# Comparative studies on railway and road traffic noise annoyances and the importance of number of trains

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## INTRODUCTION

It is estimated that about 500,000 people in Sweden are exposed to noise levels from railway traffic exceeding the outdoor guideline value $L_{Aeq,24h}$ = 55 dB, while about three times that number is exposed to noise levels from road traffic. Railway traffic on existing lines is likely to increase in the future due to environmental concerns. The combination of more frequent, heavier and faster trains could therefore increase the number of disturbances. At the same sound level, railway noise is perceived as less annoying than road traffic noise both in terms of general annoyance and sleep disturbances according to dose-response relationships from meta-analyses (Miedema & Oudshoorn 2001). However, with regard to specific effects on communication and other activities that involve listening, all field studies shows that railway noise is more disturbing than road traffic noise (Moehler 1988; Öhrström 1990; Öhrström et al. 2010). Findings in recent years from Japanese (e.g. Morihara et al. 2002) and Korean studies (Lim et al. 2006) show, unlike most European studies, that railway noise is perceived as more annoying than road traffic noise at >$L_{Aeq,24h}$ 55 dB. This applies particularly to the Japanese Shinkansen express trains, as well as conventional trains. Several of the Japanese studies have been done in areas with a very large number of trains (about 500-800 trains per 24 h). The present study aimed to investigate the following questions: How does a large number of trains affect noise annoyance and can the differences between Japanese studies (railway noise more annoying than road traffic noise) and European studies (railway noise less annoying than road traffic noise) in part be due to major differences in the number of trains?

## METHOD

### Design, study area, population, and response rate

The present study formed part of the research project "TVANE" (Train Vibration and Noise Effects; 2006-2010), which investigates in a series of empirical field studies and laboratory experiments how human responses (health and well-being) are affected by (a) road traffic- and railway noise per se, (b) combined exposure to railway noise and vibrations, and (c) high intense railway traffic. Three study sites in Sweden (Töreboda, Falköping, Sollentuna) were selected in areas with railway traffic noise and another two study sites (Kungälv and Borås) were selected in areas with road traffic noise from the major roads E6 and E40. The traffic volume in the road traffic sites varied between 38,500 and 50,000 in Kungälv and between 15,500 and 25,000 in Borås. The two railway sites Töreboda and Falköping are situated at the railway line "Västra Stambanan" between Gothenburg and Stockholm and will henceforth be called "railway area 1". The number of trains/24h on the two parallel tracks was 124:

78 passenger trains and 46 freight trains (a larger proportion during evening and night, see Table 1). The railway site Sollentuna is one of the residential areas in Sweden that is exposed to the most intense railway traffic. The number of trains per 24h on the four tracks was 481. Most of them are passenger trains, which includes commuter trains (155) and high speed trains (166), the latter travel round trip to Arlanda airport with a speed of about 200 km/h. Only 15 trains are freight trains that run during evening and night (Table 1). This site will henceforth be called "railway area 2". Table 1 provides details of the number of trains per 24 h and per hour during different periods of the day in the railway areas. During daytime (06-18), 323 trains or one train every two minutes is passing in railway area 2. This is almost seven times as many trains passing compared with railway area 1 (see Table 1).

**Table 1:** Number of trains per 24 hours and per hour during different periods of the day in the two different railway areas.

| | Number of trains/24h | Number of trains 06-18 | Number of trains 18-22 | Number of trains 22-06 |
|---|---|---|---|---|
| Railway area 1 | 124 | 50 | 48 (20 freight trains) | 26 (20 freight trains) |
| | 5.2/hour<br>1 train every 12 min | 4/hour<br>1 train every 14 min | 12/hour<br>1 train every 5 min | 3.2/hour<br>1 train every 18 min |
| Railway area 2 | 481 | 323 | 89 (4 freight trains) | 69 (8 freight trains) |
| | 20/hour<br>1 train every 3 min | 27/hour<br>1 train every 2 min | 22/hour<br>1 train every 3 min | 8.6/hour<br>1 train every 7 min |

Noise calculations using the Nordic Prediction Method (Jonasson & Nielsen 1996) were performed as well as measurements for estimating noise levels ($L_{Aeq,24h}$, $L_{day}$, $L_{evening}$, $L_{night}$, $L_{AFmax}$ and $L_{den}$) at the most exposed side for each residential building. All calculation points were determined at 2 meter above the ground as free field values. The results in the present study is based on data in the $L_{Aeq,24h}$ range from 45-65 dB, but are presented in relation to both $L_{Aeq,24h}$ and $L_{den}$. Table 2 shows the number of respondents per exposure category of $L_{Aeq,24h}$ and $L_{den}$ for the three study areas. The study comprised 1,689 participants in total and the overall response rate was 49 %.

Table 3 shows the statistics for sound exposure levels and distance to the main noise source in road traffic and railway areas. As can be seen in Table 3, the mean value of $L_{den}$ is 2.7 dB higher than $L_{Aeq,24h}$ (56.0 vs. 53.3 dB) for the road traffic area.

**Table 2:** Number of respondents per sound exposure categories of $L_{Aeq,24h}$ and $L_{den}$.

| | Number of respondents per exposure category of $L_{Aeq,24h}$ | | | | |
|---|---|---|---|---|---|
| | 45-50 dB | 51-55 dB | 56-60 dB | 61-65 dB | Total |
| Road traffic areas | 177 | 120 | 97 | 74 | 468 |
| Railway area 1 (124 trains/24h) | 127 | 266 | 88 | 25 | 506 |
| Railway area 2 (481 trains/24h) | 167 | 280 | 191 | 77 | 715 |
| Total | | | | | 1689 |
| | Number of respondents per exposure category of $L_{den}$ | | | | |
| | <55 dB | 55-59 dB | 60-64 dB | > 64 dB | Total |
| Road traffic areas | 198 | 130 | 95 | 45 | 468 |
| Railway area 1 (124 trains/24h) | 21 | 210 | 207 | 68 | 506 |
| Railway area 2 (481 trains/24h) | 109 | 319 | 204 | 83 | 715 |
| Total | | | | | 1689 |

**Table 3:** Sound levels from road traffic and railway traffic for the different residences and distance from main road and railway line: Statistics for different exposure metrics.

| Sound exposure metrics: (Mean value, minimum and maximum) | Road traffic areas | Railway area 1 124 trains/24h | Railway area 2 481 trains/24h |
|---|---|---|---|
| $L_{Aeq,24h}$ | 53.3 (44,5 – 65.2) | 52.9 (44.9 – 64.9) | 54.1 (44.6 – 65.6) |
| $L_{den}$ | 56.0 (47.2 – 67.9) | 60.4 (52.3 – 72.3) | 58.8 (49.2 – 70.3) |
| $L_{night}$ | 45.6 (36.7 – 57.4) | 53.6 (45.5 – 65.6) | 51.2 (41.6 – 62.6) |
| $L_{AFmax}$ | 58.5 (44.6 – 83.0) | 71.7 (62.4 – 84.2) | 73.2 (63.0 – 85.0) |
| Distance to major road | 179 (41 – 309) | – | – |
| Distance to railway | – | 206 (35 – 451) | 132 (11 – 343) |

In railway area 1 there is a much larger difference (7.5 dB) between $L_{den}$ and $L_{Aeq,24h}$ due to the distribution of railway traffic over the day (87 % of the freight trains during evening and night) whereas only about 22 % of the road traffic occurred during evening and night. However, the difference is smaller in railway area 2 (4.7 dB) since only 12 freight trains are passing during evening and night.

## Evaluation of effects

Annoyance and other health effects were evaluated using a questionnaire. The format is based on questionnaires previously used in larger epidemiological studies of noise annoyance in Sweden (Öhrström et al. 2006; 2007). The questionnaire was sent to selected persons (aged 18 to 75 years) together with an introductory letter in April 2007 (road and railway area 1) and in April 2008 (railway area 2), which presented the survey as a study on the environment, human health and well-being. Two reminder letters were sent out with 10 day intervals to those who not responded to the questionnaire. The first reminder consisted only of a letter while the other consisted of the reminder letter and a new questionnaire.

General annoyance caused by noise was evaluated with a 5-point category scale ("not at all", "slightly", "moderately", "very", and "extremely") and an 11-point numerical scale (0-10 with verbal endpoints "not at all" and "extremely much") according to the ISO specification of annoyance scales (Technical Specification, International Organization for Standardization 2003). The questions were phrased as follows: "Thinking about the last 12 months or so, when you are here at home, how much does noise from (source) annoy or disturb you". In the presentation of the results, the "annoyed" category (%A) consists of those who were moderately, very, or extremely annoyed on the five-point category scale. For "highly annoyed" (%HA), categories 8, 9, 10 on the 11-point numerical scale was used as a cut-off criterion, which approximates the criterion used by Miedema and colleagues for converted scales ranging from 0-100 (Miedema & Oudshoorn 2001).

Disturbances of daily activities (e.g. conversation, listen to radio/TV, rest/relaxation, difficulties to keep windows open) were measured both in terms of "How often" (0="never", 1=Sometimes, 2="Often" and "How much" (2="Slightly", 3="Moderately", 4="Much") railway and road traffic noise affected the activity. Summed scales for each question were formed ranging from 0 to 6.

RESULTS

## Background factors

In the three survey areas, the mean age of the respondents ranged between 48 and 51 years of age. More men than women participated in the road traffic area and in railway area 1 (58 and 56 %, respectively), however, the reverse was the case in railway area 2 (56 % were women). A larger proportion of the respondents in railway area 2 (74 %) were married or de facto co-habiting than in the two other areas (56 and 59 %). A majority of the respondents in the three areas were employed or had their own company (range 65-69 %) and the rest had different status such as studying, retirement (early retirement, sickness- or old-age pensioner), unemployed, or were on sick- or parental leave. In railway area 2, a larger proportion (49 %) had a high level of education (≥ 3 years at university) than in the other areas (21 and 24 %). Sensitivity to sound/noise was reported by least respondents in railway area 1 (20 %), whereas in road traffic areas and in railway area 2 the proportion was higher (about 30 %). Except for sensitivity to sound/noise, none of the abovementioned factors together with type of house (detached house or apartment building), what year the house was built, and type of windows (triple-glazed or two-glazed windows/other) were associated with noise annoyance in any of the study areas. More respondents in railway area 2 than in railway area 1 lived at a shorter distance to the railway and also reported disturbance due to vibrations and aircraft noise. This was controlled for in the analyses by excluding them and comparing the results for the whole sample. No significant differences were found.

## General noise annoyance from railway and road traffic noise in relation to sound levels in $L_{Aeq,24h}$ and $L_{den}$

The relation between sound levels ($L_{Aeq,24h}$, $L_{den}$) from road traffic and railway traffic and general noise annoyance (% annoyed) was analyzed with binary logistic regression, see Figure 1 and Table 4. Separate analyses were done for each of the three study areas. The response curves are presented without taking potential moderation factors into account (e.g. sensitivity to sound/noise, access to a "quiet" side or nearby green areas).

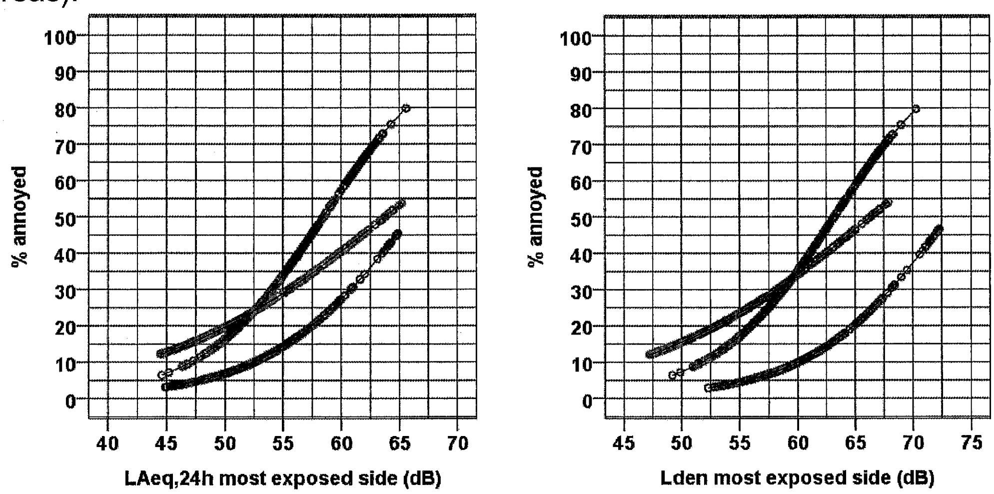


**Figure 1:** Estimated dose-response relation between sound levels in $L_{Aeq,24h}$ (left) and $L_{den}$ (right) and %A by road traffic noise (purple curve) and railway noise (railway area 1 with 124 trains/24h = grey curve and railway area 2 with 481 trains/24h = blue curve)

The estimated %A in relation to $L_{Aeq,24h}$ (left) in road traffic areas is higher than in railway area 1, a difference of 5 to 15 % units depending on sound level (Table 4). The difference in annoyance is smallest at the highest sound levels. The %A in railway area 2 is higher than in road traffic areas when noise levels are above $L_{Aeq,24h}$ 55 dB. The difference is 27 % units at 65 dB (77 vs. 50 %, for railway area 2 and road traffic areas, respectively). The largest difference in annoyance is seen between the two railway areas ranging from 10 to 32 % units. The estimated %A in relation to $L_{den}$ (right) is consistently over 20 % units higher in the road traffic areas than in railway area 1. Noise annoyance is higher in railway area 2 than in road traffic areas when $L_{den}$ is > 60 dB. The difference between the two railway areas is very large ranging from 12 to 43 % units. For road traffic areas and railway area 2, annoyance ratings were higher than predicted by standard curves presented in the EU position paper on dose response relationships between transportation noise and annoyance (Miedema & Oudshoorn 2001; EU 2002), particular for railway area 2 (see ratings in red within brackets).

**Table 4:** Estimated proportion of noise annoyed respondents to road traffic and railway noise for different noise exposure levels in $L_{Aeq,24h}$ and $L_{den}$.

| | Noise exposure levels in $L_{Aeq,24h}$ | | | |
|---|---|---|---|---|
| | 50 dB | 55 dB | 60 dB | 65 dB |
| Road traffic areas | 20 | 30 | 40 | 50 |
| Railway area 1 (124 trains/24h) | 6 | 15 | 27 | 45 |
| *Difference road – railway area 1* | *+14* | *+15* | *+13* | *+5* |
| Railway area 2 (481 trains/24h) | 16 | 35 | 56 | 77 |
| *Difference road – railway area 2* | *+4* | *-5* | *-16* | *-27* |
| *Difference railway area 2 – railway area 1* | *+10* | *+20* | *+29* | *+32* |
| | Noise exposure levels in $L_{den}$ | | | |
| | 55 dB | 60 dB | 65 dB | 70 dB |
| Road traffic areas | 25 (18) | 35 (26) | 46 (35) | *60 (47) |
| Railway area 1 (124 trains/24h) | 5 (10) | 10 (15) | 20 (23) | 37 (34) |
| *Difference road – railway area 1* | *+20* | *+25* | *+26* | *+23* |
| Railway area 2 (481 trains/24h) | 17 (10) | 36 (15) | 57 (23) | 80 (34) |
| *Difference road – railway area 2* | *+8* | *-1* | *-11* | *-20* |
| *Difference railway area 1 – railway area 2* | *+12* | *+26* | *+37* | *+43* |

* No data exist.

## General noise annoyance in relation to the orientation of balcony/patio and bedroom window

The relation between sound levels in $L_{den}$ from road traffic and railway traffic and %HA was analyzed with binary logistic regression and also taken into account the influence of the orientation of balcony/patio and bedroom window (towards noise source or towards backyard/small road), see Figures 2 and 3, respectively. Separate analyzes were done for each of the three study areas. The dose-response curves in Figure 2 for all subjects (left) show that the estimated %HA curves in relation to $L_{den}$ in road traffic areas and railway area 2 are approximately the same and they are also higher than in railway area 1.

Having balcony/patio oriented towards the noise source increased the odds of being highly annoyed in all three study areas, but mostly in road traffic areas and railway area 2 (road traffic areas, OR=5.29, 95% CI=2.87-9.75; railway area 1, OR=4.49, 95% CI=1.61-12.49; and railway area 2, OR=5.25, 95% CI=3.25-8.49). For road traffic areas and railway area 2, orientation of balcony/patio towards noise source predicted the percentage of highly annoyed residents to increase from about 23 % at $L_{den}$ 55 dB to about 48 % at 65 dB (Figure 2, middle). For railway area 1, these numbers ranged between about 5 to 17 %. The difference between %HA among those having the balcony/patio oriented towards the noise source or not is much greater in road traffic areas and in railway area 2 than it is in railway area 1 (see Figure 2 middle and right).

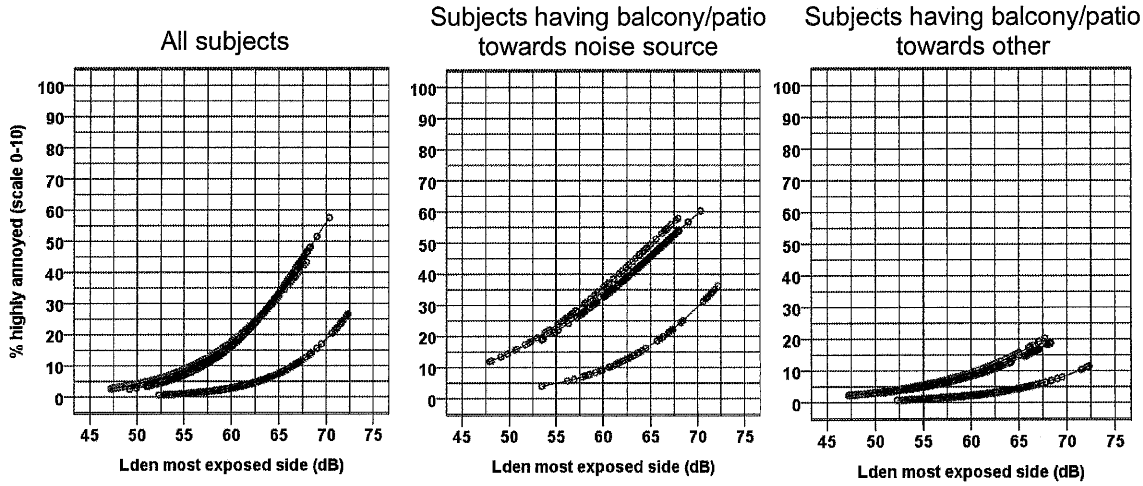


**Figure 2:** Estimated dose-response relation between $L_{den}$ and %HA by road traffic and railway noise (left=all cases included) and in relation to balcony/patio oriented towards noise source (middle) and towards other (right) for the three survey areas road traffic noise (purple curve) and railway noise (railway area 1 with 124 trains/24h = grey curve) and railway area 2 with 481 trains/24h = blue curve)

Having bedroom window oriented towards the noise source increased the odds of being highly annoyed mostly in road traffic areas (OR=5.23, 95% CI=2.85-9.59), but also in railway area 2 (OR=2.24, 95% CI=1.38-3.65). For railway area 1, the orientation of bedroom window has no significant effect on %HA ($p$>0.05). The dose-response curves in Figure 3 (middle) show that orientation of bedroom window towards the noise source in road traffic areas give larger estimated proportions of highly noise annoyed respondents at any given $L_{den}$ level than in the two railway areas.

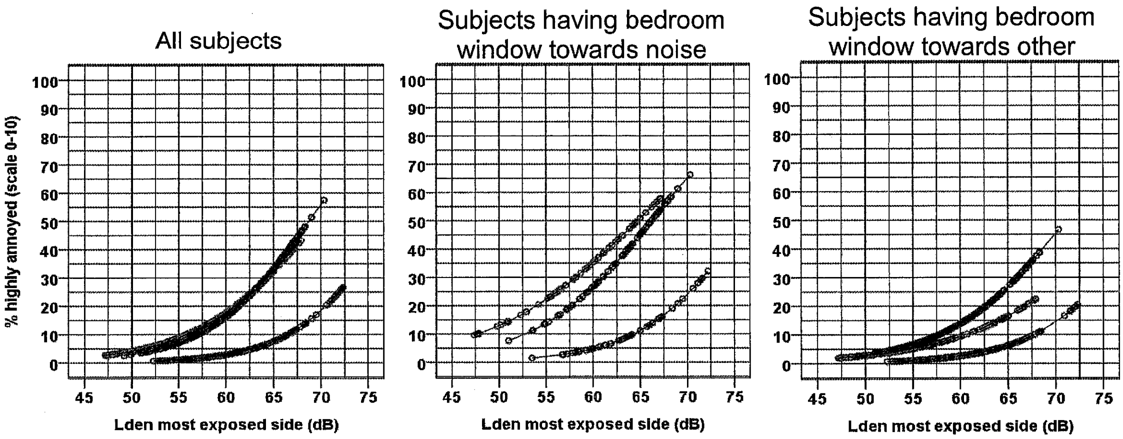


**Figure 3:** Estimated dose-response relation between $L_{den}$ and %HA by road traffic and railway noise (left=all cases included) and in relation to bedroom window oriented towards noise source (middle) and towards other (right) for the three survey areas road traffic noise (purple curve) and railway noise (railway area 1 with 124 trains/24h = grey curve) and railway area 2 with 481 trains/24h = blue curve)

Thus, in the case of road traffic noise, the difference between percentages of highly annoyed among those having bedroom window oriented towards the noise source or not is much larger than it is in the case of the two railway areas, especially for railway area 1. For road traffic areas, the orientation of the bedroom window is just as important for general annoyance as the orientation of the balcony/patio.

### Associations between general annoyance and disturbances of daily activities indoors and outdoors

Table 5 shows correlations (Spearman's $r_S$) between general annoyance (0-10 scale) and various noise disturbed daily activities indoors with windows closed and open and outdoors in the three study areas. As can be seen, both railway areas obtained higher correlations between general annoyance and activity disturbances that involved communication (listen to radio/TV, conversation) in all three situations than road traffic areas. Although the association between rest/relaxation and general annoyance were stronger in road traffic areas than in railway area 1, the strongest correlations were seen for railway area 2.

**Table 5:** Correlations ($r_S$) between general noise annoyance at home (0-10 scale) and disturbances of daily activities (range 0-6) in the three different study areas.

| Activity disturbances | Road traffic areas | Railway area 1<br>124 trains/24h | Railway area 2<br>481 trains/24h |
|---|---|---|---|
| | *Indoors with windows closed* | | |
| Rest/relaxation | 0.61 | 0.45 | 0.66 |
| Listen to radio/TV | 0.34 | 0.44 | 0.51 |
| Conversation | 0.27 | 0.39 | 0.53 |
| | *Indoors with windows open* | | |
| Rest/relaxation | 0.64 | 0.57 | 0.75 |
| Listen to radio/TV | 0.49 | 0.57 | 0.71 |
| Conversation | 0.46 | 0.53 | 0.72 |
| | *Outdoors* | | |
| Rest/relaxation | 0.67 | 0.55 | 0.78 |
| Conversation | 0.52 | 0.52 | 0.80 |

## SUMMARY AND CONCLUSIONS

The overall results in this paper suggest that road traffic noise is more annoying than railway noise at the same noise level of $L_{Aeq,24h}$ or $L_{den}$, which is consistent with most previous international and European studies (e.g. Miedema & Oudshoorn 2001; EU 2002; Öhrström & Skånberg 2006). However, the findings also suggest that the number of trains per 24h, and not just the noise levels, is relevant for how annoying railway noise is perceived. As the railway traffic is very intense, 481 trains/24h or about one train passing every three minutes, railway traffic generate higher or similar general noise annoyance as road traffic, depending on exposure metric and degree of annoyance. This is to some extent in agreement with more recent studies conducted in Japan and Korea (e.g. Morihara et al. 2002; Lim et al. 2006). Furthermore, intense railway traffic caused significantly and substantially greater annoyance at the same noise levels than moderately intense railway traffic (124 trains/24h or about 5 trains/hour). This contradicts findings by Moehler and Greven (2005), who found no effect of more annoyance with higher number of passing trains.

Of great importance for general annoyance was the position of balcony/patio and bedroom windows in relation to noise sources. For respondents exposed to road traffic noise, the orientation of the bedroom window seems to be as important for general annoyance as the orientation of the balcony/patio. The results from the railway areas suggest that it may be more important that balcony/patio is not oriented towards the railway than that bedroom window is oriented towards the shielded side. Particularly in situations with intense railway traffic, as in railway area 2.

Several factors have been proposed to explain why railway noise is less annoying then road traffic noise. These include differences in noise characteristics (railway noise more regular and predictable) as well as factors related to perceptions and attitudes towards these two noise sources (e.g. Fields & Walker 1982). Other potential influencing factors (Lim et al. 2006) in this study (distance to railway, exposure to vibrations and aircraft noise) were controlled for. Since there were no other obvious differences in background or environmental factors between road traffic and railway areas and between railway area 1 and 2 in the present study, we find it reasonable to assume that when the number of trains per 24h is high, it will be similar to noise exposure from road traffic. That is, the railway noise will be perceived as more continuous and less intermittent with fewer "quiet" periods, as previously suggested (Fields & Walker 1982). This is supported by the fact that the slope of the HA curves for high intense railway traffic is comparable with the slope of the HA curves for road traffic areas. Moreover, the dominating effect of road traffic noise is disturbance of rest/relaxation (see also Öhrström et al. 2010) and the results show that railway noise has a similar effect in the area with high intense railway traffic.

## ACKNOWLEDGEMENTS

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# The types of human response to changes in noise exposure

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## INTRODUCTION

It has been widely recognized that annoyance is one of the most common effect of environmental noise. Noise annoyance consists of several aspects including immediate behavioral effects such as disturbance and evaluative aspects such as nuisance or unpleasantness (Guski et al. 1999). Exposure-response data show that annoyance generally increases with noise levels (Fidell 2003; Miedema &Vos 1998). Due to environmental, social and personal factors (Job 1988), large heterogeneity has been observed in these curves and the actual noise level has been found to explain only 10 to 25 per cent of an individual reaction to noise (Job 1996). In addition, annoyance may not be stable over time; some studies found that annoyance due a given aircraft noise level has been increasing over time(Babisch et al. 2009; Brink et al. 2008; Guski 2004; Masurier et al. 2007).

In the literature on human response to increased (or reduced) noise exposures, annoyance is generally considered as the main indicator of the subjective response. Vallet (1996) however found that a minimum of 6 dBA change is required in noise level before annoyance changes. Moreoverannoyance reactions for those exposed to changes in noise levels might differ from those predicted by the steady-state exposure-response curves – i.e. for people with (presumed) reasonably constant noise exposure levels (for review see Brown & van Kamp 2009a, b). It is therefore questioned whether the change in annoyance is the best indicator of human reactions to changed noise exposure.

The main aim of this paper is to review the evidence on human reactions to changes in environmental noise exposures in order to present alternative reaction measures other than annoyance. Factors that influence annoyance ratings in changed noise conditions are further discussed. The implications of the findings may help guide policy decisions when impact assessment of proposed changes takes place.

## METHODS

### Study search

Web of Science, PubMed and Embase were searched from 1980 to March 2011 to indentify relevant articles written in English. In addition, the reference list from relevant original research and review articles and conference proceedings (Internoise 2001-02, 2004-05, 2007-'08, '10) were reviewed. A Google hand search was also performed for grey literature. The search terms included noise, change, reaction, perception, response, annoyance, human community, individual, air, traffic, and rail.

### Study selection

The following inclusion criteria were applied: (1) the study measured the change in environmental noise (community, traffic, road, aircraft and railway) exposure, (2) the change in noise level was due to (i) a new (or eliminated) source or change in intensity of the source (e.g. traffic flow change, road bypass construction, change in run-