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Exposure-response relationship for railway noise annoyance in the Middle Rhine Valley

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ABSTRACT

The railway line in the Middle Rhine Valley is part of the north-south transversal Rotterdam – Genoa. Residents living in the vicinity of the railway line suffer from high rail traffic density and, thus, high noise levels, in particular due to freight trains. Aiming at reducing the average sound level of the railway noise in the Rhine Valley by 10 dB the Ministries for Environment and Transport of the German states Hesse and Rhineland Palatinate published a noise control program called "Quite Rhine Valley" in 2010. Among others, for the purpose of noise monitoring the program includes the implementation of a railway noise impact index (MRI) describing the number of highly annoyed people during day time and the average number of additional nocturnal railway noise-induced awakenings (see contribution of Kerstin Giering et al. in the same Internoise session). This contribution presents results of a socio-acoustical survey with altogether 1211 residents carried out in the Middle Rhine Valley in order to provide an exposure response function for the 'annoyance part' of the MRI. Among others, the results indicate that the so-called railway bonus can be questioned at least for the noise situation in the Rhine Valley.

Keywords: Noise, Railway, Noise index, Annoyance, Quiet façade

1. INTRODUCTION

From 2002 to 2012 rail passenger transport performance (person kilometres, pkm) in Germany increased by 25% (70819 to 88352 mpkm), rail freight transport performance (Million tons kilometres, tkm) increased by 36% (81000 to 110000 mtkm) [1]. The railway line in the Rhine Valley has an important role in German railway network, particularly with regard to freight traffic, as it is part of the north-south transversal connecting Rotterdam with Genoa. Thus, due to high traffic volume on the Rhine Valley railway line, residents living along this line are strongly exposed to railway noise, in particular by freight traffic at night-time.

With the aim of reducing the average sound level of the railway noise in the Rhine Valley by 10 dB the Ministries for Environment and Transport of the German states Hesse and Rhineland Palatinate published a noise control program called "Quiet Rhine Valley" in 2010 [2]. This program specifies the demand of a noise monitoring (permanent control), the abolishment of the railway bonus (in Germany: 5 dB), a decrease in nocturnal maximum noise level, speed limit, noise quotation, implementation of innovative noise abatement measures, strengthening of railway authorities with regard to the noise

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management, launching of new noise-reduced brake systems for freight trains, economic incentives, upper noise limits for already operating trains, more strict control of noise and vibration, planning of an alternative freight railway line in order to relieve the Rhine valley.

Among others, for the purpose of noise monitoring the program includes the implementation of a railway noise impact index (Middle Rhine Valley Index; MRI) describing the number of persons highly annoyed by railway noise during day time and the average number of additional nocturnal railway noise-induced awakenings. The MRI is described in more detail in the INTER-NOISE 2013 paper of Giering et al. [3].

The MRI requires updated regional exposure-response curves for railway annoyance and sleep disturbances (awakenings). The exposure-response function for additionally railway noise-induced awakenings bases on the study of the German Aerospace Center (DLR e.V.) recently carried out in the Rhine Valley [4]. The exposure-response curve for railway noise annoyance was provided by the socio-acoustical survey presented in this paper.

As Lercher and colleagues [5] could show for the Alpine region responses to transportation noise in valleys like those in the Alps differ from the general exposure-response relationships proposed by Miedema and colleagues [6]-[7] among others due to the specific topography. In particular, difference in noise annoyance in favour of railway noise compared to road traffic noise ('railway bonus') was not observed for noise exposure above 60 dB L_{den} and for the night-time (L_{night}). In view of high railway traffic volume on the railway line in the Rhine Valley railway and, in line with this, considerably high noise exposure at day and night-time similar results compared to the Alpine Valley studies with regard to railway noise annoyance were expected for the study presented in this paper.

The objectives of the survey carried out in the Rhine Valley are (objective 1) providing representative information about the prevalence of annoyance and disturbances due to railway noise of residents living along the railway line in this area and (objective 2) providing an exposure-response function for the 'annoyance part' of the regional railway noise index MRI. Further on, there is a particular interest in the question whether options to cope with the noise such as the availability of a 'quiet façade' or one or more rooms at home that offers the opportunity to retreat from the railway noise exposure as well as closed windows e.g. in the bedroom decreases responses to railway noise such as annoyance or sleep disturbances (objective 3). It is known from previous studies that, although these noise abatement measures at the home of residents might considerably reduce indoor sound levels, their impact on annoyance and disturbances is not consistent: Whereas the availability of a quiet façade and, thus, one or more rooms at home available to retreat from noise exposure reduce the noise annoyance [8]-[11], results with regard to noise insulation (sound proof windows, ventilators, façade insulation) are ambiguous [8][12]-[14]. Concerning window position there is evidence that predominantly closed windows even seem to be associated with elevated noise annoyance, probably because of less perceived control to cope with noise [15] and/or less pleasant indoor climate [14]. Both explanations indicate that not being able to keep the windows open is in itself a disturbance closely related to sound levels [16].

This paper presents results in particular with regard to the second and third objective.

2. METHODS

2.1 Procedure and study sample

The study area of the survey and the area for which the MRI is calculated consists of two parts in the Rhine Valley in Germany: Perimeter 1 from Koblenz to Bingen/Rüdesheim (Figure 1, red contour) and Perimeter 2 from Bingen to Mainz/Wiesbaden (Figure 1, blue contour).

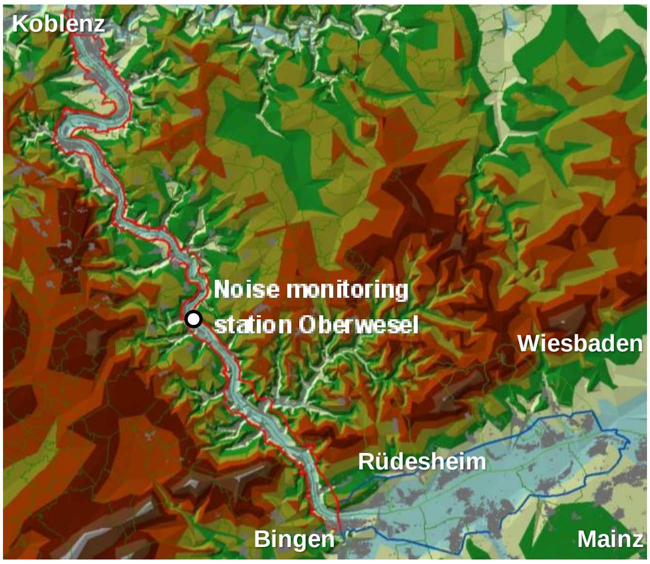

Figure 1 – Study area in Rhine Valley, Germany. Perimeter 1 (red): Middle Rhine Valley (Koblenz – Bingen/Rüdesheim); Perimeter 2 (blue): Rheingau/Rheinhessen (Bingen – Mainz/Wiesbaden)

The survey was carried out as a computer-aided telephone study (CATI). Within the study area the sampling of participants for the survey was done in several steps. Firstly, official geographical data of all dwellings in the study area were gained from regional authorities. This set of addresses was then merged with telephone numbers from public telephone data base and the households to be contacted were then sampled by random from the merged data set. Within each household contacted by phone the person to be interviewed was chosen by random (Last-birthday method).

Altogether, 1005 residents were interviewed (response rate: 41%) in this main study. This random sampling Procedure was done in order to provide the Ministries for Environment and Transport of Hesse and Rhineland Palatinate with survey data about the prevalence of railway noise annoyance that is representative for (adult) residents in communities in the Middle Rhine Valley.

When railway noise calculations were done for the address of each participant (and all other dwellings within the study area), it turned out that due to the simple random sampling (without stratification by noise exposure) in higher railway noise level classes (5dB classes of $L_{\mathrm{pAeq,24h}}$) less residents were interviewed than in lower noise classes whereas higher railway noise levels (above 60 dB $L_{\mathrm{pAeq,24h}}$) are typical for the Rhine Valley. For modeling the exposure-response relationship an almost equal distribution of participants across the whole range of noise exposure would be preferable in order to avoid larger confidence intervals and thus larger uncertainty in the upper range of noise exposure.

Therefore, in addition to the main sample a supplemental sampling was done among addresses within the study area with railway noise exposure above 60 dB in $L_{\mathrm{pAeq,24h}}$ leading to 206 further interviewees (response rate: 58%), see Tab. 1. In total, 1211 were interviewed (55% female, 45% male, age: 16 to 95 years). Because of rather low population density in the highest noise level classes the resulting relative distribution of the total sample of 1211 participants across the total range of railway noise exposure in the study area is still not perfect for exposure-response analysis in terms of equal distribution, but at least it is somewhat improved.

Table 1 – Number of participants in main sample and supplemental sample

$L_{\text{pAeq,24h}}$ in dB	Main sample n	Subsequent sample n	Total n	%
< 40	3		3	0,2
40.0 - 44.99	48		48	4,0
45.0 - 49.99	161		161	13,3
50.0 - 54.99	269		269	22,2
55.0 - 59.99	219		219	18,1
60.0 - 64.99	121	10	131	10,8
65.0 - 69.99	68	17	85	7,0
70.0 - 74.99	55	40	95	7,8
75.0 - 79.99	48	108	156	12,9
80.0-84.99	13	31	44	3,7
Sum	1005	206	1211	100,0

2.2 Railway noise exposure

For all façades of each dwelling within the study area railway noise levels were calculated on the base of the German railway noise model Schall 03 [17], but without the inclusion of the railway bonus (in Germany, according to Schall 03: 5 dB). The calculation had been done for the development of the MRI in the study of Giering et al. [3]. The railway noise calculation bases on rail traffic data per day for day (6-18h) and night-time (22-6h) of the year 2010 (number, types, lengths of trains, maximum speed of trains per section) for the railway line in the Rhine Valley provided by Deutsche Bahn AG (German Railway). The calculated noise levels were validated by comparisons with noise levels measured at a noise monitoring station in Oberwesel. For the exposure-response analysis in the study presented in this paper only the noise levels of the loudest façade of the home address of survey participants had been considered.

Calculated noise levels for railway noise are the equivalent sound level for daytime (L_{day}, 06-18h), for evening (L_{evening}, 18-22h), for night-time (L_{night}, 22-06h), and for 24 hours ($L_{\text{pAeq,24h}}$, L_{den}). For the calculation of L_{day} and L_{evening} the number of trains of the 16-hours day (06-22h) had been distributed accordingly to the 12-hours day (06-18h) and the 4-hours evening (18-22h).

Data for the assessment of exposure to other noise sources, e.g. road traffic noise, could not be obtained.

2.3 Questionnaire

The questionnaire consists of the following variables/topics:

- residential situation: length of residence, residential satisfaction, house ownership, house floor, house orientation towards the railway line, window type and predominant position in warmer seasons (in bedroom), noise insulation at home
- railway annoyance: railway annoyance in total, noise annoyance at daytime, night-time, in total, annoyance due to rail traffic-induced vibration from railway
- noise annoyance due to sources other than railway: road traffic, aircraft, shipping traffic
- railway sleep disturbances: when falling asleep, sleeping during the night, in the morning
- demographics: gender, age

The annoyances and disturbances described above where all assessed on a 5-point scale according to ISO/TS 15666 [18]. The disturbances due to railway noise when falling asleep, sleeping during the night and in the morning were averaged to a mean score for sleep disturbances (Cronbachs alpha α = 0.93).

3. RESULTS

Tab. 2 shows the Spearmen rang correlations between railway noise annoyance as assessed on the 5-point scale as well as the reported railway-induced sleep disturbances (mean score) and railway sound levels. The correlation coefficients between railway noise annoyances in general and at daytime are about 0.10 higher than the coefficients between annoyance at night-time and sleep disturbances and railway sound levels. For the railway noise responses the correlation coefficients reach from rho = .80 to rho = .86. All railway sound levels listed in Tab. 2 correlate with rho (and r) = 0.99 among each other. No difference in correlation between the annoyance and disturbance judgments on the one hand and the sound levels on the other hand was found for the sound levels at different times of day. This is plausible because of the high inter-correlations of the railway sound levels. Pearson correlation analyses between all variables described above reveal similar coefficents.

In order to better understand the lower railway sound level-response correlation for night-time (sleep disturbances, noise annoyance at nighttime) in comparison to the railway sound level-response correlations for annoyance overall and at daytime, partial correlation analyses between the sound levels for day and night-time, noise annoyance overall and at night-time as well as sleep disturbances were done, partialling out either the overall railway noise annoyance or the annoyance/disturbance responses concerning the night-time. Whereas the partial correlations between the railway sound levels and overall railway noise annoyance after control for the night-time responses decrease moderately from r =.70 to r =.50 the railway noise exposure-response correlations for the night-time responses decrease almost to zero (r = .02 for noise annoyance at night-time, r = .09 for sleep disturbances) after control for overall railway noise annoyance. This might indicate that the railway annoyance at night-time as well as the reported railway-induced sleep disturbances are mediated by the overall railway annoyance and, thus, can be understood as secondary responses to railway noise exposure.

Table 2 – Spearman rang correlation coefficients between railway noise responses and railway sound levels

Spearman rang correlation rho	Railway noise annoyance			Sleep
	overall	at daytime	at night-time	disturbances
Railway noise responses				
Noise annoyance, overall	1.00			
Noise annoyance at daytime	0.86			
Noise annoyance at night-time	0.84	0.79		
Sleep disturbances	0.80	0.77	0.88	
Railway sound levels				
L_{day}	0.70	0.69	0.59	0.58
L_{night}	0.70	0.69	0.59	0.58
$L_{\text{pAeq,24h}}$	0.70	0.69	0.59	0.58
L_{den}	0.70	0.69	0.59	0.58

For all correlation coefficients $p < .01$

Fig. 1 presents the exposure-response curves for the percentage of people in the Rhine Valley

- highly annoyed by railway noise at daytime (HA day) against L_{day},
- highly annoyed by railway noise at night-time (HA night) against L_{night}, and
- highly sleep disturbed by railway noise at night-time (HSD) against L_{night}.

Fig. 2 shows the percentage of people in the Rhine Valley highly annoyed by railway noise in general (HA rail) in comparison to the generalized exposure-response curves for the percentage of highly annoyance due to road traffic and railway noise, respectively, by Miedema & Oudshoorn against L_{den}.

HA for daytime/night-time includes all responses of the 5-point response scale with values above 3 as defined in the recommendations of the International Commission on Biological Effects of Noise (ICBEN; [9]). Accordingly, HSD includes sleep disturbance score values above 3.5

For reasons of comparison, according to the definition of Miedema and colleagues [6][7], in the exposure-response-curve in Fig. 2 HA includes all responses above the cut-off point of 72 of the response scale when transferred to a scale from 0 to 100. To meet this HA definition annoyance scores from 1 to 3 indicate a HA-value of 0, the annoyance score 5 ('extremely disturbed of annoyed') indicates a HA-value of 1 whereas a random sample of 40% of participants with annoyance score = 4 were defined as highly annoyed, the other 60% of participants not. This is equivalent to a weighting of the annoyance score of 4 with a weight of 0.4

As expected and in line with the correlations presented in Tab. 2, Fig. 1 and 2 indicate that %HA and %HSD due to railway noise increases with increasing railway noise levels. In particular for equivalent sound levels above 65 dB %HA for railway noise railway at daytime against L_{day} is somewhat higher than %HA at night and considerably higher than %HSD against L_{night}.

For the 'annoyance part' of the railway noise index for the Middle Rhine Valley MRI the exposure response curve for railway noise annoyance at daytime (red curve in Fig. 1) is used.

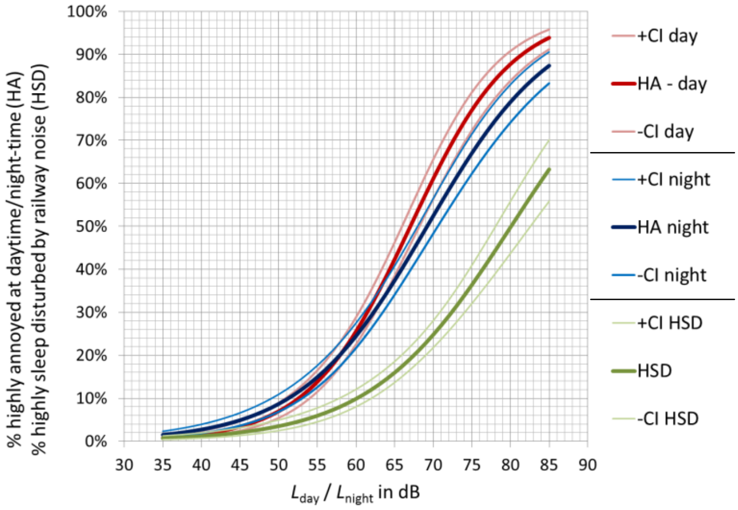

Figure 1 – Logistic regressions for the percentage of people in the Rhine Valley highly annoyed by railway noise at daytime (HA day) against L_{day} and highly annoyed (HA night) as well as highly sleep disturbed by railway noise at night-time (HSD) against L_{night}. In this figure, according to the ICBEN recommendations [9] annoyance and disturbance response values above 3 on the 5-point response scale are defined as HA and HSD, respectively.

In Fig. 2 the exposure-response curve for %HA due to railway noise is compared with the generalized curves of Miedema & Oudshoorn [7] for %HA due to railway and road traffic noise. The Rhine-Valley curve for %HA due to railway noise is clearly above both generalized curves. Unfortunately, no exposure-response information for road traffic noise annoyance is obtained for the Middle Rhine Valley in this study. Nevertheless, as far as it can be concluded from the curves in Fig. 2 there is no evidence of lower annoyance due to railway noise ('railway bonus') as compared with road traffic noise in the Middle Rhine Valley in particular in the range of higher noise exposure (above 65 dB L_{den}).

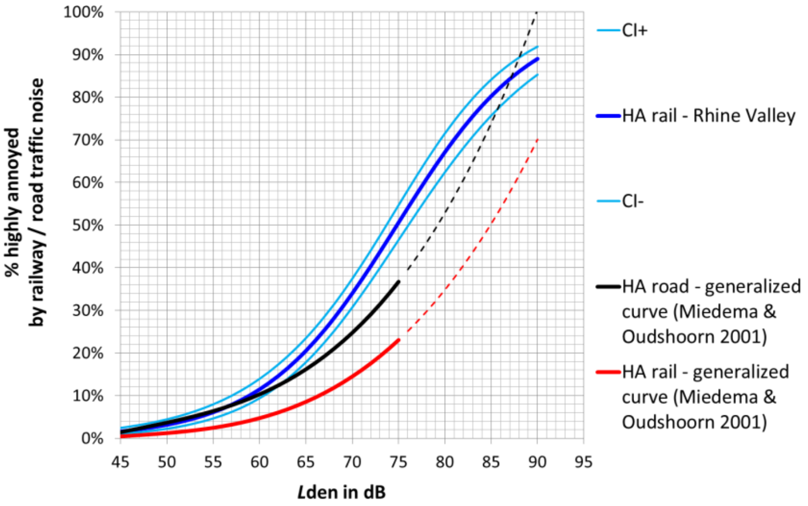

Figure 2 – Logistic regressions for the percentage of people in the Rhine Valley highly annoyed railway noise annoyance (HA rail – Rhine Valley) in comparison to the generalized exposure-response curves for the percentage of people highly annoyed by railway noise (HA rail) and road traffic noise (HA road) by Miedema & Oudshoorn [7] against $L_{den.}$ In this figure a cut-off point of 72 (on a response scale 0 – 100) according to [6] and [7] is used for the definition of HA.

Fig. 3 indicates that with increasing railway noise level ($L_{pAeq,24h}$, L_{night}) less residents reported to have a quiet façade and a room at home to retreat from railway noise exposure and an increasing number of participants reported to have the windows predominantly closed in the bedroom. However, even in the highest noise level classes still less than 50% of the interviewees have their bedroom windows usually closed at night-time.

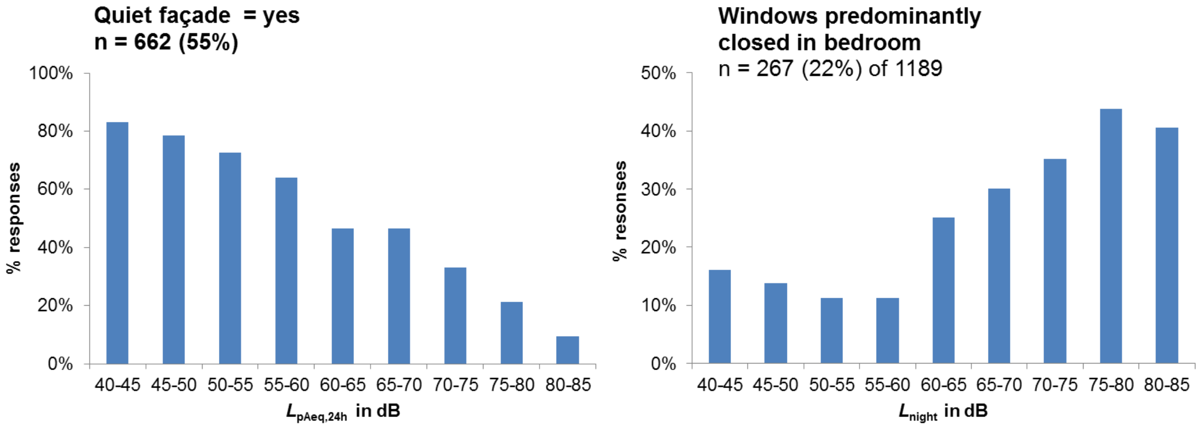

Figure 3 – Percentage of participants in percent reporting to have a quiet façade available at home by railway noise level classes ($L_{pAeq,24h}$) (left) and percentage of residents with windows predominantly closed in the bedroom by railway noise level classes for night-time (L_{night}) (right)

As expected, according to the results presented in Tab. 3, having a quiet façade at home is associated with less railway noise annoyance in comparison to those residents who did report not to have a quiet façade available (ANOVA: $F_{[1,1174]} = 20.1$; $p < .001$). In line with results of previous studies referring to aircraft noise [14] and railway noise [19] those residents with predominantly closed windows in the bedroom are higher sleep disturbed by railway noise than residents with predominantly open or half-open windows (ANOVA: $F_{[1,1168]} = 31276.0$; $p < .001$).

In tendency, this annoyance difference is more distinct in higher range of railway noise exposure (ANOVA: $F_{[8,1168]} = 2098.0$; $p < .033$). This result was found to be independent of the type of windows (sound proof windows, single-/double-glazed windows) and of the funding of sound proof windows (not presented in detail in this paper).

Table 3 – Descriptive statistics of (1) railway noise annoyance by equivalent sound level for 24 hours ($L_{\mathrm{pAeq,24h}}$) and availability of a quiet façade (yes/no) and (2) sleep disturbances by the equivalent sound level for night-time (L_{night}) and window position in the bedroom in warmer seasons (open vs. closed)

dB		40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	Total
		Railway noise level - $L_{pAeq,24}$ in dB									
(1) Quiet façade											
Yes	M	1.38	1.45	1.71	2.31	3.26	3.68	3.90	3.94	4.50	2.26
	N	39	124	192	139	61	38	31	33	4	661
	SD	.71	.96	1.06	1.34	1.32	1.32	1.33	1.17	.58	1.44
	SE	.11	.09	.08	.11	.17	.21	.24	.20	.29	.06
No	M	1.88	1.74	2.14	2.83	3.94	4.16	4.48	4.73	4.41	3.66
	N	8	34	71	78	70	45	63	123	39	531
	SD	1.64	1.21	1.20	1.45	1.31	1.19	1.00	.63	.85	1.53
	SE	.58	.21	.14	.16	.16	.18	.13	.06	.14	.07
		Railway noise level at night-time – L_{night} in dB									
(2) Window position (bedroom)											
closed	M	1.33	1.35	1.38	1.83	2.73	3.09	2.78	3.69	3.64	2.75
	N	5	18	28	26	38	27	30	67	26	265
	SD	.75	.94	.87	1.09	1.43	1.47	1.24	1.13	1.51	1.49
	SE	.33	.22	.16	.21	.23	.28	.23	.14	.30	.09
open	M	1.00	1.22	1.24	1.41	1.98	2.16	2.60	2.88	2.78	1.72
	N	26	112	221	203	113	65	57	86	38	921
	SD	.00	.68	.59	.83	1.16	1.15	1.38	1.39	1.57	1.14
	SE	.00	.06	.04	.06	.11	.14	.18	.15	.25	.04

M: Mean, N = number, SD = standard deviation, SE = standard error

4. CONCLUSIONS

A total of 1211 residents living along the highly frequented railway line in the Middle Rhine Valley and the region of Rheingau/Rheinhessen were interviewed with regard to their annoyance and disturbances due to railway noise. For the address of each participant railway noise levels were calculated according the railway noise calculation model Schall 03. Exposure-response relationships were analyzed with regard to railway noise annoyance (at daytime, overall) against L_{day} and L_{den} and sleep disturbances against L_{night}. The exposure-response curve for %HA due to railway noise at daytime is included in the 'annoyance part' of the railway noise index for the Middle Rhine Valley MRI. The MRI describes the number of persons highly annoyed by railway noise during day time and the average number of additional nocturnal railway noise-induced awakenings. The index is a tool to describe the railway noise impact in the Middle Rhine Valley and to evaluate and compare the impact of different measures of railway noise control (see [3] for more details).

In comparison to the generalized curves for noise annoyance due to railway and road traffic noise by Miedema & Oudshoorn [7] the number of people highly annoyed by railway noise is considerably higher in the Middle Rhine Valley. This is in line with findings of other studies investigating effects of railway and road traffic noise in valleys in the Alpine region (Unterinntal, Wipptal, see e.g. [5]).

The availability of a quiet façade helps to minimize the railway noise annoyance which is in line with findings of previous studies [8]-[11]. Residents with predominantly closed windows in the bedroom in warmer seasons are higher sleep disturbed by railway noise than those with predominantly open windows. This result is independent of the type of windows (sound proof windows, single-/double-glazed windows) and of the funding of sound proof windows. This indicates that the impact of noise abatement measures on responses to noise such as annoyance and disturbances cannot be simply predicted from changes in sound levels.

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