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Sleep disturbances from road traffic noise: A comparison between laboratory and field settings

A. Skånberg*, E. Öhrström

Department of Environmental Medicine, The Sahlgrenska Academy at Göteborg University, Box 414, 405 30, Göteborg, Sweden

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Abstract

The aim of this study was to investigate whether there were any differences in the effects of noise on sleep between studies performed in the laboratory and in field settings with equal road traffic noise exposure. Fourteen subjects, living along a street with a relatively high load of road traffic and with bedroom windows facing the street, slept four nights at home and four nights in a sleep laboratory, where they were exposed to played back "home road traffic noise". Effects on sleep were evaluated by questionnaires and wrist-actigraphy. No significant differences in sleep quality were found between home and laboratory conditions on variables assessed either by questionnaires or wrist-actigraphy. It was concluded that laboratory experiments do not exaggerate the effects of road traffic noise on sleep, provided that sleep is studied with the same methods and that a homelike environment is created in the laboratory.

1. Introduction

Uninterrupted sleep is known to be the most important requirement for good physiological and mental functioning of a healthy life, and sleep disturbance is considered to be a major effect of environmental noise [1]. During the early years of research, studies on the effects of noise on sleep were performed solely in the laboratory. Comprehensive development of technical equipment allowed observations of people in their own home environment [2]. Discrepancies between the

*Corresponding author. Tel.: +46 31 773 3613; fax: +46 31 82 5004.
E-mail address: annbritt.skanberg@envmed.gu.se (A. Skånberg).

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results of field studies and laboratory experiments on noise-induced sleep disturbance have called into question the accuracy of results from laboratory experiments [3]. Pearsons reanalysed results from 21 studies of the effects of noise on sleep in an effort to develop a quantitative dosage–response relationship. The studies examined concerned road, rail, aircraft, sonic booms, and artificial sounds. Most studies were performed in the laboratory and only five were performed in field settings. The number of nights varied between one night (four studies) and at most 30 nights. Large discrepancies were found between laboratory experiments and field settings regarding the variables analysed, i.e. the percentage of participants aroused or awakened and the percentage that changed to a lighter stage of sleep (as measured electrophysiologically). A total of 136 data points from 21 studies were available for analyses of arousal and awakening, while 83 data points from 12 studies were available for analysis of sleep stage shifts. The results showed that the slopes of the dosage–response relationships for laboratory data were much steeper than those for field data; this implies that the effects on the measured variables were larger in the laboratory [3].

Griefahn proposed that the results found by Pearsons probably could be due to habituation and to masking by the simultaneous influence of various environmental factors [2]. Öhrström considered that the discrepancies could be due to different noise sources and lack of control (or knowledge) of individual noise levels in many of the studies analysed [4]. Also Hume [5] pointed out that field studies could suffer because of the reduced control that could be employed, which could pose limitations on the generality of the findings. Griefahn and Schuette [6] suggested that the most striking discrepancies between the large effects observed in the laboratory and the much smaller effects in the field was considerably accounted for by the use of actigraphy as a method to assess effects of noise on sleep. Also, the recently published Schiphol study [7] that used wrist-actigraphy suggested that the differences between results obtained in laboratory and field studies might be much smaller than supposed.

The present state of knowledge on the effects of noise from experiments performed in field and laboratory do not constitute a sufficient base for the establishment of a reliable exposure effect relationship. There is a need for further research because only a small number of the studies performed to date are reliable. In particular, there is a need for more precise assessment of the noise dose immission on an individual basis. Awakenings or body motility are often used as a measure of sleep disturbance, but time to fall asleep, premature awakening, reported sleep quality, and mood and performance after exposure to nocturnal noise should also be studied. Large-scale studies have been mainly focused on exposure to nocturnal aircraft noise. Studies on sleep disturbance should therefore be broadened to encompass other types of community noise. There is also limited knowledge on which indicators are most suitable for assessing the effects of noise on sleep.

Polysomnography (PSG) is considered to be the gold standard for evaluating sleep. In the planning of this study, however, PSG was considered to be labour-intensive and burdensome as well as intrusive for the subjects, so the more convenient method of wrist-actigraphy was chosen. A modern wrist actigraph is the size of a digital wristwatch and is easy to handle for both staff and subjects. Wrist-actigraphs are also relatively cheap in comparison to PSG equipment. A large number of studies have been performed to compare actigraphy with PSG on healthy people as well as on patients with different diagnoses, for example, insomnia and psychiatric disorders. Sleep and wakefulness differ from each other by the amount of body movement, and it has been claimed that this difference can be truthfully differentiated by actigraphy [8]. Cole [9] showed that the final algorithms (which are used in this study) correctly distinguish sleep from wakefulness approximately 88% of the time. Actigraphic sleep percentage and sleep latency estimates correlated with 0.82 and 0.90 respectively, with corresponding parameters scored from the polysomnogram ($p < 0.001$). A number of studies have been performed evaluating the effects of noise on sleep with actigraphy. Horne et al. [10] performed one of the largest studies, with the participation of 400 adults living around airports in Great Britain. One of the conclusions was that actigraphy is a valid and sensitive measure of awakenings during sleep, especially those lasting for more than 15 s.

The present study is part of a larger research programme, "Soundscape Support to Health" [11]. The goal of the programme is to develop methods and models for optimising soundscapes in connection with road traffic and city planning with respect to effects on health and well-being, including sleep. The aims of this programme with reference to sleep quality and noise-induced sleep disturbances are (a) to provide knowledge on the efficiency of different noise abatement procedures used as input for the overall evaluation, to achieve a sustainable acoustic environment in residential areas; (b) to improve methodologies for assessment of effects on sleep and to provide tools for assessment of direct adverse effects of noise on sleep, to be applied especially for strategic environmental health impact assessments in connection with existing and new residential areas.

Two series of laboratory and field experiments on noise-induced sleep disturbances have been performed within this programme. In the first series of experiments [12], people living in rather quiet residential areas were selected for the study. In the laboratory, they were exposed to recorded noise from road traffic, ventilation, and a combination of these exposures. In the home, the experiment was designed so that the subjects were exposed to the same road traffic noise exposure as in the laboratory. The effects of noise on sleep were evaluated by questionnaires and wrist-actigraphy. Contrary to the findings by Pearsons et al. [3] the results from the first series showed no significant differences between sleep in the home and in the laboratory setting. It has not been previously studied whether people who were used to sleeping in a noisy environment are more disturbed by noise when they slept in a laboratory than when they sleep in their home.

2. Aim of the study

The aim of this second series of sleep studies was to assess the effects of noise on the sleep of individuals who were chronically exposed to road traffic noise and investigate whether there are any differences in effects between sleep studies performed in the laboratory and in field settings with equal road traffic noise exposure.

3. Test subjects and methods

3.1. Test subjects

Fourteen paid volunteers took part in the experiment. The subjects lived alone, ten of them female and four male, and their average age was 30.5 (SD 8.9, range 22–55). The subjects were chosen from a larger study [13] where 210 persons living along the same street answered a questionnaire on their living environment and general health and well-being including sleep. The selected population lived along a relatively busy street in the city of Gothenburg. Those who had their bedroom facing the street (78 individuals) were asked whether they wanted to participate in a sleep study. Of the 78 individuals contacted, some were not interested in participating, some had a bed partner, and some reported a hearing impairment. These individuals were excluded from participating. A total of fourteen approved subjects volunteered to participate in the experiments. Their apartments were situated on the ground floor up to the sixth floor along the same street. None of the fourteen subjects who agreed to participate in the sleep study used any type of medication, and eleven subjects passed the audiometric test without any remarks. Three subjects had a small hearing deficiency on one ear, but passed the limit of 20 dB for all tested frequencies in the other ear.

Answers on questions in the general questionnaire on health and wellbeing from the 14 subjects who participated in the sleep study showed that, with the bedroom window closed, 63% of the subjects sometimes or often had difficulties in falling asleep, 43% sometimes or often woke up during the night, and 50% considered that they sometimes or often had lower sleep quality due to road traffic noise. A total of 72% did not have their bedroom window open as often as they wished to due to the road traffic. These results from the 14 sleep experiment participants were in line with the answers from the other 64 respondents in the larger study that had their bedroom window facing the street.

3.2. Sleep laboratory

The study was performed in a sleep laboratory consisting of a simulated dwelling with three bedrooms, a living room, and a kitchenette. In each bedroom, a hidden loudspeaker was mounted above a fake window, and the sound was played from a control room separated from the dwelling. The sound exposure was calibrated in each bedroom at the pillow to assure that the subjects were exposed to the same noise level in the laboratory as in the home. The temperature in the bedrooms was 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 experiment period, sleep during daytime hours or consumption of alcohol was not permitted.

3.3. Test procedure

The subjects slept as normal in their home and in the laboratory they were exposed to play back "home road traffic noise". Sleep was evaluated for four consecutive nights in the laboratory and four consecutive nights in the home. Half of the group of subjects slept the first week of the experiment in the laboratory and the second week at home. This sequence was reversed for the other half. In the home, the subjects were asked to have their bedroom window closed during the experiment. They answered sleep questionnaires and wore actigraphs on their non-dominant wrist during four nights. The first night in both the laboratory and at home was for habituation to wear the actigraph and in the laboratory also to habituate to the environment, in the laboratory they also had one night without sound as a quiet reference night. They were supplied with actigraphs, alarm clocks, and questionnaires for the entire home period and were not visited by

Table 1
The design used in the laboratory

Evening	Monday	Tuesday	Wednesday	Thursday
Subject #	Night 1	Night 2	Night 3	Night 4
1 2 3	Traffic	Quiet	Traffic	Traffic
4 5 6	Traffic	Traffic	Quiet	Traffic
7 8 9	Traffic	Traffic	Traffic	Quiet
10 11	Traffic	Traffic	Traffic	Quiet
12	Traffic	Traffic	Quiet	Traffic
13 14	Traffic	Quiet	Traffic	Traffic

the department's staff during this time. The experimental design used in the laboratory is summarized in Table 1. The quiet night was used to enable comparisons with results from previous studies on sleep in the laboratory. Most often, three subjects slept at the same time in the laboratory and were given the following information: "We are studying your sleep in the home and in the laboratory. Sound representative for your housing area has been recorded and it will be played back when you are asleep in the sleep laboratory. In this study we are performing comparative studies on how people sleep in different housing areas". The experiments were performed from February to May 2002.

4. Sound exposure

4.1. Home

Sound levels calculated according to the Nordic prediction model [14] outside the subjects' bedroom were on average $L_{\mathrm{Aeq}\ 22\text{-}06}$ 54.1 dB (free field values), and $L_{\mathrm{Amax}\ 22\text{-}06}$ 76 ± 4 dB. Sound levels assessed by measurements outdoors were on average $L_{\mathrm{Aeq}\ 22\text{-}06}$ 57 dB. The total number of vehicles on the street was 9800 per 24 h on weekdays. Of these, 5% (490) vehicles were heavy vehicles and about 5% (490) of the total number passed during the night (2200–0600 h).

5. Laboratory

A number of sound recordings were made during weekday nights. Sound recordings from one representative night without hard wind, rain, or snowfall, recorded outdoors at the fourth floor in one of the buildings were chosen for the experiment. Some non-representative impulse sounds, such as people suddenly whistling in the night, were erased from the recording. The frequency spectrum of the sound recording was adjusted during playback to simulate a closed window situation; the sound exposure was checked at the pillow in each bedroom. This is shown in Fig. 1 together with the normal hearing threshold curve. The exposure level was $L_{\mathrm{Aeq}\ 23\text{-}07}$ 33 dB, with maximum levels at L_{Amax} 50 ± 3 dB. The sound level during the quiet reference night was $L_{\mathrm{Aeq}\ 23\text{-}07}$ 25 dB. In the laboratory, the sound exposure started at 22:00 and continued until 08:00

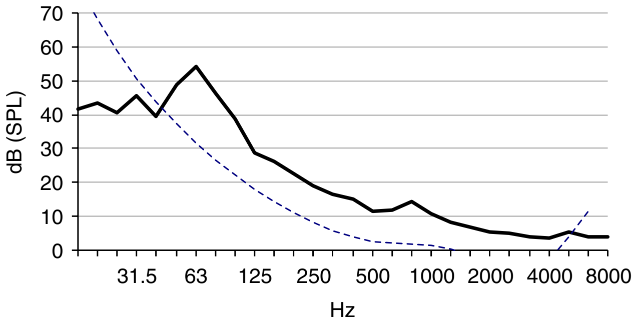

Fig. 1. Frequency spectra for the road traffic noise exposure used in the laboratory (thick line) and the normal hearing threshold curve (dotted line).

in the morning. The registration period for sleep (time from ''lights out'' to time of getting up in the morning) lasted from 23:00 until 07:00. Some subjects had a shift in time settings, but each subject had identical time settings during the experiment in the laboratory and at home.

6. Evaluation of effects

6.1. Wrist-actigraph

Body movements were registered by using a wrist-actigraph, specifically type Mini-Motionlogger^{TM} tri-mode actigraph from Ambulatory Monitoring Inc. The actigraph is based on an acceleration sensor that translates movements to a numeric presentation that is stored in a memory. The same six actigraphs were used throughout the experiment. The subjects always used the same actigraph in the laboratory and in the home. A small button on the actigraph, pressed in the evening at lights out and in the morning after waking up, made it possible to log these events. This was shown as a time mark on the output graph. Action-W, version 2.3.20 [15] and ACT 2000 [16] were used to manage and evaluate data from the actigraph memory. Data were downloaded to a computer for analysis of the following: duration, activity mean, sleep minutes, sleep efficiency, sleep latency, wake after sleep onset, wake episodes, mean wake episode, sleep episodes, mean sleep episodes.

Definitions of the descriptive statistics calculated by the software are as follows:

Duration: time in bed from the moment the button was pressed on the actigraph and the lights turned out in the evening, until the button was pressed after waking up in the morning.
Activity mean: mean activity score from counts registered by the actigraph per 30 s, the chosen epoch time.
Sleep minutes: total minutes scored as sleep.
Sleep latency: calculated as minutes to the start of the first 20-min block with more than 19 min of sleep according to the Cole–Kripke sleep-scoring algorithm [9].
Sleep efficiency: percentage calculated as sleep minutes during duration minus sleep latency and any terminal wake episodes.

Wake after sleep onset: wake minutes duration time with sleep latency excluded.
Wake episodes: number of blocks of contiguous wake epochs.
Mean wake episode: mean duration in minutes of wake episodes.
Sleep episodes: number of blocks of contiguous sleep epochs.
Mean sleep episode: mean duration in minutes of sleep episodes.

7. Questionnaire on judged sleep quality

Sleep quality was evaluated by slightly elaborated, previously used questionnaires [12,17]. Every evening, within 15 min before going to bed, the subjects completed a questionnaire and responded to questions on feelings of stress and tiredness during the day and the evening. The questions were evaluated with both a linear 100 mm scale and a numerical scale with values from 0 to 10. The end-point markings were "very stressful/not at all stressful" and "tired/alert", respectively.

Every morning, within 15 min after awakening, a questionnaire on judged sleep quality was completed. The questionnaire included questions on time to fall asleep: the subjects estimated the number of minutes it took to fall asleep. If there were difficulties in falling asleep, they could specify the reason. Questions were also asked on number of, and reasons for, awakenings, sleep quality, movements during the night, and feelings of tiredness/alertness in the morning. Two types of scales (as described for the evening questionnaire) were used to assess sleep quality, movements and tiredness/alertness, but with the end-point markings "very bad/very good", "moved hardly at all/tossed around all night", and "tired/alert" in the morning.

8. Mood questionnaire

Mood was evaluated each evening and morning using a mood adjective checklist [18], comprising 71 adjectives which can be summarised in six mood factors: "pleasentness", "extroversion", "social orientation", "activation", "relaxation" and "security". The response categories for the 71 adjectives were "completely agree", "agree to some extent", "do not agree", and "completely disagree".

9. Statistical analyses

Statistical analyses were performed with the statistical software Statview for Windows, version 5.01. Wilcoxson's test or the Friedman's test was used to evaluate differences on effects between nights. Spearman's rank correlation test was used to test correlations between variables. An average of the three nights in the home were used in the analyses and an average of the two nights in the laboratory with sound exposure were used in the analyses, the first nights were for habituation and were not included in the analyses. As the results showed high correlation between the scales 0–100 and 0–10 for judged sleep variables, only the results on the 0–100 scales are presented here. Tests were one-tailed when the sign of the change was predicted, otherwise two-tailed, p-values below 0.05 were considered statistically significant; p-values below 0.10 were considered as a tendency.

10. Results

10.1. Sleep assessed by actigraphy for nights with sound exposure

Comparisons on sleep assessed by actigraphy between road traffic noise exposure in the home and in the laboratory showed no significant differences, as seen in Table 2.

The number of sleep episodes was 1.7 fewer in the laboratory, and the mean sleep episodes calculated, as minutes were 25.9 min longer in the laboratory. An analysis of the actigraph data showed that three female subjects had only one sleep period during one of the nights in the laboratory with road traffic noise exposure.

Table 2
Sleep assessed by wrist-actigraphy as mean values and standard deviation for sleep in the home and in the laboratory with road traffic noise exposure

	Traffic noise					
	Home		Laboratory $L_{\mathrm{Aeq}\ 23\text{-}07}$ 33 dB		Difference	
	M	SD	M	SD	M	95% CI
Duration, minutes	459.7	(21.4)	459.8	(25.5)	0.1	(−14.2 to 14.5)
Activity mean, score	7.9	(4.1)	7.8	(6.6)	−0.1	(−2.7 to 2.5)
Sleep latency, minutes	17.8	(17.8)	21.2	(27.9)	3.3	(−10.4 to 17.1)
Sleep efficiency, %	94.7	(5.5)	94.8	(9.0)	0.1	(−4.1 to 4.2)
Wake minutes after sleep onset	22.7	(22.7)	21.6	(33.0)	−1.1	(−16.2 to 14.0)
Wake episodes, number	9.2	(5.5)	7.9	(3.9)	−1.3	(−4.2 to 1.6)
Mean wake episodes, minutes	4.2	(2.4)	4.9	(3.8)	0.7	(−1.0 to 2.4)
Sleep minutes	421.6	(30.1)	419.7	(54.2)	−1.9	(−23.7 to 20.0)
Sleep episodes, numbers	8.9	(5.4)	7.2	(4.0)	1.7	(−4.5 to 1.2)
Mean sleep episodes, minutes	80.5	(62.9)	106.4	(96.5)	25.9	(−10.6 to 62.5)

The difference is shown as mean and confidence interval.

10.2. Sleep assessed by questionnaire for nights with sound exposure

Table 3 shows the results on sleep assessed by questionnaires as mean values and standard deviation for the home and the laboratory. Results from judged sleep showed small and non-significant differences.

10.3. Comparisons between road traffic noise and quiet in the laboratory

The results, in Table 4, from sleep assessed by actigraphy showed only small differences between quiet and road traffic noise exposure in the laboratory. Only one significant difference was found between the two conditions. This concerned mean sleep episodes which were shorter during quiet.

Table 3
Average values of judged sleep for nights in the home and in the laboratory with road traffic noise exposure

	Traffic noise					
	Home		Laboratory $L_{Aeq\ 23\text{-}07}$ 33 dB		Difference	
	M	SD	M	SD	M	95% CI
Minutes to fall asleep	19.0	(11.3)	21.2	(8.9)	2.1	(−4.4 to 8.7)
Awakenings, number	1.9	(1.7)	1.7	(1.3)	−0.2	(−0.9 to 0.6)
Sleep quality (0–100)	62.2	(10.9)	58.5	(16.1)	−3.7	(−14.8 to 7.3)
Movements (0–100)	48.0	(15.8)	49.8	(14.9)	1.8	(−9.4 to 13.0)
Tired–alert morning after (0–100)	51.1	(20.7)	48.0	(19.9)	−3.2	(−13.2 to 6.8)

The difference is shown as mean and confidence interval.

Table 4
Average values of sleep assessed by actigraphy for the quiet night and nights with road traffic noise exposure in the laboratory

	Laboratory					
	Traffic noise $L_{Aeq\ 23\text{-}07}$ 33 dB		Quiet $L_{Aeq\ 23\text{-}07}$ 25 dB		Difference	
	M	SD	M	SD	M	95% CI
Duration, minutes	459.8	(25.5)	465.4	(30.4)	5.6	(−12.9 to 24.1)
Activity Mean, score	7.8	(6.6)	7.8	(4.3)	0.0	(−1.7 to 1.7)
Sleep latency, minutes	21.2	(27.9)	18.9	(28.8)	−2.3	(−10.3 to 5.7)
Sleep efficiency, %	94.8	(9.0)	94.2	(6.5)	−0.5	(−3.6 to 2.5)
Wake minutes after sleep onset	21.6	(33.0)	25.1	(25.7)	3.6	(−9.3 to 16.4)
Wake episodes, number	7.9	(3.9)	9.1	(4.6)	1.2	(−0.7 to 3.1)
Mean wake episodes, minutes	4.9	(3.8)	5.1	(4.7)	0.2	(−1.4 to 1.8)
Sleep minutes	419.7	(54.2)	422.9	(47.3)	3.2	(−12.5 to 18.9)
Sleep episodes, numbers	7.2	(4.0)	8.6	(4.6)	1.4	(−0.5 to 3.3)
Mean sleep episodes, minutes	106.4	(96.5)	69.9	(52.4)**	−36.5	(−65.8 to -7.2)

$^{**}p<0.01$.
The difference between the two conditions is shown as mean and confidence interval.

Sleep assessed by actigraphy for the quiet reference night showed the same activity mean (7.8), somewhat shorter sleep latency (−2.3), and an increase in number of wake episodes with 1.2, compared to the nights with road traffic noise. A significant difference ($p = 0.009$ one-tailed test) was found between the mean sleep episodes. Again, a closer look at the data shows that three female subjects only had one sleep period during one of the nights in the laboratory with road traffic noise exposure, which had an influence on the mean sleep episodes value.

The results for judged sleep in the laboratory are shown in Table 5.

Table 5
Average values of judged sleep for the quiet night and nights with road traffic noise exposure in the laboratory

	Laboratory					
	Traffic noise $L_{Aeq\ 23\text{-}07}$ 33 dB		Quiet $L_{Aeq\ 23\text{-}07}$ 25 dB		Difference	
	M	SD	M	SD	M	95% CI
Minutes to fall asleep	21.2	(8.9)	16.7	(13.1)	−4.4	(−9.8 to 1.0)
Awakenings, number	1.7	(1.3)	1.8	(1.5)	0.1	(−0.4 to 0.6)
Sleep quality (0–100)	58.5	(16.1)	67.4	(20.3)	8.9	(−4.0 to 21.7)
Movements (0–100)	49.8	(14.9)	42.1	(18.1)	−7.8	(−21.9 to 6.4)
Tired–alert morning after (0–100)	48.0	(19.9)	51.7	(23.0)	3.8	(−6.4 to 13.9)

The difference between the two conditions is shown as mean and confidence interval.

A tendency ($p = 0.054$, one-tailed test) to fewer minutes to fall asleep (−4.4) and a tendency ($p = 0.08$; 15%) to better sleep quality were reported after the quiet night compared to the night with road traffic exposure. The subjects reported that they moved 7.8 units less in the quiet condition and felt 3.8 units more alert in the morning without road traffic noise during the night.

10.4. Sleep quality in relation to individual factors

Significant differences were found between the genders on all variables assessed with actigraphy ($p < 0.05$) in the laboratory as well as in the home. Men had longer sleep latency (mean men = 35.8; woman 12.4; $p = 0.02$), higher activity mean (men = 12.1; woman 6.1; $p < 0.001$), higher number of sleep episodes (mean men = 10.8; woman 7.3; $p = 0.001$) and wake episodes (mean men = 11.4; woman 7.6; $p < 0.001$), and longer mean time for wake episodes (men = 6.2; woman 3.9; $p = 0.04$). They also had fewer sleep minutes (mean men = 384.3; woman 436.0; $p < 0.001$) during the night than women. These differences between men and women were not found for sleep assessed with questionnaires.

10.5. Effects on mood

The results on mood in the morning after the quiet night in the laboratory and after road traffic noise exposure in the laboratory and in the home are given in Fig. 2. The quiet reference night has higher mean values throughout on the mood variables.

In the laboratory with quiet conditions, the subjects felt significantly more relaxed ($p = 0.02$) and more secure ($p = 0.006$) compared to in the home. With traffic noise exposure in the laboratory, the subjects showed a tendency to be more relaxed ($p = 0.07$) and a tendency to feel more secure ($p = 0.09$) compared to in the home. (All tests were 2-tailed.)

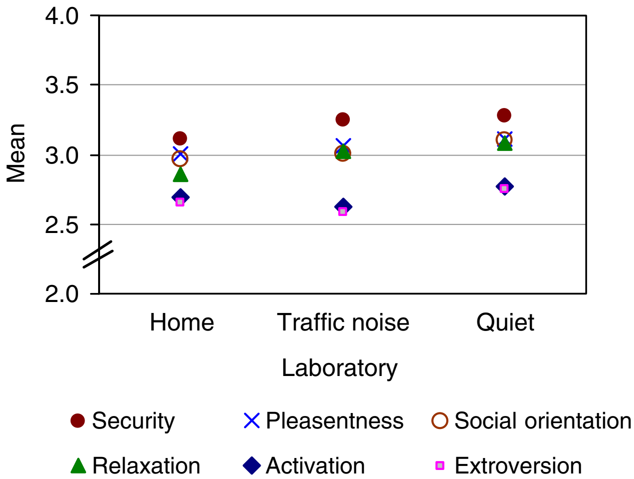

Fig. 2. Mood in the morning after the quiet night in the laboratory and nights with road traffic noise exposure in the home and in the laboratory.

11. Discussion

11.1. Method

The aim was to examine realistic sound exposure levels and test subjects living in an area with exposure levels slightly higher than the guidelines suggested by WHO [19]; the Swedish guidelines [20] were therefore chosen for this study. WHO guidelines for sound level inside bedrooms are a combination of the values $L_{Aeq,\ 8h}$ 30 dB, and L_{Amax} 45 dB; guideline limits outside bedrooms are $L_{Aeq,\ 8h}$ 45 dB and L_{Amax} 60 dB to allow for sleep with windows open [19]. The Swedish guidelines outdoors are $L_{Aeq,\ 24h}$ 55 dB and L_{Amax}70 dB, and the conditional limit indoors is $L_{Aeq,\ 24\,h}$ 30 dB with an additional nighttime limit of L_{Amax} 45 dB [20]. Measurable effects on sleep, such as difficulty in falling asleep and reported sleep quality, start at background noise levels of about L_{Aeq} 30 dB [19]. In this study, the sound exposure levels in the home and in the laboratory experiment were $L_{Aeq\ 23\text{-}07}$ 33 dB with maximum levels L_{Amax} 50 ± 3 dB. The answers from the general questionnaire showed that the subjects taking part in this study were disturbed in their homes by road traffic during the night.

In selecting subjects for the experiment, it was checked and confirmed that traffic noise was the main sound source in each apartment and that the subjects were not disturbed by other sources of sound, such as ventilation noise or disturbance from neighbours. The houses were of the same type and built in the same time period with similar windows and were situated along the same street. The sound level in the subjects' bedrooms differed somewhat, depending on differences in window insulation and on which floor they lived. This difference was however small and within the range of 1–2 dB. The sound exposure in the laboratory might have thus not exactly corresponded to the sound level in the bedroom of each subject. With more specified sound recordings in each home, a higher precision regarding the correct sound level could be achieved, but this would mean that only one subject at a time could participate in the laboratory experiment. The subjects' bedrooms were also furnished in different ways and were of different size. However, reverberation time is not so important for road traffic noise since the sound is rather continuous. The subjects lived at different locations along the same street. Some had pedestrian-operated traffic lights near their flats. As there were few pedestrians at night, this difference in location was probably of no importance. A larger number of participants in the experiment would have been desirable, but the intent was to achieve the same exposure levels with the same type of buildings for all subjects. No other street with the same exposure level was found. The subjects had to have bedroom windows facing the street, and only people who slept alone were selected to avoid disturbance from a bed partner.

Several studies have reported gender differences in actigraph measures of total nocturnal sleep with females having more sleep than males [12,21,22]. Gender differences were also found in the present study. Gender differences were found for actigraphy but there was no difference for sleep assessed by questionnaire. The gender difference from actigraphy data needs further investigation. Gender differences in activity levels during the night may lead to differential accuracy of sleep–wake scoring for males and females [21]. Analysis of the actigraph data showed that three female subjects had only one sleep period during one of the nights. This indicates that the subjects never woke up during the whole night, this is extremely unusual and raises the question whether actigraphy is sensitive enough to measure sleep in this kind of studies where awakenings are essential to detect.

11.2. Results

The results show that with subjects used to sleeping with noise from road traffic, no significant differences were found between sleep in the laboratory and at home with equal road traffic noise exposure when sleep was assessed by questionnaires and actigraphy. This is in line with the results from the first series of experiments [12] where subjects participated who were not used to road traffic noise in their homes. The equivalent sound exposure and maximum level of road traffic noise in the first series were about 5 dB higher ($L_{\mathrm{Aeq}\ 23\text{-}07}$ 39 dB and L_{Amax} 55 ± 3 dB with 64 events), compared to this series of experiments. The first series showed on average a score of 58.4 on a 100 mm scale on judged sleep quality [12]. In sleep laboratory experiments [23] with somewhat lower road traffic noise (L_{Aeq} 31.3 dB, L_{Amax} 50 dB and 64 events) the average sleep quality was 54.6. The earlier studies agree well with this study, where sleep quality is on average 58.5.

The first series showed that percentage reduction in judged sleep quality in the laboratory between noise exposure and the quiet night [12] was 22% after exposure with $L_{\mathrm{Aeq}\ 23\text{-}07}$ 39 dB compared to the quiet night. Results from the second series were in accordance with the first series and sleep quality was reduced by 13% after exposure with $L_{\mathrm{Aeq}\ 23\text{-}07}$ 33 dB. This agrees with the laboratory experiments on effects on sleep from road traffic noise [23] where sleep quality was decreased by 14% on average.

A plausible interpretation of the results from this study is that there is no difference in sleep quality with equal road traffic noise exposure in the home and in the laboratory at these exposure levels. Only one earlier study was found by Labiale and Vallet [24], where six subjects slept both at home and in a laboratory. The subjects were exposed to similar road traffic exposure

($L_{\mathrm{Aeq,8h}}$ 47 ± 3 dB) and slept five nights in each location; including two nights for habituation. The main results support the present study, the EEG-measurements and the questionnaire responses were found to be the same for both the home and the laboratory.

Earlier comparisons of the effects of noise on sleep between laboratory and field settings have rarely been made between subjects sleeping in both conditions. For example, in Pearsons' paper, which reanalysed 21 studies conducted either in the laboratory or in field settings, Pearsons chose only to compare differences between awakenings and sleep stage shift [3]. Öhrström [4] conducted a number of studies in field and laboratory settings and found results on awakening reactions, which were in line with Pearsons' findings with many fewer awakenings reported in field studies. In addition, a fairly good agreement between results in laboratory and field studies was found for difficulties in falling asleep and judged sleep quality.

Another reason for the large discrepancies in effects in earlier studies on sleep between laboratory and field settings could be that the laboratory environment is simply not sufficiently homelike. The results on mood in the morning questionnaire in this study showed that the quiet reference night had higher mean values throughout, compared to nights with road traffic noise exposure in the laboratory and in the home. No significant differences on mood in the morning were found between the home and the laboratory setting with noise exposure, either in this series or in the first series of experiments [12]. This finding implies that sleeping in the laboratory did not negatively influence the subject's mood; on the contrary, the quiet laboratory environment functioned as a homelike environment for the subjects.

12. Conclusions and comments

Laboratory experiments do not exaggerate the effects of road traffic noise on sleep, provided that sleep is assessed with the same methods and that a homelike environment is created in the laboratory. Subjects used to sleeping in a relatively noisy home environment have the same sleep quality, as assessed by questionnaires or wrist-actigraphy, when they are exposed to the same noise in the laboratory and at home. The results confirm the findings in the first series of experiments where subjects unused to noise during the night were exposed to recorded road traffic noise both in the home and in the laboratory.

When studying effects of noise on sleep in a laboratory, great care should be taken in creating as homelike an environment as possible, to allow for comparisons and generalisations to be made to the home environment.

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