which is situated about 3 km from this complex, but in the main direction of the prevailing winds. A strong association between the direction of the prevailing winds from a chemical plant and the number of noise complaints has also been reported by Häberle and colleagues (1984). A limitation of the present study is that we were unable to calculate noise levels from the petrochemical industry at the time of the survey, which also meant that we could not do any analyses on exposure-response relationships between industrial noise and annoyance.

Although the annoyance was evident in the population, the estimated noise levels we had access to indicate that the equivalent industrial noise levels during day and night was not particularly high in the studied areas. Swedish guideline values for industrial noise (existing industries) in residential areas are $L_{Aeq07\text{-}18}$=55 dB, $L_{Aeq18\text{-}22}$=50 dB, and $L_{Aeq22\text{-}07}$=45 dB, respectively. The guideline values are set to 5 dBA lower when new industries are built.

For industries that operate around the clock, industrial noise during the night is potentially the most important to estimate as the day traffic noise in most settings will dominate and mask the noise from the industries. The results also showed that for about one fifth of the respondents, the industrial noise caused disturbed sleep quality. In the present population, this seems to be particularly related to the rumbling noise of surplus gases burning off (flaring) that was often mentioned as annoying by those interviewed, although these episodes occurred rather rarely. The finding is supported by previous studies showing that impulsive noise with an abrupt onset and termination (e.g. release of gas or steam) increases annoyance (Berry & Porter 2004). Furthermore, a bright flash of light from the burning gas accompanies the rumbling noise, which in itself or in combination with the noise can particularly affect the inhabitant's sleep. The interviews also revealed that the flaring can go on for many days and nights. Some of the interviewees reported that they experienced a constant annoying background noise that they believed come from compressors, ventilators, and cooling systems at the industrial plants, which also affected their sleep. One of the interviewees experienced disturbing vibrations when lying in the bed, which she assumed was created by low-frequency noise and infrasound from the large ships that transport goods to and from the petrochemical industry. Research shows that annoyance reactions are greater for low frequency noise than other noises at comparable sound pressure levels (Berglund et al. 1995).

During the weekends when the traffic intensity and the noise are lower, the daytime noise from the industries might also be less masked and heard more clearly. This may disturb daily activities particularly in the summer when people have their windows open more often and spend more time outdoors, which also was expressed by some of those interviewed. The finding corresponds well with a study by Pierette et al. (2012), who found that annoyance due to industrial noise was not consistent, but changed depending both on the time of the day and type of season (see also Gyr & Grandjean 1984).

A consistent result is how the visibility of the petrochemical industry from the respondent's home considerably influenced their experiences. The extent of annoyances due to industrial noise is significantly higher if the industry is clearly visible from the home, than if it cannot be seen at all. Seeing the industry can mean that the home is located near the petrochemical industry, which likely increases the risk of exposure to noise. Other homes may be far away, but the industry may still be visible because of the tall stacks. The higher annoyance may be related to a perception of visual intrusion, as has been found in previous studies on wind turbine noise and annoyance (Pedersen & Persson Waye 2004). By seeing the industrial buildings or the refinery stacks or other physical manifestations such as flames and smoke, the inhabitants in the present study are constantly reminded of the presence of the petrochemical industries and this may reinforce worries and concerns about possible health effects as well as moderate noise responses (Luginaah et al. 2002). We also found that greater concern for health effects due to industrial emissions was positively related to higher degree of industrial noise annoyance.

How industrial noise affects health and well-being among residents living in the vicinity of petrochemical industries is influenced by a large number of factors and conditions. The interviews indicated that certain incidents of sound were perceived as particularly disturbing, even though they did not occur especially regularly or frequently. Chronic exposure to sounds of low frequency character was also experienced as intrusive and annoying. This shows that it is important to identify the sounds that may occur in connection with the industrial operations. However, it is also essential to have control of other factors capable of modifying noise responses, such as various physical manifestations of the industry and additional environmental stressors, attitudes towards and dependency upon the source of noise exposure, mistrust of noise source authorities, expectations of an increasing level of exposures, fear of health effects, perceived control, coping capacity, concerns about loss of property value, and warnings in the media about environmental pollution (e.g. Lercher 1996; Guski 1999). Further analyses of both questionnaire and interview data from the two presented studies will potentially provide more information about these factors' impact on the inhabitants' responses to industrial noise.

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