Experimental studies on sleep disturbances due to railway and road traffic noise

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INTRODUCTION

A "bonus" of 5 dB has been applied to railway noise in most European Union (EU) countries, e.g. Austria, Germany, France and Sweden. The reason for this is that the majority of international and Swedish studies show that railway noise is less annoying than road traffic noise and aircraft noise (Miedema & Oudshoorn 2001; EU position paper 2002). According to the meta-analysis (Miedema & Oudshoorn 2001) based on data from a large number of studies the proportion annoyed varies between the different noise sources, e.g. aircraft noise is most annoying (38 %) followed by road traffic (26 %) and railway noise (15 % annoyed) at L_{den} 60 dB.

The effect of railway noise on sleep has been studied to a much smaller extent than general annoyance. The EU position paper on sleep disturbances (2004), which is based on meta-analyses from a relatively large number of field studies, shows less sleep disturbances for railway noise than for road traffic and aircraft noise at the same (outdoor) sound levels. A large study by Moehler et al. (2000) among 1600 individuals exposed to railway noise or road traffic noise showed that reported sleep quality was less affected by railway noise than by road traffic noise. In a sub population of 400 individuals within the same study sleep was also measured by actimetry and these results showed, as opposed to reported sleep quality, no relation with sound levels and no difference in effects between the two noise sources. During more recent years a number of studies, both in field and in experimental settings, show somewhat contradictory results and the railway bonus does not always seem to be justified (Griefahn et al. 2006; Öhrström et al. 2007). According to the recent review (Öhrström & Skånberg 2006) it seems likely that a railway bonus is justified for general annoyance and possibly for sleep disturbances but not for speech interference. However, with an extensive increase in railway traffic with faster trains and heavier freight trains as well as new railway lines, new studies are needed to obtain a better basis of knowledge on adverse health effects, especially effects on sleep.

The objectives of the present study were, firstly, to study the effects on sleep quality from railway noise in comparison with road traffic noise with the same equivalent sound level (L_{night}) (a) and in comparison with road traffic noise with the same maximum sound level (L_{AFmax}) (b) and, secondly, to compare perceived disturbance during night from the three type of sound exposures.

METHOD AND MATERIALS

Laboratory settings and test subjects

The experimental studies on sleep were conducted in the new Sound Environment Laboratory at the Department of Occupational and Environmental Medicine, The Sahlgrenska Academy at the University of Gothenburg. The study was carried out during spring 2007.

The sound laboratory rooms were furnished as a homelike apartment with three bedrooms, a combined kitchen and living room (see photos Figure 1). The background sound levels (ventilation etc.) in the laboratory are very low, 13 dBA. The sound exposures used in the sleep study were played from the control room via two loudspeakers mounted on the wall in the bedrooms at the same side as the bed. The temperature in the bedrooms could be adjusted according to the subjects' requests. The subjects had their own keys to the dwelling and could come and go as they pleased during the day. During the experimental period, sleep during daytime hours or consumption of alcohol was not permitted.

Figure 1: The laboratory environment, bedroom (upper left) and combined kitchen and living room

Eighteen healthy subjects, 10 women and 8 men aged 23 – 35 years (average age 26.8 years, SD ± 4.3) took part in the sleep experiment. All subjects had normal hearing and passed the audiometric test without any remarks. A majority of the subjects (67 %) estimated their home environment as quiet or rather quiet. Most of them noticed noise from road traffic at home but few (4 subjects) noticed railway noise at home. Sixty-one percent considered themselves as "not at all" or "not very sensitive" to noise/sound and 39 % characterized themselves as "rather" or "very sensitive" to noise/sound on the 4-point verbal category scale. All subjects usually slept rather or very well at home and only 2 subjects estimated that it took more than 30 minutes to fall asleep. Half of them used to sleep with their bedroom window open at night during summer time.

Experimental design

Three subjects at a time participated in the experiment and slept 5 consecutive nights in the laboratory. The experiment started with two nights for habituation, one with road traffic noise exposure and one quiet night followed by three nights with either railway noise or two types of road traffic noise (Table 1). The three exposure nights (night 3 – 5) were presented in a randomized order during the six experimental sessions.

Sound exposures from road traffic and railway

A detailed description of sound exposures used in the experiment is given in the paper by Ögren et al. (2008) in this conference. The sound exposures were chosen to allow for comparisons with previous experimental sleep studies on road traffic noise with different numbers of events and L_{AFmax}-levels (Öhrström et al. 1990; Öhrström 1995), and the recent field studies in Lerum municipality on road traffic and railway noise (Öhrström et al. 2007). The railway noise was synthesized using recordings of freight-, local and long distance trains with the same composition during night as on the railway line Västra Stambanan between Gothenburg and Alingsås through Lerum municipality, i.e. 44 trains between 11 pm and 7 am. Two kinds of road traffic noise exposures were used, one exposure with the same equivalent sound level as the railway noise ($L_{Aeq,23\text{-}07}$ 31 dB) and one exposure with the same maximal sound level as railway noise (L_{AFmax} 54 dB).

The frequency spectra of the three sound exposures were filtered to correspond to a realistic situation in the home with the bedroom window slightly open. Table 1 gives the information on sound levels in L_{Aeq} and L_{AFmax} together with number of noise events for exposure and habituation nights.

Table 1: Sound levels and number of events during different nights

	L_{Aeq}	L_{AFmax} [1)]	Number of events 8h (11 pm-7 am) (time in bed)	Number of events 10h (10 pm-8 am)
Railway noise (**Rail**)	31	54	44	63
Road traffic (**RoadL$_{Aeq}$**)	31	50	369	714
Road traffic (**Roadmax**)	29	54	28	35
Habituation night 1, road traffic	26	45	369	714
Habituation night 2, quiet	25	26	-	-

1) *Highest sound level for one or more noise events during 8 hours.*

The railway noise (Rail) consisted of 25 freight trains with L_{AFmax}-levels of 48.6-53.9 dB, 9 fast passenger trains (L_{AFmax}: 42.8-48.6 dB) and 10 local passenger trains (L_{AFmax}: 40.3-42.7 dB). The 28 road traffic noise events (Roadmax) consisted of 12 vehicles with a L_{AFmax}-level of 54 dB, 6 vehicles at 50 dB and 10 vehicles at L_{AFmax} 46 dB.

Table 2 shows sound level distribution for L_{Aeq} and L_{AFmax} for 2-hour periods during the three different sound exposure nights. L_{Aeq}- and L_{AFmax}-levels are evenly distributed during night Roadmax and relatively even distributed during night Rail. The equivalent sound level is 4-6 dB lower between 01 – 05 hrs as compared with the first and last 2-hour period of night RoadL$_{Aeq}$.

Table 2: L_{Aeq} and L_{AFmax} per 2-hour intervals during the three exposure nights

	11-01 hrs	01-03 hrs	03-05 hrs	05-07 hrs
$L_{Aeq,2hrs}$:				
Railway (**Rail**)	32.0	30.3	30.5	31.3
Road traffic (**RoadL$_{Aeq}$**)	33.4	28.7	26.6	33.0
Road traffic (**Roadmax**)	28.8	28.8	28.8	28.8
$L_{AFmax,2hrs}$:				
Railway (**Rail**)	53.9	53.9	53.9	53.9
Road traffic (**RoadL$_{Aeq}$**)	49.8	48.4	41.7	49.9
Road traffic (**Roadmax**)	54.1	54.1	54.1	54.1

Evaluation of effects on sleep

The test subjects answered a questionnaire each morning, within 15 minutes after the final awakening. The questionnaire contained questions on falling asleep, awakenings, sleep quality, movements and tiredness in the morning. Furthermore, two questions were posed on annoyance due to sound/noise during night: “Were you annoyed by sound/noise during night?” and “Do you think that sound/noise during the night affected your sleep in such a way that you: had difficulties to fall asleep (a), woke up (b) got worse sleep quality? (c). Answer alternatives were; not at all, not very much, rather much, very much and extremely much. None of the test subjects answered that they were extremely annoyed/disturbed by sound/noise. The test subjects also answered a questionnaire each evening within 15 minutes before going to bed with questions on tiredness during the day and evening.

Statistical analysis and treatment of data

Data were analyzed using SPSS for Windows version 15.0.1. Repeated analysis of variance, General Linear Model and Wilcoxon Signed Ranks Test, was used to test differences in effects between nights with different sound exposures. The relation between sleep parameters, e.g. sleep quality and annoyance due to noise during night was tested with Pearson correlation coefficient (r). Differences associated with p-values below 0.05 were considered statistically significant.

RESULTS

The results on sleep (falling asleep, awakenings, sleep quality and tiredness the next morning, day or evening) obtained for the second, quiet habituation night did not deviate significantly from any of the three exposure nights with railway and road traffic noise. In the following results are given for the three exposure nights for the different sleep parameters and for disturbance of sleep during night in terms of falling asleep, awakenings and sleep quality.

Time for falling asleep

There were no differences in difficulties for falling asleep or time to fall asleep between the three different exposure nights (Table 3). Twenty-two percent had rather or very difficult to fall asleep both during night Rail and night RoadL$_{Aeq}$, and 33 % during night Roadmax. A majority, more than 75 %, estimated that they had fallen asleep within 30 minutes during all exposure nights. The average time to fall asleep reported by the test subjects was 20.6 (SD 13.5) minutes for Rail, 19.4 (SD 19.1) minutes for Road L_{Aeq} and 21.6 (SD 19.4) minutes for Roadmax.

Table 3: Difficulties and time for falling asleep during the three exposure nights

	Rail	RoadL_{Aeq}	Roadmax
Difficulties to fall asleep (%)			
Not at all	27.8	50.0	44.4
Not very	50.0	27.8	22.2
Rather /very	22.3	22.3	33.3
Time for falling asleep (%)			
< 15 minutes	33.3	61.1	44.4
15-30 minutes	50.0	16.7	33.3
30-60 minutes and > 60 minutes	16.7	22.3	22.3

Sound levels during the early part of the night are of vital importance for the time needed to fall asleep. A somewhat higher proportion of subjects, 61 %, reported less than 15 minutes to fall asleep during the night with RoadL_{Aeq} This exposure night had the lowest maximal sound level ($L_{AFmax,23-01}$ = 49.8 dB) during the first 2-hour period (see Table 2) and no noise event exceeded L_{AFmax} 50 dB during the first 60 minutes after going to bed.

Awakenings

Only a few of the test subjects (2-3 persons) reported that they woke up during any of the nights. The average number of awakenings varied between 1.3 (RoadL_{Aeq}), 1.5 (Roadmax) and 2.2 (Rail). The difference in number of awakenings between Rail and the two road traffic exposures (repeated analysis of variance test) was statistically significant, (Rail vs. RoadL_{Aeq}; Mean difference 0.889, p = 0.03 and Rail vs. Roadmax; Mean difference 0.722, p = 0.03).

The test subjects were also asked if they remembered when they woke up before the final awakening in the morning, which between 56 and 72 % reported that they did. This is shown in Figure 2 as number of subjects who woke up in different 2-hour periods during the three exposure nights.

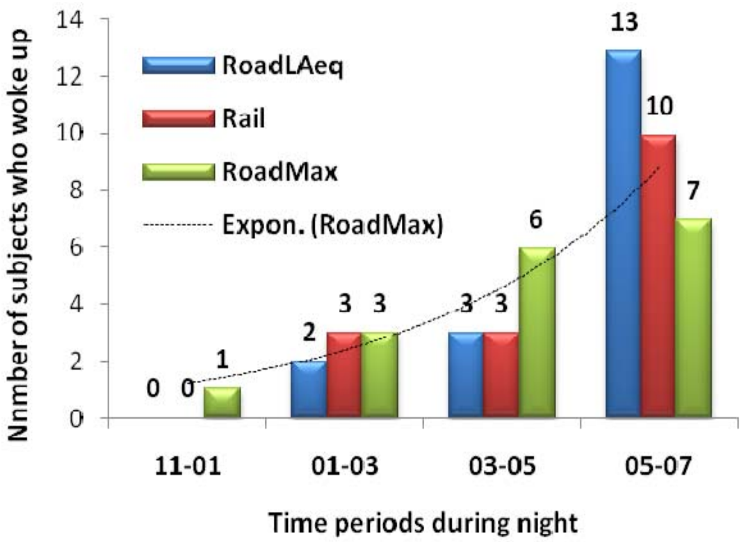

Figure 2: Number of test persons who reported awakenings in different 2-hour periods during the three exposure nights

The number of test subjects who woke up during night increased over the four 2-hour periods irrespective of type of sound exposure. Almost half of the subjects woke up in the last 2-hour period, for example, 13 subjects woke up 05-07hrs during the night with RoadL_{Aeq} compared with 3 subjects at 03-05hrs. This was expected as the proportion of deep sleep is much higher during the first period of the night. Both Rail and RoadL$_{Aeq}$ nights have higher equivalent sound levels during the last 2-hour period which may explain why some more subjects woke up during these nights as compared with the RoadMax night.

Sleep quality and tiredness in the morning

Reported sleep quality is closely related to difficulties falling asleep and awakenings during night and also with how rested one feels in the morning after the final awakening. Sleep quality, movements and tiredness the following morning, day and evening after the different exposure nights was measured with several different questions (5-point verbal category scale and a numeric 0-10 scale). The results are shown in Table 4.

Table 4: Sleep quality and tiredness after different exposure nights

	Rail	RoadL$_{Aeq}$	Roadmax
Sleep quality (%)			
Very bad/bad/not very good	22.2	5.9	16.7
Rather good	50	58.8	61.1
Very good	27.8	35.3	22.2
Sleep quality, Scale 0-10 (Mean, SD) (0 very bad - 10 very good)	6.9 (2.14)	7.4 (1.62)	7.2 (1.83)
Movements, Scale 0-10 (Mean, SD) (0 lay still - 10 moving all night)	3.6 (2.28)	3.1(1.71)	3.6 (1.69)
Tired- alert morning (%)			
Very tired/tired/rather tired	55.5	50	50
Rather alert and rested	38.9	44.4	33.3
Very alert and rested	5.6	5.6	16.7
Tired-alert, Scale 0-10 (Mean, SD) (0 very tired – 10 alert and rested)			
Morning after	5.4 (2.48)	5.9 (2.19)	5.9 (2.24)
Day after	6.1 (2.53)	5.4 (2.48)	5.8 (2.67)
Evening after	3.6 (1.72)	4.0 (2.33)	3.9 (1.94)

There were no significant differences for any of the sleep parameters between the three exposure nights. The proportion of test subjects who reported *very* good sleep quality was slightly higher after RoadL$_{Aeq}$ (35 %) and this was also the case for the numeric scale (Mean value 7.4) and movements during sleep (Mean value 3.1).

Reported annoyance and disturbance of sleep by sound/noise

The test subjects answered questions on how sound/noise annoyed them during night and how sound/noise disturbed falling asleep, awakenings and sleep quality. The proportion of test subjects being disturbed in falling asleep by sound/noise was the same for the three sound exposures (28 %).

A slightly higher proportion of the test subjects reported that they were annoyed and disturbed by Rail as compared with RoadL$_{Aeq}$ and RoadMax, but there were no significant differences between the three exposure nights (Figure 3).

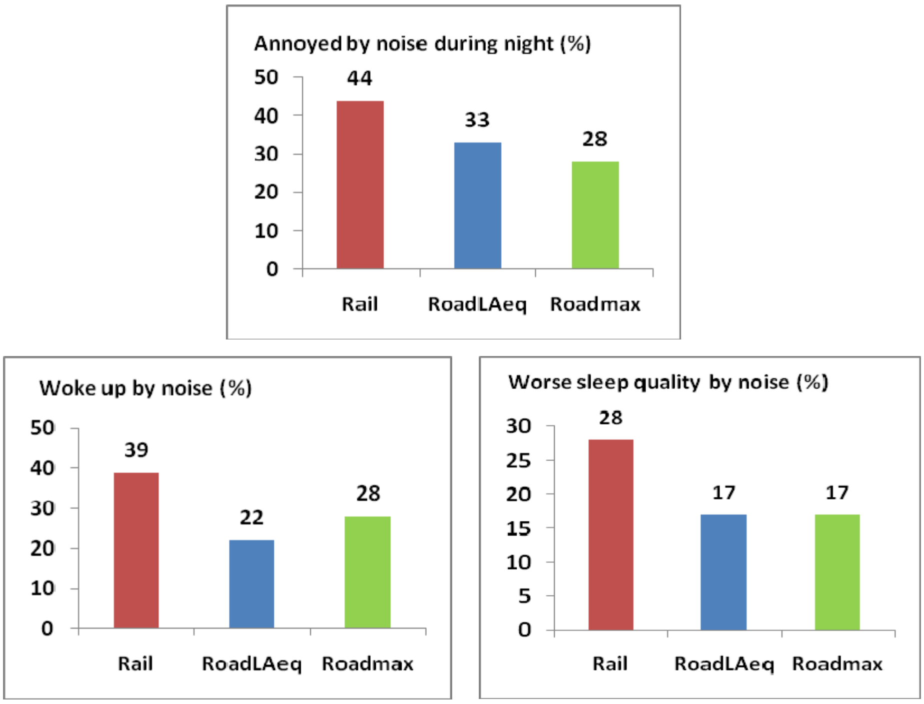

Figure 3: Proportion annoyed or disturbed (% rather and very) by sound/noise during the three exposure nights; annoyed during night (upper), woken up due to sound/noise (lower, left) and worse sleep quality due to sound/noise (lower, right).

Relationship between sleep quality and annoyance/disturbance due to noise

There was a statistically significant correlation ($p < 0.001$, Pearson correlation test, r) between sleep quality (Table 4) and reported annoyance/disturbance due to sound/noise during night, for exposure nights RoadL_{Aeq} and for exposure nights Roadmax; $r = 0.68$ and for exposure nights Rail; $r = 0.71$. This means that annoyance/disturbance due to road traffic noise explained 46 % of the variance (r^2) in sleep quality during nights with road traffic noises. Annoyance/disturbance due to railway noise explained 50 % of the variance in sleep quality during nights with railway noise.

COMMENTS AND CONCLUSIONS

The overall results revealed no differences between nights with railway noise and nights with road traffic noise with the same sound levels in L_{night} or L_{AFmax}. The average number of awakenings per night was however somewhat higher for railway noise (2.2) as compared with road traffic noise (1.5 and 1.3 respectively).

The reduction in sleep quality compared with the second, quiet night was small, -11 % for Rail, -5 % för Roadmax and -3 % for RoadL_{Aeq}. In the previous series of sleep experiments (Öhrström et al. 1990; Öhrström 1995) we studied effects of road traffic noise with different L_{AFmax}-levels (45–60 dB) and number of noise events (4–128) and found on average a similar decrease (-12 %) in sleep quality and about the same number of awakenings per night (1.9, variation 1.1– 3.1).

The test subjects in the present study were all young and healthy with normal hearing. Thus, the results cannot be generalized to a general population without caution. The sound exposures used in the study correspond to normally occurring indoor sound levels and frequency spectra for road traffic and railway noise when the bedroom window is kept slightly open which is common, provided that the outdoor sound levels are not too high, above L_{night} 55 dB (e.g. Öhrström et al. 2006). If windows are kept closed, the same outdoor sound level from road traffic and railway noise would result in a 5 dB lower indoor sound level for railway noise than for road traffic noise. With windows slightly open, however, the difference in sound level would only be about 0.5 dB. The exposure situation in this experiment, where we used a frequency filter to simulate an open window situation, is therefore reasonably similar to a homelike sound environment with windows slightly open. Considering this, comparisons between the present experiment and sleep studies in the field are probably more appropriate than experiments with no adjustment of the frequency spectra for the two types of noise sources.

The results from the present experiment disclosed somewhat more awakenings due to railway noise as compared with road traffic noise with the same sound levels corresponding to a situation with the window slightly open but no other significant differences in reported sleep disturbances were found. The results contradict to some extent, the EU position paper (2004) on sleep disturbances and the results obtained in the updated meta-analysis by Miedema & Vos (2007) of dose-response relationships between sleep disturbances and different types of traffic noise, which suggest that railway noise causes less sleep disturbances than road traffic noise.

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