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# DIFFERENCES BETWEEN RAILWAY AND ROAD TRAFFIC NOISE

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In a field study, carried out between 1994 and 1998, the noise impact as well as psychological reactions in four areas exposed either to railway or to road traffic noise were measured for 1600 persons. Furthermore, body movements during sleep were assessed for about 400 persons by actimeters. The noise impact was determined by noise measurements and calculations inside and outside the bedrooms of all persons concerned and was described by different acoustical indices. The psychological reactions were recorded by questionnaires. The analyses show typical differences in the acoustical and psychological factors between road and rail traffic noise; on the other hand, the differences with regard to body movements are rather low. There is also a high correlation between the acoustical and psychological variables for both road and rail traffic sources, whereas the correlations between the body movements on the one hand and the acoustical and psychological variables on the other are rather low.



## 1. INTRODUCTION

In many countries, the regulations for the evaluation of traffic noise pollution give limit values that are around 5 dB(A) lower for railway traffic than for road traffic ("railway bonus"). This difference between the two means of transport is the result of the difference in the nuisance caused by rail and road traffic noise with the same noise level $L_{Aeq}$.

Reviews of the literature carried out by Moehler and Schuemer-Kohrs [1], Moehler [2], and Schuemer and Schuemer-Kohrs [3] summarize the results of a number of international studies on the railway bonus. These studies all agree that the difference in nuisance depends on the level of noise, the period of time studied (day or night) and the specific disturbance reaction (e.g., communication, sleep):

 

— in the lower noise level range (approx. $L_{Aeq}$ = 50–60 dB(A)), the railway bonus seems to be less than in the higher noise level.
— during the day, the railway bonus of approx. 0–4 dB(A) is less than the night-time level of approx. 10 dB(A).
— with communication disturbances, the railway has a disadvantage of up to 4 dB(A), whilst there is a railway bonus of about 10 dB(A) with respect to sleep.

Since then, further field studies have been carried out in Austria by Lang [4], and in Japan by Yano *et al.* [5], which have produced very different results; whilst the above railway bonus was confirmed in the Austrian study, there was no railway bonus in the Japanese study, because of the special Japanese situation (e.g., no traffic at night). Laboratory tests carried out by Fastl *et al.* [6, 7] showed a railway bonus of 5 dB(A).

In all these studies, the disturbance from traffic noise at night was determined by questionnaires carried out by day. Since on the one hand the railway bonus at night is rather high, and on the other there is a lack of factual evidence as to whether the disturbances about which respondents are questioned by day correctly reflect the actual disturbances at night, it proved necessary to study the night-time disturbance, in particular in more detail through specific surveys. For this reason, a sleep study was carried out by an interdisciplinary team.

## 2. STUDY DESIGN

The study design required acoustic measurements, social surveys and physiological measurement of sleep disturbance to be carried out in areas with predominant railway noise or road traffic noise. The aim of the survey was to determine both day-time and night-time disturbances and thus to obtain up-to-date results on the difference in the problems caused by road and rail. The physiological part of the study, on the other hand, covered the noise-related disturbance of sleep in order to evaluate any source difference effect.

The acoustic impact caused by the relevant type of noise was to be varied on the one hand by use of areas with different traffic densities and on the other hand by selection of respondents at different distances from the noise source. For the study design (see Table 1), four different area types were defined which were each to be formed from two study areas (total eight areas).

TABLE 1

*Area types for the sleep study*

| Noice source | Traffic density | Number of passing vehicles per day (24 h) | Number of passing vehicles per night |
|---|---|---|---|
| Train | High frequency | >200 trains | >60 trains |
| | Low frequency | <200 trains | <60 trains |
| Road | High frequency | >15 000 vehicles | >1000 vehicles |
| | Low frequency | <15 000 vehicles | <1000 vehicles |

TABLE 2

*Subject statistics*

| | Traffic density | Study period | Number of social survey interviews | | Participants in the physiological study | |
|---|---|---|---|---|---|---|
| Road | High | Spring 97 | 522 | $\sum = 890$ | 96 | $\sum = 188$ |
| | Low | Spring 96<br>Autumn 97 | 368 | | 92 | |
| Rail | High | Autumn 96 | 310 | $\sum = 710$ | 93 | $\sum = 189$ |
| | Low | Spring 96<br>Autumn 97 | 400 | | 96 | |

In each of the study areas, a minimum of 150 repondents were to be included in the social survey and 50 respondents for the subsequent physiological sleep measurements. The subject statistics are shown in Table 2. The acoustic impact was to be determined for all respondents by calculation of the individual outdoor noise level. For the participants in the physiological sleep survey, accompanying sound level measurements would be carried out outside and inside the bedroom.

The studies were carried out in 1996 and 1997. In order to check, as far as possible, seasonal effects, particularly those caused by temperature-related window positioning, the surveys and measurements were carried out during the spring and autumn. The areas were distributed in such a way that road and rail areas were studied both in the spring and in the autumn.

## 3. METHODS

The data in the study were collected in the following steps:

- social survey interviews with subsequent acquisition of subjects for physiological study,
- noise and physiological measurements over $2 \times 5$ survey nights per area,
- second part of the social survey interviews with smaller random sample,
- calculation of the noise exposure data for individuals interviewed.

### 3.1. NOISE SURVEY

The noise surveys for the total sample (all the respondents who had participated in an interview) were carried out by calculation of individual average noise levels. The values were calculated separately for each of the two sources and the relevant periods of day and night. The calculations were made on the basis of the standards regarded in Germany as being state of the art.

For respondents who also participated in the physiological sleep study, extensive sound level measurements were carried out during the study period of 2 × 5 nights, which were then used to prepare individual noise-time patterns [8]. The aim of these patterns was, on the one hand, to allow an event-related evaluation of the sleep disturbances recorded in the same time period and on the other to allow a number of noise indices to be calculated. Since measurements could not be carried out on all respondents in an area at the same time during the entire sleep survey, continuous measurements close to the predominating source in the area were supplemented by short-time measurements on respondents (approx 1 h). The short-time measurements were made both outside and inside the bedroom of the participating respondents and were aimed at achieving the following:

— determining the inside and outside sound level of vehicles passing the individual respondents;
— assigning passage incidents at the continuous measuring point on a time basis to events occurring for the respondents (allowing an event-related evaluation).

From the combination of permanent measurements with the short-time measurements, individual noise-time patterns were calculated, using a specially developed algorithm, for the study period for all the respondents in the sleep survey (see Figure 1).

### 3.2. SOCIAL SURVEY

The surveys for the social part of the study were carried out in face-to-face interviews using more or less standardized questionnaires [9]. Because of the wide

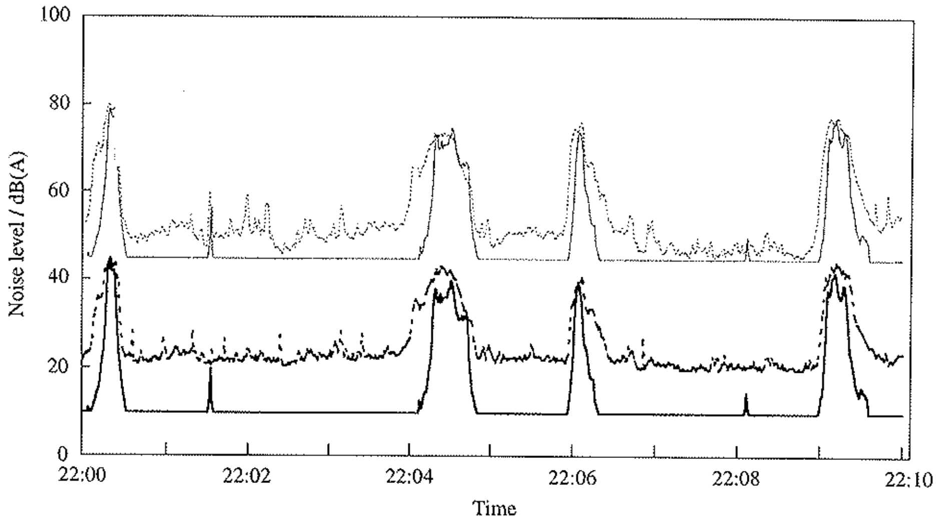


Figure 1. Example of short-time measurements and noise-time pattern outdoor and indoor calculated from continuous measurements: ······, outdoor measurement; ——, calculated outdoor noise level; ----, indoor measurement; ——, calculated indoor noise level.

scope of the themes in the interviews, the questions were divided between two interviews or questionnaires per respondent.

In addition to the usual demographic characteristics, the surveys included particular questions on the following topics:

— personal characteristics which would potentially have a moderating influence on reactions to the disturbance (moderator variables);
— source- and non-source-specific reactions to rail and road traffic noise: nuisance/disturbance through rail and/or road traffic noise, non-source-specific activities to prevent noise;
— evaluation of the noise quality of road and rail traffic.

### 3.3. PHYSIOLOGICAL STUDY OF SLEEP DISTURBANCES

The following variables were registered as indicators of the disruptive effect:

— body movement with an actimeter (primary reaction);
— a qualitative and quantitative evaluation of the daily sleep using a questionnaire (secondary reactions);
— sensor motoric performance (secondary reactions).

#### 3.3.1. *Primary reactions*

Body movement was recorded using actimeters. This method was chosen for scientific and economic reasons; in the project carried out here, 377 subjects were observed for 10 nights each. It had already been used successfully by other authors [10]. The devices are fixed with a strap to the wrist of the person being studied and register when a fixed threshold value for acceleration is exceeded (0·1 g). Movements occurring in this way are recorded every 2 s. The appliances were collected and read off after each of the 10 study nights per subject.

To calibrate the actimeters, EEG, EOG and EMG were also recorded in one night for 238 subjects.

#### 3.3.2. *Secondary sleep disturbances*

*Subjective evaluation of quality of sleep*: In addition to the objective measurements, a brief questionnaire was completed every night and morning to evaluate the current situation and the quantitative and qualitative parameters of the sleep. This questionnaire made no direct reference to the primary sound source or to the problem of noise.

*Sensor motoric performance*: In the first or second week, all the participants were given a choice reaction test in the evening and morning which allowed an evaluation of the qualitative and quantitative performance by registering both the work speed and the error rate. The respondents were instructed to carry out the test immediately before going to sleep and after getting up. For more information on this subject, see Griefahn *et al.* [11].

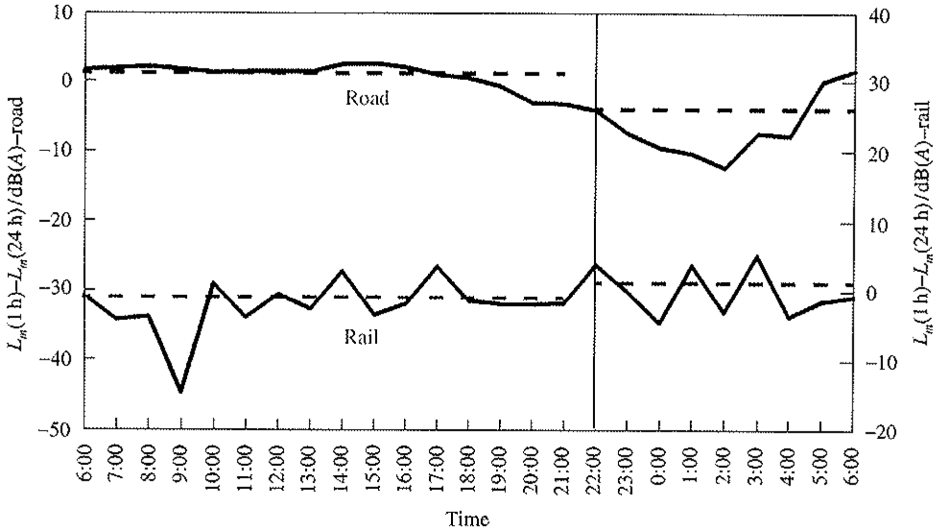


Figure 2. Time varying pattern of the hourly average noise level in a rail and a road area: ——, road/rail; - - -, Lm D/N.

## 4. RESULTS

### 4.1. NOISE EXPOSURE

To clarify the primary questioning with regard to a nuisance difference between road and rail traffic noise, the following will only use the energy-equivalent average noise level $L_{Aeq}$ for the periods day (06–22 h) and night (22–06 h). Evaluations for further acoustic dimensions will not be covered at this point.

There is a clear difference between the course of the noise pattern over time during the day and during the night (see Figure 2). Whilst noise from road traffic decreases considerably at night-time (22–06 h), the pattern from rail traffic remains fairly constant over 24 h. In addition, road traffic noise does not vary dramatically from hour to hour, whilst the average hourly noise levels for rail traffic tend to be more variable.

The distribution across the noise range of rail and road subjects in this study are therefore different for day and night. During the day, road subjects predominate in the high average noise levels, whilst a night-time high average noise levels occur primarily amongst rail subjects. The distribution of the subjects who took part in the physiological study is shown in Figure 3. The abscissa shows the measured average levels (median over 8 study nights) for the night-time period in the groups of 2·5 dB(A) width.

The noise measurements were concurrent with the physiological studies on 2 × 5 nights, with working days being selected in two consecutive weeks. In the road areas, there was no significant difference in the traffic nuisance between the individual study nights, whereas in rail areas the first study night of a week (Sunday/Monday) was characterized by the fact that goods traffic at night was much reduced. These nights were therefore not used for further evaluations.

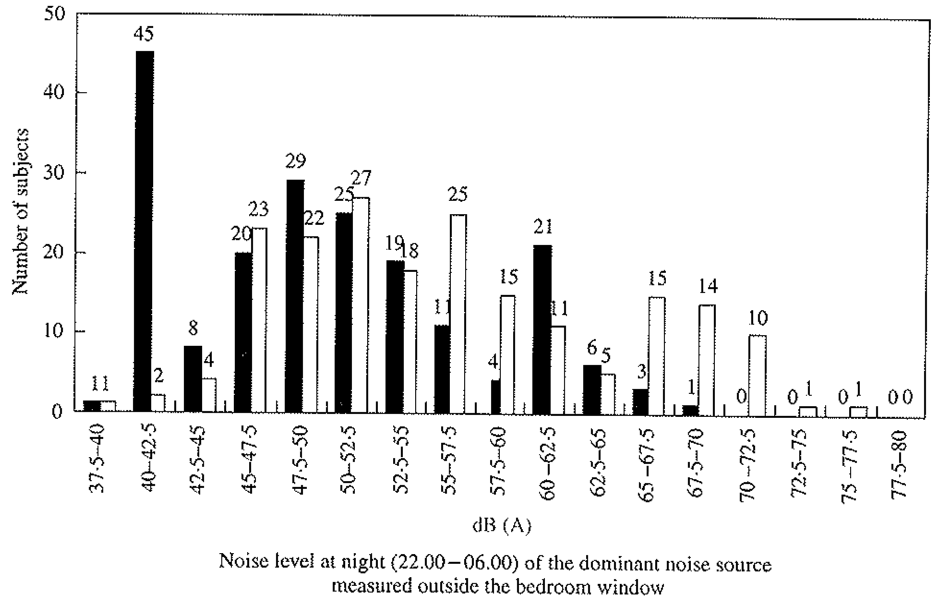


Figure 3. Noise-subject distribution for subjects of the physiological study: ■, road area; □ rail area.

### 4.2. SOCIAL SURVEY INTERVIEWS

From the wide range of data collected from the social survey interviews, the following core variables, which also allow comparison with earlier studies, were selected:

— *Disturbance during the day*: Total disturbance during the day in relation to road or rail traffic noise.
— *Disturbance during the night*: Total disturbance at night in relation to road or rail traffic noise.
— *Thermometer*. Total disturbance by road/rail traffic noise by 24 h (thermometer scale).
— *Sleep disturbances in social survey*: Source-related combined measure of individual questions regarding disturbance of sleep by road and rail traffic noise. With these questions, every subject was asked once about road traffic noise and once about rail traffic noise.
— *Direct comparison*: Since every subject was exposed basically to both the road and rail traffic noise, the subjects were asked to indicate in a comparative question which source—road or rail—they found more disturbing overall in their situation.

### 4.3. PHYSIOLOGICAL SURVEY

For each night, characteristic data were calculated from the actimeter recordings which demonstrated different characteristics of the pattern of movement in that night. These night-time values serve as indicators for quiet or restless sleep or sleep disturbances. In addition, dimensions describing the quality of sleep were developed from the daily questionnaires. The characteristic data under discussion are:

— *Movement index*: The Movement Index represents the total number of 2-s time periods with movement added together for the period of sleep, divided by the total number of 2-s time periods from the beginning of sleep to the end.
— *Time taken to fall asleep*: The time taken to fall asleep describes the period of time calculated from the difference between the time of falling asleep taken from the actimeter recording and the time of going to bed as given in the daily questionnaire.
— *Quality of sleep on weekdays*: Values generated on the basis of an analogue scale for typical sleep quality on weekdays determined by a daily questionning.

In addition, the actimeter recordings were used to develop various indices relating in part to different periods of the night. The use of other indices, however, does not provide significantly different results from those shown in the following (see reference [11]).

### 4.4. INTERDISCIPLINARY EVALUATION

The precondition for the occurrence of a nuisance difference between rail and road traffic noise is that the observed reaction should depend on the extent of the noise exposure. This dependence was examined by means of correlation calculations of the immission level with the various reaction data. In order to allow a selection of the most important core variable in the social survey interviews and the physiological study, the correlation coefficients are shown separately for road and rail subjects in Tables 3 and 4.

As Table 4 shows, there is a high correlation between reactions given in interviews and noise levels both on an individual bases ($r > 0{\cdot}2$) and at aggregate

TABLE 3

*Correlation coefficients of the calculated average levels with core variables from the social survey interview*

| | Individual data | | 2·5 dB class width | | 5 dB class width | |
|---|---|---|---|---|---|---|
| | Road | Rail | Road | Rail | Road | Rail |
| Total disturbance 24 h (thermometer) | 0·38 ($n$ = 733) | 0·41 ($n$ = 678) | 0·97 ($n$ = 11) | 0·97 ($n$ = 9) | 0·98 ($n$ = 6) | 0·99 ($n$ = 5) |
| Disturbance—day-time | 0·36 ($n$ = 744) | 0·32 ($n$ = 599) | 0·97 ($n$ = 11) | 0·98 ($n$ = 9) | 0·95 ($n$ = 7) | 0·99 ($n$ = 5) |
| Disturbance—night-time | 0·26 ($n$ = 647) | 0·24 ($n$ = 710) | 0·84 ($n$ = 10) | 0·94 ($n$ = 8) | 0·83 ($n$ = 6) | 0·99 ($n$ = 5) |

TABLE 4

*Correlation coefficients of measured noise data with medical core variables (individual data)*

| | $L_{Aeq}$ measured outside the bedroom | | $L_{Aeq}$ measured inside the bedroom | |
|---|---|---|---|---|
| $n_{road} = 188$, $n_{rail} = 189$ | Road | Rail | Road | Rail |
| Movement index sleeping period† | 0·09 | 0·09 | − 0·05 | 0·01 |
| Time taken to fall asleep† | 0·15 | 0·05 | 0·01 | 0·07 |
| Quality of sleep on weekday (not source-related)† | 0·11 | 0·06 | 0·01 | 0·12 |
| Disturbance at night from road/rail‡ | 0·35 | 0·32 | 0·28 | 0·18 |

† Spearman's rho.
‡ Pearson's *r*.

data level ($r > 0{\cdot}8$). The reactions during the night, however, correlate slightly less with the noise levels for the corresponding period than do the daytime and 24 h reactions.

The reactions assessed by the physiological measurements, however (see Table 4) do not correlate with the measured average noise levels (at night) in any way that is statistically significant. There is no correlation between the measured primary reactions by actimeter and outdoor or indoor noise levels (see in Table 4 the movement index sleeping period), there is also no correlation between the secondary reaction (the responses to questions which were not source related) and the outdoor or indoor noise levels (see Table 4: quality of sleep on weekday). As a comparison, Table 4 also shows the reaction variable "disturbance at night by road/rail" from the social survey interview for the part-random sample for the physiological survey and the noise levels measured. This reaction correlates significantly with the outdoor noise levels in all cases and with the indoor noise levels in the case of the road subjects.

### 4.5. NUISANCE DIFFERENCES

The answers to the question "what do you perceive to be more disturbing here—railway noise, road traffic noise or both about the same?" show a clear result (see Figure 4). Where two noise sources with a noise difference of 0 dB(A) would be expected to be named equally frequently, even if rail traffic noise predominates the road traffic noise by about 5–10 dB(A) both sources are listed as disturbing with equal frequency. In addition, even if rail traffic noise predominates strongly this noise is only given as more disturbing by 60–70% of the respondents in question,

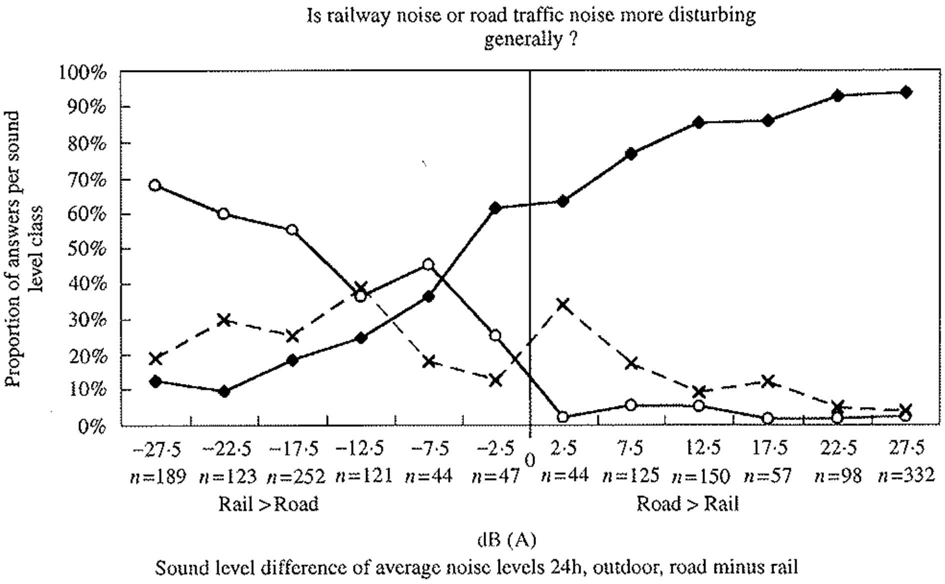


Figure 4. Direct comparison of the disturbing effect of rail and road traffic noise: --O--, rail noise more disturbing; —×—, both the same; —◆—, road noise more disturbing.

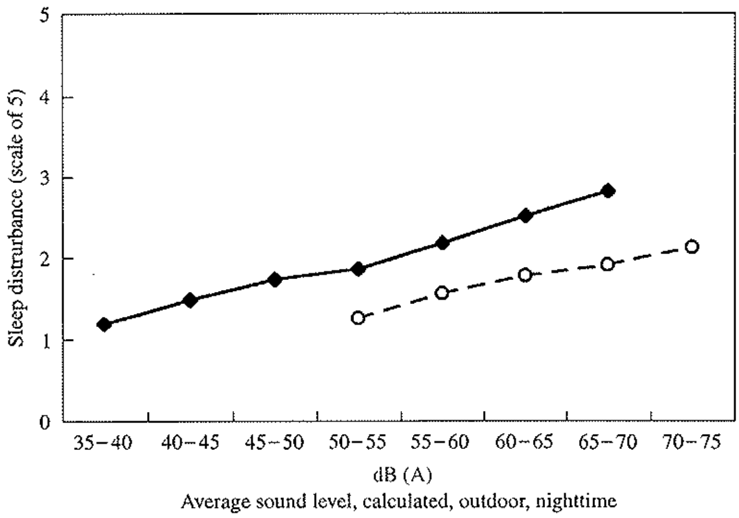


Figure 5. Source-specific sleep disturbance determined by interview, depending on the sound level: —◆—, sleep disturbance from road; --O--, sleep disturbance from rail.

whilst, in reverse, when road traffic noise predominates, 80–100% of respondents evaluate road traffic noise as more disturbing.

If the sleep disturbances determined from interviews are shown in a diagram (see Figure 5) over the average sound levels at night (summarized in noise level classes of 5 dB(A) width), two things can be noticed:

(1) the source-related disturbance determined from interviews increases steadily with the source-specific average levels at night for both road and rail subjects;

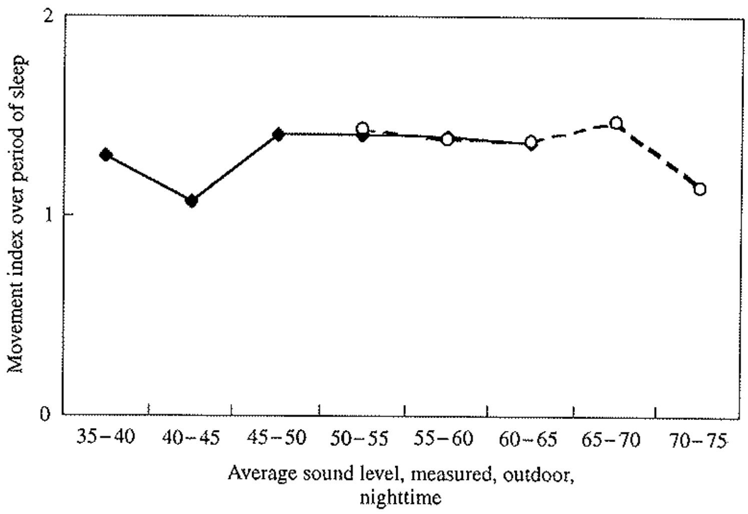


Figure 6. Measured disturbance of sleep depending on the sound level: —◆—, sleep disturbance from road; --O--, sleep disturbance from rail.

(2) the disturbance from road noise in a 5-level scale with the same average level is about 0·5–1 unit higher than for rail subjects, or, with the same disturbance, the average level of road traffic noise is about 3 sound level classes higher than that for rail traffic noise.

If the measured sleep disturbances are similarly shown over the noise level (see Figure 6) there is no dependence on the noise exposure. Similarly, there is no significant difference between sleep disturbances from railway and road noise.

## 5. SUMMARY ASSESSMENT

The results of the interdisciplinary evaluations basically show the following results:

— the differences found in earlier studies [1–3] between rail and road traffic noise in terms of night-time disturbance determined through interviews were confirmed; according to this, although the average sound level is the same, night-time disturbance from rail traffic is considerably less than the disturbance from road traffic noise;

— in contrast, the measurement of sleep movements using actimeters were unable to find any correlation between sleep movements and the noise nuisance from rail and road traffic noise. For this reason, it was also impossible to find any difference in the sleep reaction measured by actimeter for rail and road noise.

The reasons for this may possibly lie in the sound level range studied, which was relatively low in comparison with aircraft noise for which the actimeter method was successfully used [10].

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