



# Annoyance due to vibration from freight railway lines in the Netherlands and Poland

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## Summary

An important aim of the EU-project CargoVibes was to derive exposure-response relationships for the expected annoyance due to vibration among residents living near freight railway lines. This was done based on existing survey data, as well as on some new survey data gathered within the project. To this end, a questionnaire was sent by mail to residents living in the vicinity of railway tracks with freight traffic at two sites in the Netherlands and at one site in Poland. Response rates were respectively 30% (N=112), 26% (N=131) and 45% (N=114). For most of these respondents, railway vibration exposure was either measured or extrapolated from measurements in similar dwellings in the neighbourhood. Apart from providing additional input for a pooled meta-analysis, these survey data offered the opportunity to investigate in more detail the situational and attitudinal factors that influence annoyance by vibration from freight railway lines.

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**1. Introduction** One of the aims within the EU-project CargoVibes [www.cargovibes.eu] was to derive exposure-response relationships for vibration annoyance among residents living near freight railway lines [1-3]. Although several surveys have previously been undertaken to investigate the effects of railway vibration on annoyance, the existing database is relatively small compared to that on railway noise annoyance. Also, previous surveys did not specifically address freight railway traffic, which might be responsible for the highest annoyance response due to vibration. Therefore, in

addition to collecting, pooling and analysing existing data, new survey data was gathered at three railway sites characterized by heavy freight traffic, two in the Netherlands and one in Poland.

## 2. Methods

### 2.1.1. Barendrecht (the Netherlands)

Barendrecht, a small city in the Netherlands near Rotterdam, is crossed by a busy railway line consisting of 9 tracks. Every 4 min a passenger train travels through the line; high-speed trains run

along the line approximately twice per hour in each direction; and each hour 4 to 8 freight trains cross the city. A 1.5 km tunnel-like structure was constructed over the railway track to reduce the airborne propagation of railway noise. This site was chosen because of the opportunity to investigate the response to railway vibration in the absence of noise exposure.

### 2.1.2. Den Bosch (the Netherlands)

The railway line in Den Bosch, a large city in the southern part of the Netherlands, consists of 8 tracks in the vicinity of the Central Station. During daytime, every 2 min a passenger train stops at the station, and each hour 1.5 freight trains pass by (36 per 24h with a slight concentration during evening and about 1 freight train per hour during the night). This site was chosen since previous measurements indicated vibration levels high enough to cause a substantial annoyance response from inhabitants.

### 2.1.3. Radzionków (Poland)

The railway line in Radzionków, a small industrial town in the southern part of Poland, consists of 3 tracks with primarily freight trains passing by (about 60 per 24h, of which about 25 during night) and electric multiple units (24 per 24h, of which only 2 during night) serving as passenger trains. A typical freight train set at this location consists of 30 coal wagons. This location was chosen to study the response to heavy freight traffic in the relative absence of other railway traffic.

## 2.2. Vibration measurements

The vibration metric used in the Netherlands is  $V_{max}$ , which is very similar to the  $KB$  metric in the German regulations (DIN 45669-1, also used in Poland). It represents the overall maximum value based on the maximum velocities in the dominant direction per train passage (determined by a running rms-value using a fast exponential time window), frequency-weighted according to the combined weighting curve from DIN 45669-1 (almost identical to  $W_m$  in the ISO 2631-2). However, within CargoVibes it was decided to separately weight vertical and horizontal vibration according to the ISO 2631-1 weighting curves  $W_k$  and  $W_d$ , and then determining the maximum in the dominant direction (usually vertical), or in any given direction. To distinguish it from  $V_{max}$ , this value is here called  $V_{dir,max}$  (dir stands for directional). Note that the directionally weighted  $V_{dir,max}$  is on average 15% higher than  $V_{max}$  (or  $KB$ ).

The measurement procedure comprised continuous monitoring of vibration in 2-4 reference houses during a period of around a week. In addition, short measurements (30 min in Den Bosch and up to 4 hours in Radzionków) were done in 10 and 16 reference houses respectively (no additional short measurements were done in Barendrecht). In each reference house two accelerometers were installed, one at the foundation on the ground floor and one in the middle of the room. The data acquisition was done with a sampling frequency of 500 Hz, in combination with an analog Butterworth low-pass filter (cut-off frequency of 100 Hz). Vibration levels in houses other than the reference houses were subsequently estimated by using observed distance relations to estimate the vibration at the foundation, and then applying the amplification factor between foundation and middle of the room of the reference houses to other, similar houses.

## 2.3. Survey procedure

A similar procedure for gathering survey data was used at the three sites, with only slight differences for practical reasons due to local circumstances. Questionnaires were sent by mail to all addresses within 150 m of the railway track in a chosen area: 369 in Barendrecht, 510 in Den Bosch, 100 (and 150 more in a second round up to 200 m) in Radzionków. An accompanying letter explained that the study concerned the response of residents to noise and vibration in their living environment. In order to avoid a bias in the household member filling in the questionnaire, it was indicated that the questionnaire was meant to be filled in by the person in the household who is 18 years or older and whose birthday comes first from now. In Barendrecht and Radzionków, the questionnaire was collected by research assistants during a specified period, while in Den Bosch respondents were asked to return the questionnaire by mail. People who did not want to fill in the questionnaire were asked to return a short nonresponse questionnaire (this was done by 39 people in Barendrecht and by 32 in Den Bosch) in which they had to fill in the reason for not wanting to participate, some- demographic characteristics and the primary question on annoyance due to vibration from railway. The response percentage was 30% (N=112) in Barendrecht, 26% (N=131) in Den Bosch, and 45% (N=114) in Radzionków (for 104 of which the exposure could be estimated).

## 2.4. Questionnaire

A questionnaire was developed (in English and then translated into Dutch and Polish by native speakers) to measure self-reported response to vibration and noise (both vibration-induced noise inside the dwelling and air-borne noise). Following the ICBEN team 6 recommendation on standardized annoyance questions [4], 11-point numerical scales (0-10) were chosen for measuring annoyance. The questionnaire comprised the following sections:

- Questions on the dwelling (years living in the dwelling, satisfaction with the neighbourhood, year of building, ownership, type of dwelling, construction of the dwelling, insulation and view from window);
- Questions on vibration from road and railway traffic and from specific railway sources (perception, annoyance, sleep disturbance, rattling objects, vibration tolerance and worry);
- Questions on noise from road and railway traffic and from specific railway sources (perception, annoyance, sleep disturbance, window opening, noise sensitivity and perceived necessity);
- Questions on health (perceived general health and vitality, sleep quality, sleep onset latency, use of sleep medication, perceived tiredness/stress);
- Personal characteristics (gender, year of birth, education level, employment, ethnicity).

## 3. Results

Figure 1 shows the number of respondents at each survey site reporting low (0-2), medium (3-7) or high (8-10) annoyance due to vibration from freight trains on an 11-point scale ranging from not at all annoyed (0) to extremely annoyed (10). This demonstrates that there was hardly any annoyance in Barendrecht, very high annoyance in Den Bosch (45% highly annoyed) and intermediate annoyance in Radzionków (27% highly annoyed). This is partly explained by differences in exposure levels: measurement-based vibration exposure estimates in Barendrecht revealed very low vibration levels ( $V_{dir,max}$  all below 0.25). Remarks of respondents suggest the vibration situation had improved considerably since the railway has been covered. Indeed, in Den Bosch, where annoyance was very high, vibration levels were much higher (mean  $V_{dir,max}$  0.9, maximum 2). However, vibration levels in Radzionków were still higher than those in Den Bosch (mean  $V_{dir,max}$  2.3, maximum 10!), whereas their annoyance response was lower.

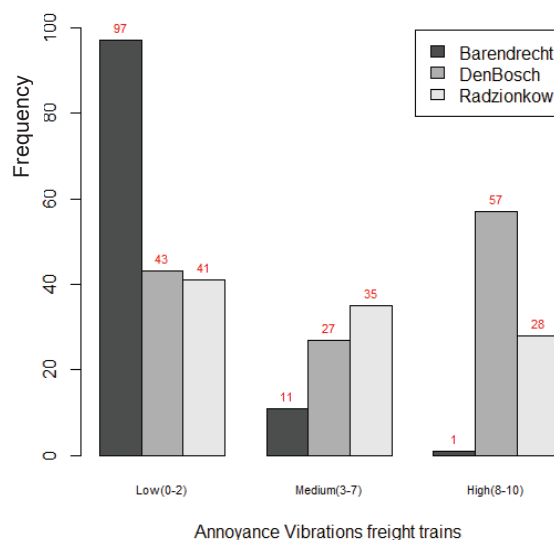


Figure 1. Number of respondents reporting low, medium or high vibration annoyance by freight trains.

Table I shows the correlations between vibration exposure (in  $V_{dir,max}$  as well as the log-transformed  $\log_{10}V_{dir,max}$ ) and annoyance due to railway vibration in general, and that due to freight train vibration (note that the exposure metric represents overall and not freight-specific railway vibration). Vibration exposure correlated significantly with annoyance in Den Bosch, both with annoyance due to railway vibration in general (the higher N is due to non-responders who indicated their annoyance), and with annoyance due to freight train vibration. However, in Radzionków vibration annoyance did not correlate significantly with vibration exposure.

Next, it was investigated what other factors besides the exposure (demographic, situational and attitudinal) may influence annoyance by vibration. To this end, a stepwise regression analysis was performed, in which three blocks of variables were added stepwise ( $P_{in} < 0.05$ ) to  $V_{dir,max}$ , the latter forced as a predictor in the model: 1) demographic variables (male versus female, age and age<sup>2</sup>, high versus lower education, being employed, >10 years of residence, rented versus owned dwelling); 2) situational variables reflecting ways in which a train passage may be noticed other than through vibration (viewing the railway track from the living room, hearing the noise daily, hearing rattle; and 3) attitudinal variables (self-reported tolerance to vibration, noise sensitivity, worry about accidents, concern about damage to property, or the degree to which freight trains are thought of as environmentally friendly or necessary).

Table I. Correlations between vibration exposure and annoyance; \* denotes significance at  $p < 0.05$ , \*\* at  $p < 0.01$ .

Pearson R correlations	$V_{dir,max}$	$\log_{10} V_{dir,max}$	N
Annoyance vibration railway Den Bosch	0.273**	0.251**	140
Annoyance vibration freight trains Den Bosch	0.223**	0.203*	127
Annoyance vibration railway Radzionków	0.056	0.109	103
Annoyance vibration freight trains Radzionków	0.014	0.078	103

The stepwise regression demonstrated that in Den Bosch none of the demographic variables had an influence on annoyance from vibration due to railway or freight trains. However, vibration annoyance was higher when residents can hear the trains daily, and when there was audible rattling of objects in the home. The latter seems to be an important way in which vibration induces annoyance, since  $V_{dir,max}$  no longer directly contributed to annoyance after adding rattle as a predictor to the model. Furthermore, annoyance was higher for residents who are concerned about damage, or who reported to be noise sensitive.

The stepwise regression in Radzionków showed very similar results. Again, no influence was found of the demographic variables on annoyance due to railway vibration. While in Radzionków the influence of  $V_{dir,max}$  itself was not significant, vibration annoyance was found to be higher when residents can view the railway track from their living room, when they heard the trains daily, and when there was audible rattling of objects in the home. Furthermore, annoyance was higher for noise sensitive residents and for those concerned about damage, and lower for those who believe freight trains are necessary. Since residents in Radzionków had a rather positive opinion on the necessity of freight trains (as well as on their environmental friendliness, which is perhaps related), this latter factor may have contributed to the relatively low annoyance observed in Radzionków as compared to that of Den Bosch.

#### 4. Conclusions

Questionnaire and vibration exposure data were collected at two railway sites in the Netherlands and one in Poland. At one of the sites in the Netherlands (Barendrecht) the vibration exposure was so low, presumably due to a successful (noise) mitigation measure consisting of the covering of the railway tracks, that hardly any annoyance was

reported. At the other site in the Netherlands (Den Bosch), higher vibration levels were found with a rather high annoyance response (see Figure 1), showing a clear relationship between exposure and response. At the site in Poland (Radzionków) the exposure levels were even higher, but annoyance was relatively low and no clear relationship with vibration exposure was found. Perhaps this was due to differences in attitudinal factors, such as the higher perceived necessity of freight trains in the industrial town of Radzionków, which was shown to reduce annoyance, or the higher concern for damage in Den Bosch, which was shown to increase the annoyance response to vibration. Furthermore, noise sensitivity (perhaps serving as a proxy for sensitivity to vibration), self-reported hearing of railway noise and noise from rattling objects were all found to influence the response to vibration. The results indicate that while vibration due to freight trains causes annoyance, the degree of annoyance also depends on other factors.

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