Effects of road traffic noise and the benefit of a quiet side in newly built houses

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ABSTRACT

Previous research shows that access to a quiet side of the apartment can reduce the adverse effects of noise on health and wellbeing. However, it is relatively unknown whether the same effects apply to newly built houses. A socio-acoustic survey was conducted in 29 residential areas exposed to various levels of road traffic noise (N = 870) in Örebro, Sweden. A majority (8 %) of the participants lived in houses built between 2002 and 2013, and 20% in houses built between 1985 and 1996. One group was exposed to low noise levels from road traffic (L_{Aeq,24h} < 50 dB; n = 113) and two groups were exposed to noise levels between L_{Aeq,24h} 53 and 67 dB at the most exposed façade and had either access to a quiet side (n = 383) or not (n = 371). Access to a quiet side reduced annoyance; at noise levels between L_{Aeq,24h} 58-62 dB 37% of those without access to a quiet side were highly annoyed but only 19% of those who had access to a quiet side. Sleep disturbances among residents with their bedroom facing a busy road was about three times higher than among those with their bedroom facing a courtyard.

Keywords: Noise, Annoyance, Quiet Side, I-INCE Classification of Subjects Number(s): 66.1

1. INTRODUCTION

Traffic noise is a widespread environmental problem and it affects the largest number of people in Sweden. No signs are seen that the noise problem is reduced, rather the opposite (1). Traffic noise cause irritation and annoyance and affects e.g. sleep, restoration, communication, concentration, and learning (2, 3, 4). Growing evidence show an increased risk for hypertension and cardiovascular disease due to prolonged road traffic noise exposure (5-9). Recent studies have also found a relationship between road traffic noise and an increased risk of stroke (10) and diabetes (11). However, noise responses to a given exposure are influenced by attitudinal, personal, social, situational factors, as well as exposure modifiers (e.g. a quiet side, acoustic insulation). The benefit of access to a quiet side has previously been studied and the results show that a quiet side can reduce the adverse health effects of noise (12-19). However, it is relatively unknown whether the same effects of noise and a quiet side apply to newly built houses, since most of the studies have either just investigated older houses, or a mix of older and newer ones. Older apartment blocks may differ in relation to newer ones in design of the apartments and building construction (e.g. soundproof windows and facades).

In Sweden, as in other countries, there is a large migration into city regions. In order to resolve the housing shortage and to counteract urban sprawl, authorities often want to densify or build in areas that previously have been considered inappropriate, often due to excessive noise exposure from traffic. There is an opinion that new buildings with high noise insulation is a satisfactory solution to the adverse noise effects, but there is still no scientific evidence that this would be true. Our purpose of this study was, therefore, to investigate the effects of road traffic noise and the benefit of access to a quiet side in a selected population of individuals living in newly built apartments.

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2. METHOD

2.1 Study Areas, Study Population and Questionnaire

Our intention was to choose newly built residential areas (apartment buildings) exposed to road traffic noise in varying noise levels and having access or not to a quiet side. After visit and examination of different residential areas proposed by the Technical Administration at Örebro Municipality in Sweden, 29 areas in the central zone of Örebro were selected: 18 areas with a quiet side, 8 areas without a quiet side and three reference areas with low noise levels from road traffic. Table 1 shows the year the properties were constructed. Only areas with a quiet side had properties built between 1985 and 1996, but the majority was built between 2004 and 2012. For areas without a quiet side, half of the properties were built between 2002 and 2008 and half between 2009 and 2012. Properties in the reference areas were built between 2007 and 2013.

Table 1 – The properties year of construction

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>Access to a quiet side</th>
<th>Without access to a quiet side</th>
<th>Reference areas with low noise levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985-1987</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1991-1992</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1996</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2002</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>2004-2006</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>2007-2008</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2009-2010</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2011-2012</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>2013</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

In September 2014, a socio-acoustic survey was conducted and a questionnaire was distributed by mail to all residents between 18 and 75 years of age in the selected areas. An introductory letter presented the survey as an investigation on health and wellbeing in housing environments. A reminder letter was sent about 10 days later with a new questionnaire to all who had not responded, and after another 10 days an additional new reminder in the form of a small card was distributed. The format of the questionnaire was based on previous socio-acoustic studies investigating the adverse health effects of traffic noise (13, 16, 19) and included about 60 questions in total. 933 persons answered the questionnaire and the overall response rate was 54% (58% in areas with a quiet side; 50% in areas without a quiet side; 54% in reference areas). However, based on the participants’ responses to questions about housing windows positions, we identified apartments that didn’t fit to its original residential category. In order not to reduce the population too much, we decided to move a number of apartments in the following way: Areas with a quiet side – 45 apartments were moved to areas without a quiet side as they had no windows facing a quiet side, 43 apartments were excluded because only the windows faced a quiet side (no window faced the traffic exposed side); Areas without a quiet side – 4 apartments were moved to the areas with a quiet side as the windows faced a quiet side and an exposed side, 11 apartments were excluded because the windows only faced a quiet side (no window faced the traffic exposed side), 9 apartments were excluded because of low levels on the exposed side ($L_{Aeq,24h} 45-48$ dB). The final population consisted of 870 participants.

Please note that in the following presentation of the results, we have chosen to name the areas as follows: A-apartments with a quiet side, B-apartments without a quiet side, and reference-apartments (reference areas) with low levels of noise from road traffic.

A larger proportion of the respondents with than without a quiet side lived in a condominium (77% and 23%, respectively). The others lived in rented apartments. These numbers for the reference apartments were 80% (condominium) and 20% (rented apartment). The average age of the respondents was 56 (SD 15.0), 48 (SD 18.7), and 54 (SD 15.0) years of age and the proportion of women was 53%, 56% and 5% in A-apartments with a quiet side, B-apartments without a quiet side and
reference-apartments, respectively. The majority was cohabiting or married (82%, 75% and 77% respectively). Approximately one third of the respondents in the three apartment objects perceived themselves to be quite or very sensitive to sound/noise and dust/air pollution. In both A- and B-apartments, half of the inhabitants worked as employees. This number was higher in the reference-apartments (66%). The highest proportion of pensioners was in the A-apartments (39%), while this number for B- and reference-apartments was 27%. Highest proportion of students had B-apartments (15%) compared with about 5% in the two other apartment objects. Approximately 40% of the residents in each apartment object had completed a university degree (3 years or more). A majority (about 79%) in the three apartment objects assessed their overall health as quite or very good.

2.2 Noise Exposure and Distribution of Respondents in Noise Exposure Categories

Determination of individual noise exposure from road traffic was made for all properties in the residential areas at the most exposed facade. The calculated noise values (L$_{deq}$, L$_{Aeq,24h}$, L$_{night,22-06}$) were based on the latest strategic noise mapping of the END (European Environmental Noise Directive) and was conducted by an acoustic company in 2011-2012 (20). The Nordic Prediction Method and the calculation program CadnaA version 4.2 were used. By using property designation, questionnaire responses about the location of the apartment and its design (floor level and the location of the windows to the exposed and quiet side) each respondent received individual noise levels of their apartment. Table 2 shows the statistics (mean value, SD, minimum and maximum) for L$_{Aeq,24h}$ at the most exposed side for each of the apartment objects. The noise level (L$_{Aeq,24h}$) was on average highest for the A-apartments with a quiet side (62.5 dB) compared to the B-apartments without a quiet side (60.8 dB) and lowest for the reference-apartments (44.7 dB).

Table 2 – Statistics for L$_{Aeq,24h}$ for each of the apartment objects

<table>
<thead>
<tr>
<th>Type of apartment object</th>
<th>Reference-apartments (n=116)</th>
<th>A-apartments with a quiet side (n=383)</th>
<th>B-apartments without a quiet side (n=371)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>44.7</td>
<td>62.5</td>
<td>60.8</td>
</tr>
<tr>
<td>SD</td>
<td>3.4</td>
<td>4.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Minimum</td>
<td>37.3</td>
<td>53.8</td>
<td>51.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>48.8</td>
<td>67.6</td>
<td>67.2</td>
</tr>
</tbody>
</table>

We created four noise categories based on noise levels at the most exposed side of the apartments (Table 3). More A-apartments with a quiet side were exposed to the highest noise levels (63-67 dB) than the B-apartments without a quiet side, which instead were most exposed to noise levels between 58 and 62 dB.

Table 3 – Number of respondents in different noise exposure categories

<table>
<thead>
<tr>
<th>Type of apartment object</th>
<th>Number of respondents per noise category (L$_{Aeq,24h}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 50 dB</td>
</tr>
<tr>
<td>Reference-apartments</td>
<td>116</td>
</tr>
<tr>
<td>A-apartments with a quiet side</td>
<td>-</td>
</tr>
<tr>
<td>B-apartments without a quiet side</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>116</td>
</tr>
</tbody>
</table>

2.3 Statistical Analyses

Differences in proportions for categorical variables were determined with the Chi-square test ($\chi^2$). We analyzed the relationship between noise exposure (L$_{Aeq,24h}$, continuous variable) and general noise annoyance in relation to various influencing factors with logistic regression analysis. General annoyance due to road traffic noise was classified as follows: 0 = not annoyed (not at all/slightly/moderately annoyed) and 1 = highly annoyed (much/very much annoyed). In Model 1, only the relationship between noise level and highly annoyed was tested and in Model 2 we included
building-related factors of importance for noise annoyance. These were: access to a quiet side (0 = yes; 1 = no), orientation of the bedroom window (0 = facing a courtyard/green space; 1 = facing a busy road), and type of residence (condominium = 0; 1 = rented apartment). In Model 2, we also adjusted for sex (female/male), age (continuous), education level (0 = no college or university education ≤ 2 years; 1 = university education ≥ 3 years), and noise sensitivity (scale 1-5).

All tests were two-tailed and a p-value below 0.05 was chosen as the threshold for considering a given relationship significant. The statistical analyses were conducted with SPSS Statistics 22.

3. RESULTS

3.1 General Noise Annoyance

The present paper will only present results on general noise annoyance and disturbances of sleep (sleep quality and opening of bedroom windows).

General noise annoyance caused by road traffic noise was assessed with a 5-point category scale. The question was part of a battery of questions concerning various sources of annoyance (e.g. noise from industry, railway traffic, ventilation, neighbors, and odor from industry). The exact wording was: “Thinking about the last 12 months, how much are you annoyed or disturbed by the following nuisances in or near your home?” The response alternatives were: “not at all”, “slightly annoyed”, “moderately annoyed”, very annoyed”, and “very much annoyed”. The question has been used in the Swedish National Environmental Health Survey 2007 (1) and differs slightly from the ISO standardized annoyance scale (21).

Figure 1 a-b shows the association between general annoyance by road traffic noise and noise exposure categories (L_Aeq,24h) for the three apartment objects. As shown in Figure 1 a, the proportion who are annoyed (“moderately”, “very”, and “very much”) is low in the lowest noise category (<50 dB, reference-apartments), but becomes far more extensive in the A- and B-apartments. For A-apartments with a quiet side, the amount of annoyed residents increases from 31% at 53-57 dB to 49% at 63-67 dB. For the B-apartments without a quiet side, the amount of annoyed residents is high even at 53-57 dB (55%) and only increases by two percentage-points to 57% at about 58-62 dB. The number then drops to 52% in the highest category. At 53-57 dB, B-apartments have a significantly higher proportion of annoyed residents than A-apartments (31 resp. 55%, p < 0.05). In the higher noise categories, the difference was not significant (p > 0.05). The proportion of highly annoyed (very and very much) (see Figure 1 b) shows a similar relationship with noise exposure as the proportion of annoyed. For B-apartments without a quiet side, the percentage of highly annoyed is high (35%) even in the 53-57 dB category. The difference in the percentage of highly annoyed between B- and A-apartments are statistically significant in all the noise categories (p < 0.05).

![Figure 1 a-b](image_url)

Figure 1 a-b – Percentage of respondents who are (a) annoyed (moderate, much or very much annoyed) and (b) highly annoyed (much or very much annoyed) by road traffic noise in relation to L_Aeq,24h for reference-apartments (green bars), A-apartments with a quiet side (blue bars) and B-apartments without a quiet side (red bars). Significant differences *p < 0.05; **p < 0.01; ***p < 0.001.
3.2 Sleep Disturbances and Bedroom Orientation

Disturbed sleep quality and unable to have the bedroom window open due to road traffic noise were evaluated with two questions concerning: “How often” (0 = “never”, 1 = sometimes, 2 = “often” and regarding “How much” (2 = “slightly”, 3 = “moderately”, 4 = “much”). A disturbance score ranging from 0 to 6 was constructed, in which the value for frequency was added to the value for degree of disturbance. When analyzing the data, a score above three is used for assessing the percentage of disturbed respondents. This includes individuals who report that they are alternatively sometimes and moderately disturbed (score 4), often and moderately disturbed (score 5), or often and very disturbed (score 6).

Figures 2 a-b and 3 shows sleep disturbances due road traffic noise in relation to bedroom orientation (facing a courtyard/green space or a busy road) and noise exposure categories (L_{Aeq,24h}) at the most exposed side. The orientation of the bedroom window was based on a survey question and plan drawings of the apartments. About half (51%) of the study group stated that their bedroom window was facing a courtyard/green space and the other half a busy road. Figures 2 a-b and 3 shows clearly a beneficial effect of bedroom orientation on sleep disturbances.

In the situation with bedroom window closed (Figure 2 a), few with their bedroom window facing a courtyard/green space reported disturbed sleep quality and the disturbance increased very little with increasing noise levels (from 3% at < 50 dB up to 7-8% > 57 dB). For those, with their bedroom window facing a busy road, the amount with disturbed sleep quality is high even at 53-57 dB (23%) and increases only by three percentage-points to 26% at 58-62 dB and the it declines to 20% in the highest noise category. With bedroom window open (Figure 2 b), disturbed sleep quality increases considerably and there is a clear association with increasing noise exposure in both groups. The amount of respondents with disturbed sleep quality (> 52 dB) is between 16 and 28 percentage-points lower if the bedroom window is facing a courtyard/green space than a busy road. In the three highest noise categories, the differences between the two groups were statistically significant (p < 0.01).

Figure 2 a-b – Percentage of respondents with disturbed sleep quality due to rad traffic noise with bedroom window closed (a) and with bedroom window open (b) in relation to bedroom orientation and L_{Aeq,24h}. Significant differences *p < 0.05; **p < 0.01; ***p < 0.001.

Figure 3 shows that disturbance of being unable to have bedroom window open due to road traffic noise is about twice as low when the bedroom window is facing a courtyard/green space compared to a busy road. For those with the bedroom window facing a courtyard/green space, the disturbance increase from 6% at the lowest noise level to 34% at 58-62 dB, but then drops to 22% in the highest noise category. These numbers for those with their bedroom window facing a busy road are 15% at < 50 dB and 60% at 58-62 dB and 52% in the highest category. The differences are statistically significant in the three highest noise categories (p < 0.05).
3.3 The Influence of Type of Residence on Noise Annoyance

A majority (62%) of the respondents lived in a condominium and 38% lived in a rented apartment. Figure 4 shows that the percentages who are highly annoyed by road traffic noise are considerably higher in rental apartments than in condominiums (13-33 percentage-points difference). The differences are statistically significant in the three highest noise categories ($p < 0.01$).

**Figure 4** – Percentage of highly annoyed respondents in relation to type of residence and $L_{Aeq,24h}$. Significant differences *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

3.3.1 The Influence of Building-Related Factors on Annoyance

We found a significant association between noise level and noise annoyance (see Table 4). Model 1 shows that the odds ratio for being highly annoyed (OR 1.04; 95% CI 1.02–1.07, $p < 0.001$) increases significantly by 4% for every increasing decibel. In Model 2 (adjusted for sex, age, education and sensitivity to noise), the significant association between exposure to noise and annoyance remains, even when building-related factors are taken into account (OR 1.03; 95% CI 1.00–1.07, $p = 0.05$).
The odds ratio (OR) for being highly annoyed was 1.65 times higher with no quiet side compared to having a quiet side (95% CI 1.10–2.49, \( p < 0.05 \)), 2.15 times higher if living in a rented apartment compared to a condominium (95% CI 1.43–3.24, \( p < 0.001 \)), and 3.51 times higher if the bedroom faces a busy road compared with a courtyard/green space (95% CI 2.33–5.28, \( p < 0.05 \)). Besides noise sensitivity, sex, age and education had no statistically significant association with being highly noise annoyed.

Table 4 – Results from logistic regression analysis: Association between road traffic noise exposure (\( L_{\text{Aeq,24h}} \)), access to a quiet side, type of residency, orientation of bedroom window, and the probability of being highly noise annoyed.

<table>
<thead>
<tr>
<th>Variables</th>
<th>( p )</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textit{Model 1}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L_{\text{Aeq,24h}} ) (continuous)</td>
<td>0.00</td>
<td>1.04</td>
<td>1.02-1.07</td>
</tr>
<tr>
<td>\textit{Model 2*}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L_{\text{Aeq,24h}} ) (continuous)</td>
<td>0.05</td>
<td>1.03</td>
<td>1.00-1.07</td>
</tr>
<tr>
<td>Access to a quiet side (0 = yes, 1 = no)</td>
<td>0.02</td>
<td>1.65</td>
<td>1.10-2.49</td>
</tr>
<tr>
<td>Type of residence (condominium = 0; 1 = rented apartment)</td>
<td>0.00</td>
<td>2.15</td>
<td>1.43-3.24</td>
</tr>
<tr>
<td>Bedroom window facing (0 = courtyard/green space, 1 = busy road)</td>
<td>0.00</td>
<td>3.51</td>
<td>2.33-5.28</td>
</tr>
</tbody>
</table>

*Adjusted for sex, age and noise sensitivity.

4. SUMMARY

There are discussions and wonderings whether adverse health effects due to traffic noise (e.g., annoyance and disturbances) actually occurs to any significant extent in newly constructed residential buildings since they generally have good soundproof windows and facades and shall meet the Swedish guideline values for indoor noise (\( L_{\text{AeqT}} \) 30 dB, \( L_{\text{AFmax}} \) 45 dB). In the present study, a majority of the residents lived in apartment buildings built between 2002 and 2013 and our results clearly show that the scales of the noise effects are not negligible. The results show a significant positive benefit of access to a quiet side, which is consistent with previous studies (12-19), but the relationship between road traffic noise exposure and noise responses was weaker than found in previous research (12-19). However, several factors influenced the findings.

At low sound levels \( L_{\text{Aeq,24h}} < 50 \) dB, few (6%) were highly annoyed by noise from road traffic. This agrees fairly well with synthesized exposure-response data (22) and other similar studies (13, 18). At sound levels around \( L_{\text{Aeq,24h}} 55 \) dB, about one third with and about half of without a quiet side were annoyed, respectively. These numbers are in line with what Bodin et al found (18), but higher than what were found by Öhrström et al (13). The proportion highly annoyed was also higher than expected – 16% with and 35% without a quiet side, respectively. The association between noise exposure and annoyance was weak at higher noise levels, but having a quiet side gave consistently lower noise annoyance than lacking a quiet side – a difference that for the proportion of highly annoyed, was statistically significant at all noise categories. This result supports the hypothesis of a beneficial effect of access to a quiet side even amongst residents in newly built houses exposed to road traffic noise. With increasing noise levels, annoyance increased slightly – somewhat more for those with a quiet side than for those without. For the latter a small decrease was seen instead. It is possible that in apartments exposed to the highest noise levels, windows and facades have higher noise insulation than in apartments exposed to the lower noise levels. Furthermore, the perceived physical environmental quality of the quiet side (degree of naturalness and utilization) may also have influenced annoyance, which has been shown in a previous study (23).

The finding of the rather high amount of annoyance at the lower noise levels (\( L_{\text{Aeq,24h}} 53-57 \) dB) among those without a quiet side could possibly be explained by the substantial increase in the number of vehicles that have occurred in recent years in some of the residential areas in this noise category. Small local streets, which previously had little traffic, has turned into thoroughfares for both cars and heavy vehicles when large new residential areas have been built in the neighborhood. In general,
people’s responses to changes in noise exposure include both an exposure and a change effect (24-26). This means that changes in the noise exposure can cause other changes for those living in the affected area, which influence how one reacts to the noise. In this case, a considerable increase of the traffic volume has not only increased noise levels, but may for instance, have led to more air pollution, more concern about reduced road safety, and a more negative impression of the residential area. This type of impact is referred to as a surrogate effect and it modifies the exposure-response relationship between noise levels and for example, noise annoyance. Additionally, there may also be concerns that the traffic will increase even more in the future and an exaggerated response can then be a way for the inhabitants to show their worries for the authorities. Although it is newly built houses (in 2008), it is also possible that the facades and windows in these buildings were not constructed to withstand an increase in noise levels.

Having the bedroom window facing a courtyard/green space compared to a busy road was clearly associated with better sleep quality. This finding for newly built houses is in line with previous studies (12-19). Even with the bedroom window closed, this benefit was quite large and significant and it is rather notable that so many as about one fourth of the residents lacking a quiet side had disturbed sleep quality, but the association with noise exposure was rather weak. However as mentioned before, it is possible that apartments exposed to the highest noise levels have windows with higher noise insulation than in apartments exposed to the lower noise levels. This reasoning receives some support as the association between road traffic noise and sleep-related problems was positive and stronger for both disturbed sleep quality in the situation with bedroom window open, and whether noise makes it difficult to sleep with the bedroom window open. For these two activities as well, a significant benefit of bedroom orientation towards a courtyard/green space was present.

Type of residence (to live in a condominium or a rented apartment) was another factor that turned out to be of great importance for noise annoyance. The descriptive analysis showed a two- to a threefold increase in the percentage of highly annoyed in the rented apartments compared to the condominiums. Using logistic regression analysis, we investigated the simultaneous influence of access to a quiet side, bedroom orientation, type of residence for being highly noise annoyed (in addition to noise exposure from road traffic at the most exposed side of the dwelling). We also took into account other factors that may affect the relationship between annoyance and noise exposure (sex, age, education, and noise sensitivity). In the adjusted model, there was a significant positive association between noise levels at the most noise exposed side of the dwelling and being highly noise annoyed. The absence of a quiet side led to an OR of 1.6 for being highly annoyed, but bedroom orientation had the greatest impact for noise annoyance. Respondents having their bedroom facing a busy street were 3.5 times more likely to be highly annoyed than respondents having their bedroom facing a courtyard/green space. Living in a rented apartment compared to a condominium resulted in a significant increase in noise annoyance (about 2 times). This result is consistent with findings in other studies in Sweden (27). Another project, also found that more residents in apartment buildings than in detached houses (the latter is largely owned by the residents) were dissatisfied with various environmental factors in their home (28). Thus, if you own your home, then you will be less likely to report various environmental problems and disturbances (e.g. noise annoyance) related to your property as this may lead to a reduction of its economic value. The Environmental Protection Agency in Denmark, for example, estimates that houses exposed to road traffic noise > 55 dB decrease in value by 1.2% for each increase in the noise level by 1 dB (29).

A limitation of the present study is the rather low response rate (54%), but it corresponds to a level that is common today (15, 18). A dropout analysis showed that the selected study population included more women (52%) than men (48%). This is consistent with the distribution of women and men in Örebro city center. Women, however, had a slightly higher response rate (55%) than men, which is normal in surveys (13, 18). This may have resulted in an overestimation of the noise annoyance as the proportion of very annoyed by road traffic noise was slightly higher among women (26%) than men (21%). Older people were more likely to respond to the survey than younger people, which is also seen in other studies (13, 18). The average age in the group of participants was 52 years compared with 39 years in the non-response group. This may have caused a slight underestimation of noise annoyance since the younger respondents were slightly more annoyed than the older ones in this study. An important aspect is that the response rate was not higher among those who were exposed to higher noise levels compared to lower noise levels. Based on our dropout analysis, we estimate that the results are representative of the entire target group.
The noise mapping is holding a good standard, which is the strength of the study. Furthermore, we could also determine each respondent’s individual noise levels through information about property designation, questionnaire responses about the location of the apartment and its design (floor level and the location of the windows to the exposed and quiet side). Another strength is that many of the survey questions are well proven and previously used (such as the ISO-standard noise annoyance question), and the results are, therefore, comparable with results in other studies.

Based on the results of this study we can conclude that residents in newly built houses exposed to road traffic noise around $L_{A_{eq,24h}}$ 55 dB and above at the most exposed façade were adversely affected by the noise. Having access to a quiet side was associated with a lower risk of noise annoyance. Having a bedroom window facing a busy road compared to courtyard/green space was associated with higher risk of sleep disturbances. To live in a rented apartment increased the risk of being highly noise annoyed and this effect was particularly evident among residents lacking a quiet side. Annoyance was relatively weakly related to noise exposure in this study. However, a changed traffic situation during the last years in some of the residential areas (exposed to the lower noise levels) and possibly better noise insulated windows and facades in apartments exposed to the higher noise levels as well as type of residency (living in a condominium or a rented apartment) and its noise exposure are factors that might explain the finding. The results suggest that to protect 80% of the people from being annoyed or 90% of being highly annoyed, the sound levels should not exceed $L_{A_{eq,24h}}$ 55 dB at the most exposed façade, even when there is a quiet side.

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