COMPARATIVE EVALUATION OF SLEEP DISTURBANCE DUE TO NOISES FROM AIRPLANES, TRAINS AND TRUCKS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1. INTRODUCTION

This report provides an overview of the results on the comparative effects of disturbance by noises with different sound levels and from different sources of noise. It is one of the deliverables, to the Dutch Ministry of Housing, Planning and Environment, of the project titled *Comparative study of effects of train-, air- and road-traffic noises on sleep*. (Project number 511.153.01). The Dutch ministry financed the analysis and reporting of the data partially. Data collection took place at the University of Lund, Lund and this was financed by the Swedish Environmental Protection Board. For more detailed description of the results see previous reports of this project with the following topics:

- global and temporal variables of the sleep pattern;
- EEG arousals and awakening reactions;
- cardiac reactions.

1.1. OBJECTIVES

Our environment becomes more noisy every day. Not only during the day, but also during the night transport has to continue in order to fulfill the needs of society. The three main sources of noise during sleep are airplanes, trains and road traffic. Differences between the various sources of noise in the effect they may have hardly have been investigated. The few studies investigating multiple noise sources at the same time are either from different laboratories or are based on different subjects. It is, therefore, not easy to conclude whether the differences in the effects are a result of differences in methods and subjects or are due to differences in the sound characteristics of the noises.

The objective of the present study is to compare the sensitivity to sleep disturbance caused by three different noise sources: airplanes, trains and trucks

- in the same subjects;
- for the same peak noise level;
- with the same number of stimuli per night;
- with the same methodology and
- in the same measurement situation.

Another aim of the present investigation was to study whether a noise measure, frequency weighted according to the B-spectrum correlates better with the magnitude of the observed sleep disturbances than the A-weighted measure.

This study aims at answering the following questions:

- *Are there differences in the disturbance of sleep by stimuli from airplane, train and trucks?*
- *Is the disturbance of sleep by stimuli with a maximum level of 45 dB(A) different from that by stimuli with a maximum level of 65 dB(A)? Are these effects different for different sources of noise?*
- *What are the disturbing effects on sleep of different frequency characteristics of the sound of these noise sources (measured by the A- and B-weighting)?*

2. BACKGROUND

2.1. SLEEP, SLEEP DISTURBANCE AND ILLNESS

The sleep pattern can be measured by the electroencephalogram (EEG), the electroculogram (EOG) and the electromyogram (EMG). Roughly speaking the EEG has a high frequency (desynchronised) in the wake state and becomes slower during sleep with the slowest frequencies (synchronised EEG) during deep sleep.

The structure of sleep is characterised by the cyclic (around 90 minutes) alternation of REM-sleep (rapid eye movement sleep) and non-REM sleep. During REM sleep the EEG has a higher frequency, like in very light sleep or wake state, the muscle tone drops to almost zero and there are rapid movements of the eye, often occurring in bursts. Non-REM sleep has four stages:

- a transitional stage between sleeping and waking (stage 1), characterised by higher frequencies (desynchronised EEG);
- stage 2, also characterised by a desynchronised EEG (higher frequencies), the appearance of sleep spindles and K-complexes;
- stage 3, partly characterised by a synchronised (lower frequencies) EEG;
- stage 4, largely characterised by a synchronised (lower frequencies) EEG.

Stages 3 and 4 together are called deep sleep. Stages 1 and 2 are called light sleep. The awakening threshold for sound stimuli is not the same in the various sleep stages. In stage 3 and 4 the awakening threshold is highest and in stage 1 and 2 lowest (Bonnet and Moore, 1982). In REM-sleep the awakening thresholds are variable depending on several factors like the information value of the sound stimulus or the time of the night.

This cyclic alternation of 90 minutes occurs 4 or 5 times a night, depending on the total sleep time. The occurrence of the different sleep stages is not evenly distributed across the night. Deep sleep mainly occurs in the first half of the night, while the duration of the REM periods increases with increasing time of the night.

Sleep is a rhythmical process, but sleep itself is also part of the larger 24 or circadian rhythm of sleeping and waking. Circadian rhythms have been found in most of our physiological functions. Temperature and heart rate, for example, decrease during sleep and increase during the day. The periodic occurrence of physiological processes is a basic property of the adaptive nature of the organism. The importance of this periodicity follows from the fact that disturbances of sleep often become evident in the temporal structure of sleep. Also, sleep disturbances connected with psychiatric syndromes like depression or schizofrenia become evident in disturbances of the temporal structure of sleep (International Classification of Sleep Disorders).

Sleep has many functions like restoration of body and mind, instinctive protective behaviour, pleasure, energy conservation etc. The relative importance of these functions and the mechanisms behind these functions are not yet clear. In any case both body and mind are restored during sleep (Horne, 1988).

A disturbance of sleep interferes with the restorative function of sleep. A disturbed sleep may manifest itself during the day in one or more of the following:

- a feeling of tiredness or lower well-being;
- poor performance;
- disturbed circadian rhythm;
- increased irritability.

The chances for the above effects depend on the amount and the type of sleep disturbance and how a person copes with the situation. A disturbance of sleep by something unwanted and unpleasant has more effect than when sleep is disturbed by something expected or pleasant.

In the literature the following disturbances of sleep are considered as harmful to health:

- awakening during the sleep period;
- disturbance of the rhythmicity of sleep;
- a reduction of the amount of deep sleep;
- changes in heart rate.

A direct pathological relation between sleep disturbance and medical problems is difficult to ascertain. But there are clear evidences of sleep disturbance as a marker of psychological or psychiatric problems.

Moreover disturbed sleep leads to poor functioning, and poor functioning and dissatisfaction during the day lead to bad sleep on the following night. A persistence of such cyclic interaction for a longer time may lead to poor health. Moreover it leads to many economical and social losses (for example accidents) because of sleepiness during daytime (Mitler et al., 1988).

Heart rate normally decreases during the night. Also it was found that sleep stages have a modulating effect on heart rate. Verrier (1988) concluded in a review on effects of sleep on cardiavascular disorders that "Slow Wave Sleep appears to result in a moderate antiarrythmic effect in some subjects". Disturbed sleep is manifested in either more awakenings or reduced slow wave sleep. It can therefore be easily postulated that with a persistance of disturbed sleep, the chances that the cardiovascular system does not get enough quiet periods become high. Long-term persistence of disturbed sleep is associated with a persistent state of the feeling of tiredness. Persistent tiredness and complaints of poor-sleep may lead to symptoms of 'vital exhaustion'. Vital exhaustion is shown to be a potential risk indicator for future myocardial infarction (Van Diest, 1993).

Disturbing influences on sleep can be measured during the night by means of physiological variables like EEG and ECG and after awakening in the morning with psychological variables like the subjective sleep quality, mood and performance measures.

Several variables can be measured in the sleep EEG:

- **global variables** of the sleep pattern (sleep latency, number of awakenings after sleep onset, sleep stage changes, amount of time in the various sleep stages and sleep efficiency or time asleep divided by time in bed);
- variables of the **temporal structure of sleep** (temporal distribution of deep sleep, temporal distribution of REM sleep);
- stimulus related **arousal reactions**.

In the ECG during sleep can be measured:

- global changes in heart rate;
- stimulus related reactions in heart rate.

Awakening after sleep onset is an important variable as it is probable that this can be remembered after final awakening in the morning. Moreover, the continuity of sleep also seems to be of importance for the restoration of the organism. The sleep continuity theory (Bonnet, 1986; Downey and Bonnet, 1987) states that the continuity of sleep (at least 10 minutes of uninterrupted sleep) is more important for the restoration of the human organism than the total sleep time or the amount of time in the various sleep stages.

2.2. EFFECTS OF NOISE

Sounds from many different sources play a role in our daily life. When the sound is unwanted we call it 'noise'. During the day noise can disturb daily activities, whereas during the night, sleep can also be disturbed by noise. How disturbing the effect is of the sound stimulus depends partly on the attitude of the subject towards the stimulus. Control over the situation is an important factor (Glass and Singer, 1972; Lundberg and Frankenhaeuser, 1978; Jue, 1984). For example people living near an airport reported less annoyance by the aircraft sound when they felt they could influence the decisions concerning the airport and the direct environment.

Another factor is the predictability of the stimulus. When the occurrence of the sound can be predicted, the reactions are less strong than when the occurrence of the sound stimuli are unpredictable. But also the time of occurrence plays a role. For example, if a stimulus occurs in deep sleep it has less chance of awakening a subject than if the stimulus occurs in light sleep. Similarly if a stimulus occurs in the beginning of sleep when the subject is trying to fall asleep, it may cause more annoyance and the subject might remember the disturbance in the morning.

The frequency of occurrence is also of importance, for example if a stimulus follows another stimulus quite closely than there is more chance of awakening because the previous stimulus might have changed deep sleep into light sleep.

Such factors complicate the interpretation and the comparison of results from different studies. In this study these factors were kept constant for different sources, so that the effects of different noise sources could be compared without intervening effects of these factors.

Moreover noise stimuli are of a transient nature, whereas various sleep parameters do not show immediate effects. For example, an awakening by a stimulus diminishes slow wave sleep at that moment, but slow wave sleep can be compensated by more slow wave sleep after the stimulus later on. Thus disturbance by one noise stimulus may not have a harmful effect, but if various stimuli occur after each other, the chance that slow wave sleep can be compensated are low. Even if slow wave sleep is compensated in the quiescent periods, the overall effect is the disturbance of the temporal structure of sleep. Such effects cannot be allocated to a specific stimulus. They can be studied by comparison of different conditions. It is also important to take into account the frequency and number of stimuli.

As in this study the lower sound level condition contained a larger amount of stimuli than the two high sound level conditions, we do not expect differences between the effects of the 45 dB(A) condition and those of the 65 dB(A) or 75 dB(B) condition.

2.3. NOISE PARAMETERS

The human auditory system is more sensitive for frequencies between 100 and 8000 Hz than for higher or lower frequencies. The correction of the sound level in decibels, for these differences in sensitivity of the auditory system, results in weighted sound level measures. The A-characteristic is used most often and the resulting A-weighted sound level is denoted as dB(A). In comparison with the A-weighted sound level the B-weighted sound level takes lower frequencies more into account.

The lower frequencies in the B-weighted sound travel more through matter (floor etc.) than the higher frequencies. They are thus difficult to insulate.

It is also postulated that the differences in reactions to noise from trains, airplanes and trucks might be due to the differences in the frequency characteristics. This study therefore compares noises with A-weighted sound-level with noises with B-weighted sound-level.

The equivalent sound level, L_{Aeq}, is the A-weighted sound level averaged over a certain period. The distribution parameters like L_1, L_{10}, L_{90} etcetera are used to indicate the sound level which is present during 1 percent, 10 percent or 90 percent of the time respectively. Thus L_1 is an approximation of the maximum sound level.

These parameters depend upon the time chosen for the analysis. For example if there is continuous traffic of vehicles on a road and L_1 is measured for a period of the whole night, then L_1 can not be a good approximation of the maximum sound level of stimuli generated by the passing vehicles.

The traffic density during a night is generally not the same for different types of traffic (air, rail and road). Moreover, the traffic is also not uniform during the night. Therefore the parameters L_1, L_{10} etcetera are not a good indicator of the noise load of the sound stimuli.

L_{Amax} is used to characterise sound peaks. It is the maximal value of the sound level (for instance during the passage of an airplane) averaged for 0.125 or 1 second. The maximum sound level of the stimuli from airplane, trains and trucks were made equal in this study. Also, the frequency and pattern of occurrence of stimuli was kept constant in this study. This allows us to compare the effects of noise source separately without confounding factors like traffic density or time of measurement.

3. METHODS

3.1. DESIGN OF THE STUDY

For every noise source 50 stimuli were presented during sleep with a maximum sound level of 45 dB(A) and 15 stimuli with a maximum sound level of 65 dB(A). During 2 extra nights also 15 train and 15 airplane stimuli were presented with a maximum sound level of 75 dB(B). The following procedure was used in order to equalise exposure according to dB(B). With the noise level adjusted to 65 dB(A) in the bedroom, the average sound level of truck noise, airplane noise and train noise were measured in dB(B). The noise level in dB(B) for truck noise was 75 dB(B), for airplane noise 69 dB(B) and for train noise 71 dB(B). These were amplified to 75 dB(B) to match the maximum level of the truck noise.

Seven male subjects, aged 20-30, participated in the investigation. They were healthy and had normal hearing. Every subject was measured for 9 consecutive weeks, two days a week. This design was chosen to avoid adaptation to the noise. The complete first week and the first measurement night of every week were meant as adaptation nights to enable the subjects to get used to the laboratory situation.

3.2. PROCEDURE

3.2.1. Collection of stimuli

The noise was measured with a portable Bruel & Kjær noise meter model 2204. The truck noises were recorded about 10 meters from a motor way with a speed limit of 70 km per hour. The recordings were performed during the late evening hours, thus enabling the recording of isolated truck passages.

The noises of airplanes taking off were recorded at different sites around the airport of Copenhagen 300-400 meters from the take-off air-strip. Both the sounds of propeller planes and jet planes were recorded.

Train noises were recorded about 50 meters from a railroad. The sounds of short, local trains, inter-city trains and goods trains were recorded. The approximate estimated train speed was 70 km per hour.

Train and airplane noise were recorded on a Nagra portable tape recorder, whereas a Tandberg model 11 tape recorder was used for truck noises. After inspection of the recordings, about 10 different stimuli of each traffic type were copied onto cassette tapes (using Dolby noise reduction) for reproduction in the sleep laboratory. The modulation-depth for each stimulus was adjusted to give equal reproduction peak sound levels for all stimuli on a cassette.

The mean duration of the 10 different stimuli of each of the three noise sources are given below.

Table 1. Duration of stimuli in different conditions.

	Airplane			Train			Truck	
	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)
Mean in sec's.	24.7	32.5	36.0	12.4	20.1	14.8	12.9	17.43
Standard dev.	11.35	14.26	19.12	9.57	14.82	10.49	6.20	9.6
Reference level	37 dB(A)	52 dB(A)	62 dB(B)	37 dB(A)	52 dB(A)	62 dB(B)	37 dB(A)	52 dB(A)
No. of stimuli	240	50	84	227	86	82	211	86

39 48 59 34 47

Leq

The duration of the stimulus was measured from a reference level. This level was determined by the dynamic range of the measurement equipment. In all conditions the airplane stimuli had a higher duration than the train or truck stimuli.

3.2.2. Presentation of stimuli

Noise stimuli were presented quasi-randomly during the night through 2 loudspeakers (Tandberg) positioned on either side of the window. When 50 stimuli were presented during the night, the time interval between stimuli was on average 9 minutes. In the case of 15 stimuli per night, the time interval was on average 30 minutes. The first stimulus was presented 10 minutes after lights out. A computer program generated a quasi random sequence for the presentation of each type of traffic and number of stimuli per night.

3.2.3. Signals measured

The following signals were recorded: 2 bipolar electrooculogram (EOG) derivations with electrode placements symmetrically lateral of the eyes on the Zygotic bone, 2 electroencephalogram (EEG) derivations (C3-A2 and C4-A1), 2 submental electromyogram (EMG) derivations, electrocardiogram (ECG) and the noise level in dB, measured at about 1 m from the subjects head.

3.2.4. Subjective sleep quality measurements

Each morning the subjective sleep quality was measured with the help of a questionnaire. The sleep quality was measured in two different ways:

- an absolute judgement of the sleep quality of the previous night (measured by an analogue scale);
- a judgement of the sleep quality of the previous night relative to the sleep quality of the night before (measured by an analogue scale).

On experimental nights the second measurement provided a measurement of the sleep quality as compared with the quiet night before. In this report only the relative sleep quality measurements were taken into consideration, as this gave a better indication of changes in the sleep quality.

3.2.5. Recording apparatus

All electrophysiological signals, obtained from Ag-AgCl electrodes, were fed into differential preamplifiers (Oxford Medical Systems) which were mounted on the head close to the electrodes. This arrangement reduced artefacts in the recordings. The symmetric EOG electrode placement should reduce EEG artefacts entering into the EOG. The amplified signals were lead to the apex of the head in order to ensure as much moving freedom as possible for the subjects, and fed into main amplifiers (Johne & Reilhofer). The EMG signals were rectified and slightly integrated.

The sound level was recorded with a Bruel & Kjaer 2204 sound level meter with the 'fast' time constant. The DC output from the sound level meter was fed into a linear to logarithmic converter (home made construction) which was connected to an amplifier (J & R). For the first half of the experimental series all signals were after time division in conjunction with pulse code modulation (PCM) (Johne & Reilhofer Multi-din system) recorded on one track of a 4-track portable PCM recorder (Stellavox). For the low tape speed used, the bandwidth of the system was 2-25 Hz (-3 dB).

3.3. ANALYSIS

All data were digitized. The EEG signal was used for the classification (with the help of the eye movements (EOG) and the muscle tone (EMG)) into sleep stages and for the analysis of the arousal reactions on the stimuli. The ECG was used to study the changes in heart rate as a reaction on the noise stimuli.

3.3.1. Electroencephalogram

The EEG was analyzed automatically with the help of The Sleep Analyzer (Kumar et. al, 1981 en Campbell et. al, 1980) and classified into sleep stages, based on the standard criteria of Rechtschaffen and Kales (1968). The first occurrence of sleep stage 2 was the time of onset of sleep.

From these data various parameters were calculated that could give an indication of possible disturbances of sleep. These parameters are:

Global parameters of a night:

- **Total sleep time TST**: time in minutes from the onset of sleep till the last awakening;
- **Wake after sleep onset WASO:** total time in wake stage in minutes;
- **Latency to REM:** time from sleep onset till the first occurrence of REM-sleep;
- **Latency to Slow Wave Sleep:** time from sleep onset till the first occurrence of stage 3 or 4;
- **Percentage REM sleep:** total time in minutes spent in REM sleep, relative to the total sleep time;
- **Percentage Slow Wave sleep:** total time in minutes spent in stage 3 and 4, relative to the total sleep time.

Temporal parameters of a night

Both slow wave sleep (SWS) and REM sleep have a distinct temporal structure with an ultradian periodicity and they are supposed to be a manifestation of the main temporal characteristic of sleep. Therefore the changes in the temporal structure of SWS and REM were analyzed. The total durations of SWS and REM sleep per hour were calculated. Only the first six hours of the night were used because the inter-individual variance in the last two hours is very high, due to incomplete hours and/or to the almost total lack of slow wave sleep.

Arousals caused by the noise stimuli

Reactions on individual noise stimuli were analysed by the detection of arousals in the EEG. The occurrence of a stimulus was semi-automatically detected by calculating the value of L_{75} per epoch. A computer program marked epochs with a L_{75} value above the background sound level. One trained judge verified each occurrence of the stimulus. For all calculations, 1.5 minutes before and 1.5 minutes (including the stimulus epoch) after the stimulus were used as the pre- and post-stimulus period respectively.

Two methods were used to analyse responses to the sound stimuli: visual classification of arousals and automatic classification of EEG arousals.

In the method of visual classification the changes in EEG and EOG were classified in four categories:

- **Class 0**: no reaction;
- **Class 1**: short duration arousals (high-frequency, high-voltage activity) in the EEG;
- **Class 2**: a change from deep sleep or REM sleep to light sleep;
- **Class 3**: awakening.

The awakening reactions were corrected for the existence of a pre-stimulus wake stage. The probabilities for post-stimulus awakening reaction were compared with the probabilities of pre-stimulus awakening.

The second method was based on fully automatic analysis of the EEG. This method is not subject to any bias or error that may adhere to the first method of visual classification of arousals.

The Sleep Analyzer determines the absence or presence of different frequencies in EEG above a threshold. A ratio of the average duration of alpha and beta in the pre-stimulus period to the average duration of alpha and beta in the post-stimulus period was calculated. An increase of post-stimulus alpha and beta by a factor of two was defined as EEG arousal. For each stimulus, two measures were calculated:

- EEG arousal, a dichotomic variable (1: EEG arousal, 0: no EEG arousal);
- Intensity of EEG arousal (Log10 of the ratio multiplied by 100).

In order to establish the validity of the arousal reactions on the stimuli, pseudo-reactions were calculated in quiet nights. One quiet night from each subject was analyzed to classify pseudo-reactions. Using the random-number list of the presentation time of stimuli, in the 45 dB(A) and the 65 dB(A)/75dB(B) condition, a pseudo-stimulus was marked and arousal reactions were classified according to the method described in the previous sections. The probability of the occurrence of arousal reactions (awakening and EEG arousal) in the quiet nights was then calculated.

Statistics

The global parameters and the temporal parameters of the EEG were statistically analysed with analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) for repeated measures respectively. These analyses were done for the comparison between the nights with noise and the nights without noise, as well as for the comparison between the nights with various sources of noise. Also within each noise source a comparison was made between the 45 dB(A), the 65 dB(A) and the 75 dB(B) sound level condition.

The overall difference in the visual as well as the EEG arousal reactions between the conditions was tested with the Pearson Chi-Square statistics. All conditions were also compared in a pair-wise fashion by calculating a relative risk ratio of occurrence of awakening reactions or EEG arousals. The significance of the relative risk ratio was tested with the Pearson Chi-Square statistics. The reliability of the awakening reactions was tested by comparing the poststimulus awakening reaction to the awakening reaction in pre-stimulus control period, according to a method described by Miettinen (1969). Each stimulus acted as its own control. A chi-square test, with 1 degree of freedom, can be calculated on the probabilities of a reaction in 'case' and 'control' condition.

3.3.2. ECG

The digitized ECG signal was automatically processed and the occurrence of an R-wave was determined. The R-wave was detected by means of an adaptive threshold procedure. A mean value of the heart rate per epoch together with the location of the stimuli were plotted on a hypnogram for each night. Subsequently, nine epochs around each stimulus were evaluated visually for the accuracy of heart-rate detection.

A window was defined to determine the cardiac reponse on the sound stimulus. This window was separated in two periods:

- a pre-stimulus period of 60 beats which was at least 10 beats before the start of the rising slope of the stimulus;
- a response period of 90 beats which was started from the start of the rising slope of the stimulus.

The starting point for each stimulus was manually chosen at the beginning of the rising slope of the stimulus.

Similarly a pre-stimulus period was selected manually. The purpose was to select a pre-stimulus period which was as close as possible to the post-stimulus period and did not contain extreme values due to errors in the detection of the R-wave. The pre-stimulus period represented the base-line heart rate from the same part of the night and from the same stage.

The baseline of the heart rate was calculated as the mean heart rate in beats per minutes over the pre-stimulus period. The cardiac response was defined as the maximum increase in the heart rate from the mean of the baseline heart rate in the pre-stimulus period (converted to Z-values).

3.3.3. Analysis of the subjective sleep quality

The analogue scale of the relative subjective sleep quality was statistically analysed with analysis of variance (ANOVA) and t-tests for related measures. These analyses were done for the comparison between the nights with noise and the nights without noise, as well as for the comparison between the nights with various sources of noise. Also within each noise source a comparison was made between the 45 dB(A), the 65 dB(A) and the 75 dB(B) sound level condition.

4. RESULTS OF GLOBAL EEG VARIABLES

The mean and standard deviations of the overall sleep parameters are shown in table 2.

Table 2 **Mean values (standard deviation in parentheses) of the overall parameters of sleep in different conditions.**

	Airplane			Train			Truck		Quiet
	45dB(A)	65dB(A)	75dB(B)	45dB(A)	65dB(A)	75dB(B)	45dB(A)	65dB(A)	35dB(A)
Total sleep time in minutes	**438.6** (31.45)	**441.2** (16.22)	**442.5** (30.04)	**389.6** (62.25)	**444.9** (11.11)	**455.42** (21.34)	**429.1** (43.46)	**426.5** (34.24)	**443.5** (33.3)
Wake after sleep onset in minutes	**8.1** (8.30)	**12.7** (12.25)	**7.9** (4.82)	**12.3** (17.37)	**8.3** (8.17)	**15.3** (8.81)	**9.5** (5.57)	**23.1** (26.54)	**5.8** (7.78)
Percentage REM sleep	**18.3** (5.06)	**17.08** (2.86)	**18.0** (3.52)	**17.0** (4.46)	**20.6** (5.93)	**13.9** (4.11)	**18.5** (4.05)	**16.9** (4.64)	**17.2** (5.95)
Percentage SWS	**21.92** (9.19)	**18.75** (13.14)	**21.9** (6.08)	**17.9** (9.00)	**17.0** (6.71)	**18.7** (9.20)	**17.4** (7.87)	**16.6** (6.24)	**20.7** (6.33)
Latency to SWS in minutes	**15.0** (16.31)	**12.7** (11.31)	**13.1** (14.47)	**13.5** (12.32)	**13.9** (11.61)	**16.5** (12.25)	**13.6** (7.61)	**17.3** (10.44)	**17.3** (13.11)
Latency to REM in minutes	**33.2** (21.93)	**44.7** (12.64)	**52.4** (57.88)	**34.2** (19.56)	**39.2** (17.65)	**34.5** (24.03)	**32.7** (9.07)	**42.6** (14.74)	**53.3** (40.96)
Number of subjects	7	6	7	7	6	7	7	7	7

Comparison beween the noise sources

Differences between the noise sources became visible in the higher sound level conditions. In the 45 dB(A) condition there was no difference between the three noise sources. In the higher (65 dB(A)) condition a difference was found between the noise sources in the percentage of slow wave sleep ($F=3.6$, $p<.02$) and the number of minutes awake after sleep onset (WASO) ($F=3.1$, $p<.03$). After the exposure to truck noise the number of minutes awake after sleep onset was highest and the percentage slow wave sleep lowest. The exposure to train noise had less effect than the exposure to truck noise, while in the condition of airplane noise WASO was lowest and percentage of slow wave sleep was highest.

In general in this study in which for each noise source stimuli were used with the same sound level and the same number of stimuli airplane noise had less effect on the global parameters of the EEG than train or truck noise.

Comparison between the noise conditions and the quiet condition

The effects in each noise condition were compared with the effects in the corresponding quiet condition with a paired t-test. The resulting t-values are shown in Table 3.

Table 3. **T-values of the comparison of noise sources with the quiet condition. 1-tailed significance values were used, except for REM sleep. p-values of 0.06 or less are given in bold.**

Source	Level	N	Total SleepTime	Wake after sleep Onset	REM sleep	Slow Wave Sleep(SWS)	Latency to SWS	Latency to REM sleep
	45 dB (A)	7	-0.21(p=0.42)	0.60(p=0.28)	0.94(p=0.38)	0.22(p=0.42)	-0.63(p=0.28)	-0.95(p=0.19)
Airplane	65 dB (A)	6	-0.15(p=0.44)	**3.02(p=0.01)**	-0.54(p=0.30)	-1.20(p=0.14)	-1.55(p=0.09)	-0.70(p=0.26)
	75 dB (B)	7	-0.04(p=0.48)	1.11(p=0.15)	1.58(p=0.16)	0.35(p=0.37)	-0.93(p=0.20)	-0.10(p=0.46)
	45 dB (B)	7	-1.63(p=0.07)	0.87(p=0.21)	-1.43(p=0.20)	-1.65(p=0.07)	-1.06(p=0.16)	-1.06(p=0.16)
Train	65 dB (A)	6	0.54(p=0.31)	1.70(p=0.07)	2.19(p=0.08)	-0.90(p=0.20)	-0.92(p=0.40)	-0.70(p=0.26)
	75 dB (B)	7	0.66(p=0.26)	**3.12(p=0.01)**	-1.94(p=0.1)	-0.61(p=0.28)	-0.16(p=0.49)	-0.85(p=0.21)
Truck	45 dB (A)	7	-1.25(p=0.13)	1.02(p=0.17)	0.45(p=0.67)	-0.94(p=0.19)	-1.12(p=0.15)	-1.33(p=0.23)
	65 dB (A)	7	**-2.10(p=0.04)**	**1.82(p=0.06)**	-0.39(p=0.71)	**-2.35(p=0.03)**	-0.03(p=0.49)	-0.65(p=0.27)

When we compare the separate noise conditions per noise source with the quiet condition the following was found:

- In the 45 dB(A) condition no difference was found in the sleep parameters with the quiet condition for all noise sources;
- In the 65 dB(A) condition there was an increase in number of minutes awake after sleep onset after the exposure to airplane noise. After truck noise more WASO, a longer total sleep time and less slow wave sleep were found compared with the quiet condition. After the exposure to train noise a trend was found towards more WASO than in the quiet condition;
- In the 75 dB(B) condition after train noise more WASO was found than in the quiet condition.

The intensity of the stimuli of 45 dB(A) was not strong enough to cause a substantial amount of disturbance of the global EEG parameters. As will be shown later in chapter 6 exposure to the 45 dB(A) stimuli did cause arousals in the EEG. Also in the higher sound level conditions the effects on the global EEG parameters were not very strong. It is important to remember, however, that only 7 young and healthy subjects participated in this study.The fact that effects were found, despite these points is important enough. Also it is possible that, because the number of stimuli in the higher sound level conditions was not very high, there was more time between the stimuli to compensate for the disturbance.

Comparison of the sound level conditions

No differences were found between any of the sound level conditions within a noise source. This means that adjusting the sound level of 65 dB(A) stimuli to the B-spectrum did not have an effect. The result that no difference was found between the condition with 50 stimuli of 45 dB(A) and the higher sound level conditions with 15 stimuli was not unexpected. It is possible that the higher number of stimuli in the low sound level condition acted as a compensation for the fewer stimuli with a higher sound level.

5. RESULTS OF TEMPORAL EEG VARIABLES

Slow wave sleep and REM sleep are the two most important variables of interest for the study of the temporal structure of sleep.

5.1. TEMPORAL DISTRIBUTION OF SLOW WAVE SLEEP

The total duration of slow wave sleep per hour for the first six hours of each night was calculated (see table 4 and figure 1). The differences between the various conditions and the quiet condition were tested with MANOVA for repeated measures using the first six hours of slow wave sleep and with subsequent ANOVAs.

Table 4. Mean minutes in slow wave sleep per hour for the first six hours of sleep.

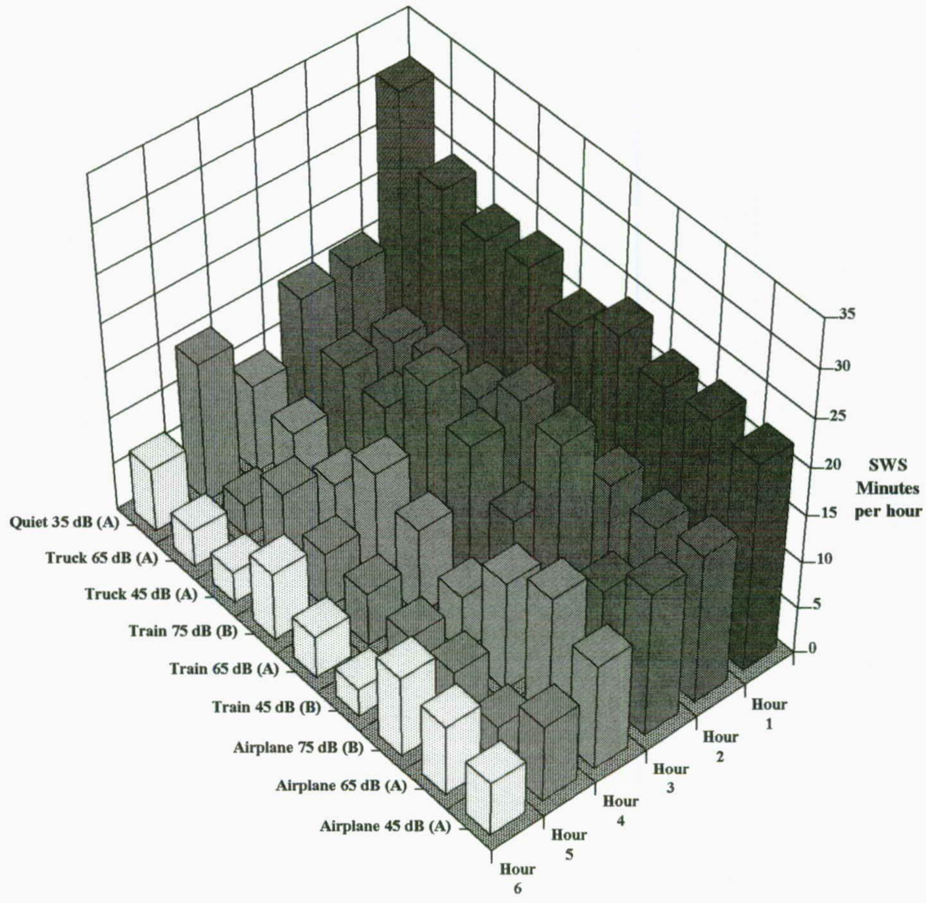
			Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6
Source	**Level**	**N**	Mean (sd.)	Mean (sd.)	Mean (sd.)	Mean (sd.)	Mean (sd.)	Mean (sd.)
Airplane	45 dB (A)	7	22.21 (13.60)	16.00 (13.60)	15.43 (6.45)	11.29 (6.87)	8.36 (9.19)	5.93 (4.59)
	65 dB (A)	6	22.83 (14.50)	14.83 (10.82)	11.50 (12.75)	14.25 (14.75)	3.92 (5.05)	7.67 (7.03)
	75 dB (B)	7	22.29 (9.56)	15.43 (8.94)	22.93 (10.52)	11.71 (10.36)	5.57 (5.92)	8.57 (7.30)
Train	45 dB (B)	7	23.93 (12.59)	14.14 (14.13)	10.93 (9.65)	6.07 (5.57)	5.14 (9.53)	3.00 (4.57)
	65 dB (A)	6	21.17 (9.94)	16.58 (8.15)	15.00 (12.88)	9.33 (4.83)	5.75 (5.89)	4.50 (6.16)
	75 dB (B)	7	23.57 (12.31)	13.00 (9.89)	17.64 (14.74)	11.43 (11.67)	6.07 (5.51)	7.29 (7.69)
Truck	45 dB (A)	7	22.86 (11.74)	13.14 (5.98)	11.43 (10.19)	6.29 (6.32)	8.57 (8.42)	3.36 (3.11)
	65 dB (A)	7	24.57 (10.87)	11.64 (7.30)	12.00 (8.02)	8.07 (9.43)	3.43 (4.76)	3.86 (5.44)
Quiet	35 dB (A)	7	31.21 (9.11)	15.93 (11.04)	15.71 (10.01)	9.43 (8.85)	14.93 (16.52)	6.71 (5.27)

The information given in this table is also illustrated in figure 1 in order to give an impression of the dynamical changes in slow wave sleep over a night in the different conditions.

The temporal characteristics of SWS over the night follows closely the ultradian NREM-REM periodicity, but with a declining amount of SWS as the night advances.

The cyclicity of SWS over a night can be described by different trends. The first (linear) trend gives an impression of the speed of the decline of SWS over the night. Higher trends give an impression of the cyclicity of slow wave sleep over the night. Disturbances of the temporal characteristics of SWS can become visible in changes in the speed of decline as well as in changes in the cyclicity over the night.

Figure 1. Temporal distribution of slow wave sleep in all conditions.



Comparison of the noise sources

In the first hour not many difference in the amount of slow wave sleep were found between airplane noise and train noise, but from the second hour onwards the amount of slow wave sleep was lower during train noise than during airplane noise ($F=7.21$, $p<.05$). No other significant differences were found between the noise sources. It can be concluded that again airplane noise showed the smallest effect.

Comparison of the noise conditions with the quiet condition

For all noise sources in the 45 dB(A) condition less slow wave sleep was found in the first hour and the decline of slow wave sleep over the night was less steep compared with the quiet condition (see figure 1). After truck noise also a difference was found in the cyclicity of SWS over the night, indicating a disturbance in the temporal structure of slow wave sleep over the night.

In the 65 dB(A) condition of train and truck noise less slow wave sleep was found in the first hour of sleep and the decline of slow wave sleep over the night was less steep than in the quiet condition.

In the 75 dB(B) condition no difference was found between the noise conditions and the quiet condition.

Exposure to the 45 dB(A) stimuli and the 65 dB(A) stimuli caused, when compared with the quiet condition, a disturbance of the temporal characteristics of slow wave sleep.

Comparison of sound levels: the 65 dB(A) condition as compared with the 75 dB(B) condition

No difference was found between the 75 dB(B) and the 65 dB(A) condition, indicating that adjustment of the 65 dB(A) sound level stimuli to the B-spectrum did not have an effect.

5.2. TEMPORAL DISTRIBUTION OF REM SLEEP

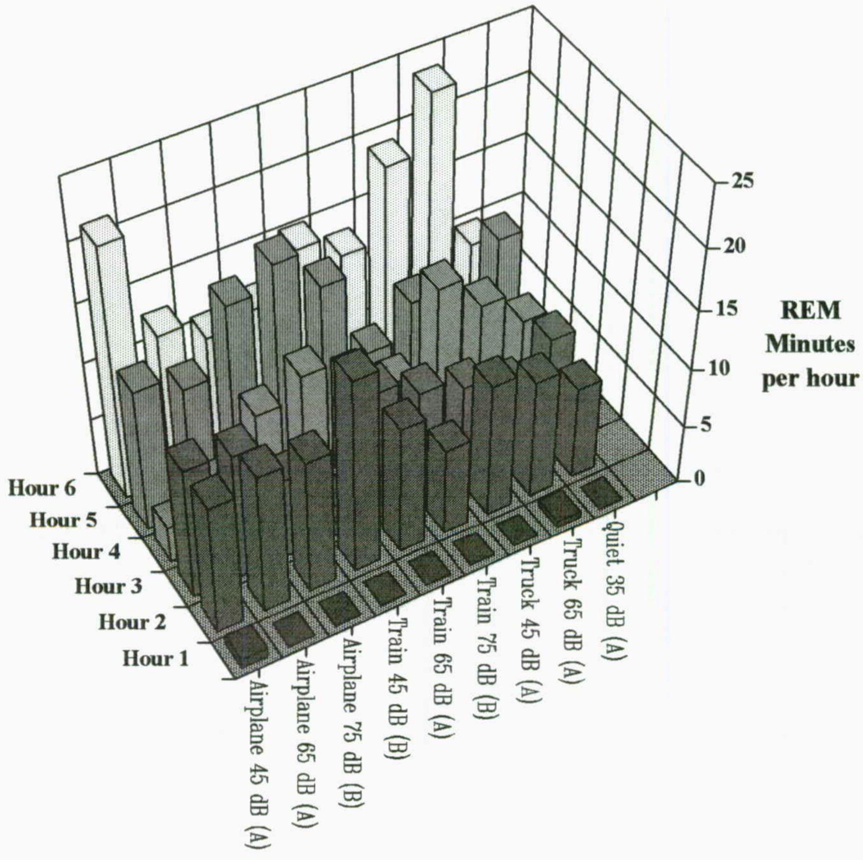
In the same way as for SWS the total duration of REM sleep per hour for the first six hours of each night was calculated (see table 5 and figure 2). The differences between the different conditions and the quiet condition were tested with MANOVA for repeated measures, using the first six hours of REM sleep, and subsequently with ANOVA's.

Table 5. Mean minutes in REM sleep per hour for the first six hours of sleep.

			Hour 1		Hour 2		Hour 3		Hour 4		Hour 5		Hour 6	
Source	Level	N	Mean	(sd)	Mean	(sd)	Mean	(sd)	Mean	(sd)	Mean	(sd)	Mean	(sd)
	45 dB(A)	6	0.79	2.08	11.29	8.76	11.36	11.16	3.21	5.21	12.21	9.69	21.36	19.16
Airplane	65 dB(A)	7	.00	.00	12.10	3.96	10.90	11.98	5.10	9.33	10.80	11.69	12.60	14.13
	75 dB(B)	7	.00	.00	11.57	9.36	7.00	6.22	9.79	9.63	16.21	8.88	10.86	10.75
	45 dB(A)	6	.00	.00	16.71	11.76	2.93	3.89	11.50	8.83	18.07	14.26	11.71	10.78
Train	65 dB(A)	7	.00	.00	11.00	6.20	11.17	16.08	9.67	11.11	14.75	6.19	15.25	14.83
	75 dB(B)	7	.00	.00	7.43	8.30	9.57	13.58	7.71	13.03	7.57	6.05	13.29	11.51
	45 dB(A)	7	.00	.00	11.36	8.02	8.43	7.97	14.14	20.05	10.36	7.78	19.14	10.11
Truck	65 dB(A)	7	0.57	1.51	10.07	7.35	6.93	9.76	11.21	15.39	8.07	8.56	23.64	13.12
	75 dB(B)	7	0.57	1.51	10.07	7.35	6.93	9.76	11.21	15.39	8.07	8.56	23.64	13.12
Quiet			.00		7.86	7.80	9.43	8.06	8.36	10.43	12.79	12.34	9.86	9.29
Grand Mean			0.16	.87	11.01	8.19	8.52	9.90	9.08	11.82	12.33	9.77	15.39	12.89

The information given in this table is also illustrated in figure 2 in order to give an impression of the dynamical changes in REM-sleep over a night in the different conditions.

Figure 2. Temporal distribution of REM sleep in all conditions.



The temporal distribution of REM sleep is opposite to that of slow wave sleep: the peak of REM sleep is found in the early morning, while in the beginning of the night only a small amount of REM-sleep is seen. The rise in REM sleep can be described by linear and polynomial trends. The linear trend gives an impression of the speed of the rise of REM sleep over the night. Disturbances in the rhythmicity or temporal characteristics of REM-sleep over the night can be described by higher order trends (2-4th degree).

Comparison of noise sources

After the exposure to train noise of 45 dB(A) sound level the temporal characteristics of REM sleep over the night were more disturbed than after truck noise of comparable sound level ($F=5.61$, $p<.05$). None of the other comparisons were significant. It can be concluded that the effect of the three noise sources on the temporal structure of REM-sleep over the nights did not differ.

Comparison of the noise conditions with the quiet condition

Taking into account the temporal sequence of REM sleep over the night, the *amount* of REM sleep per hour was less in the 45 dB(A) condition of all noise sources than in the quiet condition (F-value = 12.12 for airplane, 4.18 for train and 6.26 for truck noise, all significant for $p<.05$). This was also the case for the 65 dB(A) train condition ($F=6.73$, $p<.05$). A disturbance of the *temporal characteristics* of REM sleep over the night was only found in the 45 dB(A) airplane ($F=23.63$, $p<.002$) and train condition ($F=4.31$, $p<.04$).

The disturbance of the temporal structure of REM sleep, even if small, as well as of slow wave sleep is an important result. The temporal relationship between slow wave sleep, REM sleep and light sleep is a manifestation of an interaction between different neurochemical substances (McCarley, 1992). This neurochemical activity has its own physical characteristics (metabolic rate, decay times etc.). Therefore a disturbed temporal relationship means that the interaction between the activity of different substances is not optimal.

Comparison of the sound levels

Only the condition with train noise showed an effect of the adjustment of the maximum level to the B-spectrum: there was less REM sleep in the 75 dB(B) condition than in the 65 dB(A) condition ($F=4.09$, $p<0.05$), and the temporal structure was also disturbed ($F=5.80$, $p<0.05$). Less REM sleep per hour was also found when the 75 dB(B) condition was compared with the 45 dB(A) condition ($F=18.37$, $p<.003$).

It can be concluded that also for the variable REM sleep the adjustment of the 65 dB(A) stimuli to the B-spectrum did not have much effect.

6. RESULTS OF EEG AROUSAL REACTIONS AND AWAKENINGS

6.1. VISUAL AROUSALS

Percentages of reactions to the individual noise stimuli are listed in Table 6. As was explained in the method section (section 3.3.1) the arousal reactions were classified in 4 arousal classes ranging from 'No arousal' to 'Awakening'. A difference was found between the noise conditions in the way the arousal reactions were distributed over the 4 arousal classes (chi-square: 124.58, df=21, p=0.00).

Table 6. Distribution of arousal classes in different noise conditions.

	Airplane			Train			Truck	
	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)
Awakening.	13.3%	20.0%	34.5%	15.0%	27.9%	46.3%	14.7%	26.7%
Micro arousals	16.3%	20.0%	20.2%	18.9%	29.1%	19.5%	17.1%	18.6%
Change to light sleep	0.0%	6.0%	3.6%	1.8%	3.5%	3.7%	0.5%	8.1%
No reaction	70.4%	54.0%	41.7%	64.3%	39.5%	30.5%	67.8%	46.5%
No. of stimuli	240	50	84	227	86	82	211	86

The awakening reactions were compared with possible 'reactions' in the pre-stimulus control period to test their reliability. All awakening reactions proved to be genuine reactions (P<0.001). Chi-square test, according to a method by Eberhardt which is a modification of the method of Miettinen, was used.

If an awakening reaction in the post-stimulus period was associated with wake stage in the pre-stimulus period, then that awakening reaction was considered as no reaction. The figures in table 6 were also corrected according to this rule.

The percentage of awakening reactions in the three conditions 45 dB(A), 65 dB(A) and 75 dB(A) were similar to that found by other authors. Hofman (1991) showed, in a literature review, a positive relation between the maximal sound level and the probability of awakening, but the variability between studies was high. It was also found that the airplane data showed a larger variability than the studies using traffic noise stimuli.

Comparison of noise sources

To test the differences between the noise sources, the relative risks of awakening reactions in one condition compared to awakening reactions in the other condition were calculated in a pair-wise fashion.

Table 7. Relative risk of awakening reactions in different conditions. ***=p<.005, **=p<.01 and *=p<.05.

		Airplane			Train			Truck	
	Max level	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)
Airplane	45 dB(A)								
	65 dB(A)	0.67							
	75 dB(B)	0.38***	0.58*						
Train	45 dB(A)	1.08	1.62	2.80***					
	65 dB(A)	0.47***	0.71	1.23	0.44***				
	75 dB(B)	0.29***	0.43***	0.74	0.26***	0.60*			
Truck	45 dB(A)	0.94	1.41	2.43***	0.87	1.96**	3.28***		
	65 dB(A)	0.50***	0.67	1.29	0.46***	1.04	1.73**	0.53**	

The relative risk (RR) in a cell shows the risk of the occurrence of awakening reactions in the condition, shown at the top of the column, in proportion to the condition shown at the left of the row. An RR value greater than 1 means a higher risk for the condition at the top of the column, an RR value less than 1 means a lower risk.

In the lowest sound level condition of 45 dB(A) there was no difference between the three noise sources. In the 65 dB(A) condition airplane noise elicited somewhat more awakening reactions than train noise or truck noise, but the risk ratios failed to reach statistical significance. In the 75 dB(B) condition the exposure to truck noise resulted in the least number of awakening reactions. Airplane noise elicited more awakening reactions than truck noise, but less awakening reactions than train noise.

In the 45 dB(A) condition no difference could be found between the noise sources. The awakening reactions in the 65 dB(A) condition were more sensitive to the source of noise. However, it has to be concluded that a difference in sound level seems to be more important than a difference in noise source.

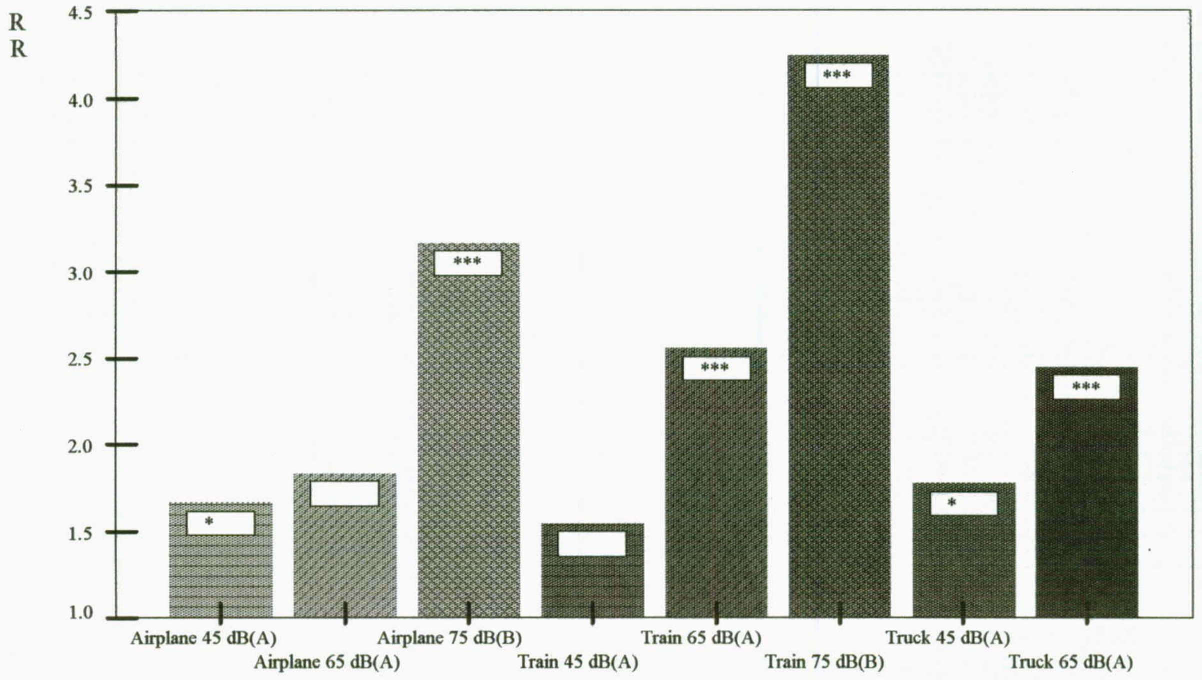
Vernet and Simmonet (1983) reported 18.5% probability of awakening for the train traffic and 15% for the road traffic. These results agree with our finding, indicating that within one night, train traffic did not cause less sleep disturbances than road traffic noise.

Comparison of the noise conditions with the quiet condition

Spontaneous awakenings do occur in normal sleep. It is then important to know what would be the normal percentage of awakening reactions in a quiet environment. For this reason visual arousals to pseudo-stimuli were classified in the quiet nights. In the quiet night matching the 45 dB(A) condition, the probability of the awakening reactions was 8.0% whereas in the quiet nights of the 65 dB(A) or 75 dB(B) condition the probability was 10.9%. Table 6 shows that in all sound level conditions the percentage of awakenings was higher than in the corresponding quiet conditions.

A relative risk (RR) of awakening in the noise conditions compared to that in the quiet nights was calculated (see figure 3).

Figure 3. Relative risk of awakening reactions in different conditions compared to quiet nights. *=p<0.05 and ***=p<0.005.



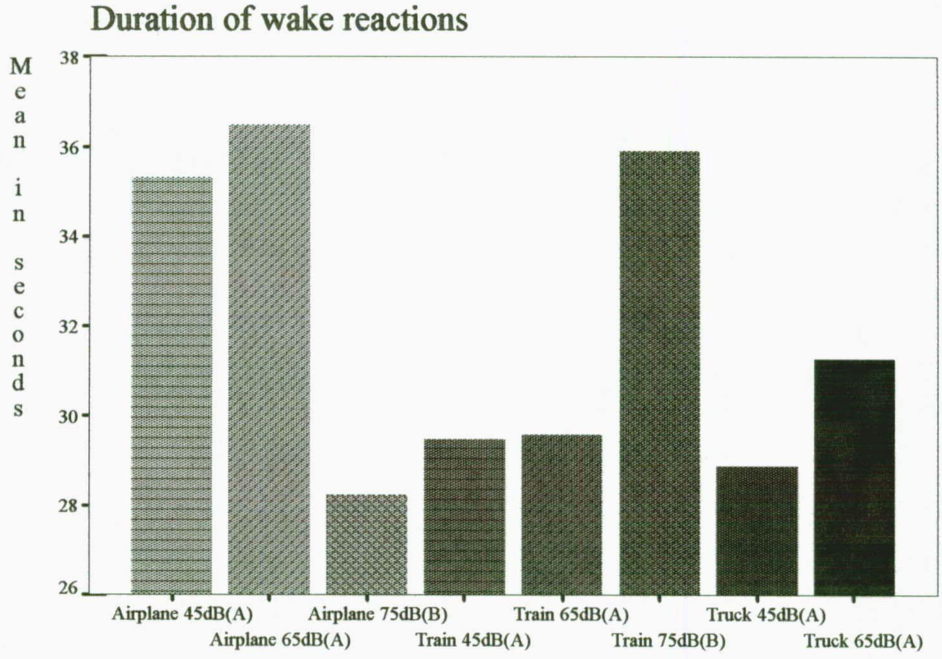
The values of the relative risk of occurrence of awakening in all noise conditions were higher than one, indicating that the awakening reactions as were found in the various conditions were reliable.

Comparison of the sound levels

Figure 4 shows the distribution of awakening reactions and the duration of those reactions in different conditions. It shows that the percentage of awakening reaction increased with increasing sound level, but the duration of the awakening reactions did not show such a clear relation.

The adjustment of the loudness to the B-spectrum (the 75 dB(B) condition) of the airplane stimuli and the train stimuli resulted in both cases in more awakening reactions than in the condition without adjustment (the 65 dB(A) condition). In both cases the risk ratios were statistically significant. It can be concluded from these results that when the difference in the lower frequency bands among the three noise sources is accounted for, the truck noise elicited less awakening reactions as compared with the airplane or the train stimuli

Figure 4. Distribution of the probability and the duration awakening reactions in different conditions.



For all noise sources there were more awakening reactions in the 65 dB(A) condition than in the 45 dB(A) condition:

- the airplane stimuli of 65 dB(A) maximal sound level elicited 33% more awakening reactions than the 45 dB(A) airplane stimuli. The risk ratio of .67 was not statistically significant;
- the train stimuli caused 56% more awakening reactions in the 65 dB(A) sound level condition than in the 45 dB(A) sound level condition (RR=.44, $p<.005$);
- the truck stimuli elicited 47% more awakening reactions in the 65 dB(A) sound level condition than in the 45 dB(A) sound level condition (RR=.53, $p<.01$).

The expectation that the stimuli with a sound level of 45 dB(A) might cause more reactions of minor importance like micro-arousals or sleep stage changes instead of awakening could not be confirmed convincingly.

6.2. EEG AROUSALS

As was already described in the methods section a second method was used to detect arousal reactions on the noise stimuli. This method was based on fully automatic analysis of the EEG and was therefore not subject to any bias or error that may adhere to the first method of visual classification of arousals.

For every stimulus a ratio of the average duration of alpha and beta (as determined automatically by The Sleep Analyzer) in the pre-stimulus period to the average duration of alpha and beta in the post-stimulus period was calculated. An increase of post stimulus alpha and beta by a factor of two was defined as EEG arousal.

The probabilities of the occurrence of EEG arousals and the mean intensity of EEG arousals are summarised in table 8.

Table 8. **Probability of occurrence of EEG arousals and the mean intensity of these arousals (standard deviation between parenthesis) in different conditions.**

	Airplane			Train			Truck	
	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)
EEG arousals.	29.6%	38.0%	50.0%	27.3%	52.3%	43.9%	24.2%	45.3%
Mean Intensity	2.69(.45)	2.84(.44)	2.69(.34)	2.75(.42)	2.69(.35)	2.67(.29)	2.79(.44)	2.79(.41)
No. of stimuli	240	50	84	227	86	82	211	86

The distribution of EEG arousals over the different conditions was different (Chi-square=46.8, df=7, p=0.000). The mean alpha+beta ratios did not show consistent differences between the conditions.

Each condition was compared in pair-wise fashion and a relative risk of occurrence of an EEG arousal was calculated. See table 9 for results. The relative risk (RR) in a cell shows the risk of the occurrence of EEG arousal reactions in the condition, shown at the top of the column, in proportion to the condition shown at the left of the row.

Table 9. **Relative risk of EEG-arousals in different conditions. ***=p<.005, **=p<.01 and *=p<.05.**

		Airplane			Train			Truck	
	Max level	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)	75 dB(B)	45 dB(A)	65 dB(A)
Airplane	45 dB(A)								
	65 dB(A)	0.82							
	75 dB(B)	0.59*	0.74						
Train	45 dB(A)	1.10	1.34	1.83					
	65 dB(A)	0.68*	0.61	0.95	0.51**				
	75 dB(B)	0.67*	0.82	1.14	0.61**	1.19			
Truck	45 dB(A)	1.22	1.48*	2.06**	1.11	2.16**	1.81**		
	65 dB(A)	0.65**	0.81	1.10	0.61**	1.15	0.99	0.53***	

Comparison of noise sources

More EEG arousal reactions were elicited by the train stimuli in comparison to the truck stimuli. Both in the 45 dB(A) and the 65 dB(A) conditions the difference between the probability of awakening by the train stimuli and by the truck stimuli was not statistically significant. The adjustment of the loudness of the train stimuli to the loudness of the B-spectrum did also not result in statistically significant RR-values in comparison to the truck stimuli. In general EEG arousals were less sensitive to noise source than awakening reactions.

Comparison of the sound levels

The effect of sound level on EEG arousals was similar to the effect on awakening reactions. For all noise sources the risk of the occurrence of an EEG arousal was higher in the 65 dB(A) and in the 75 dB(B) condition than in the 45 dB(A) condition. However, the difference between the 65 dB(A) and the 75 dB(B) condition was not statistically significant.

7. RESULTS OF THE ECG

7.1. VALIDATION OF RESPONSE PARAMETERS

As the heart rate is continuously changing it is important to be sure that the response was indeed caused by the stimulus and was not just an epiphenomenal aspect of normal changes in heart rate. Therefore the standardized response parameters ZRES (= maximum change in heart rate) and ZRESMAX (= maximum heart rate) were compared with a pre-stimulus period without sound stimuli. The results are shown in table 10.

Table 10. Parameters of the regression equation of the maximum change in heart-rate (ZRES) and of the maximum heart-rate (ZRESMAX) with the pre-stimulus variables.
- **B=coefficient of regression, SE-B= standard error of B**
- **t=t value, Sig-t= the probability of t**

Variable	B	SE-B	t	Sig-t
ZPremean	.110830	.060893	1.820	.0694
ZPre	.003129	.012085	.259	.7958
(Constant)	19.758181	3.422013	5.774	.0000
ZPremean	3.21	0.53	5.96	.000
ZPremax	-.13	0.12	-.0.863	.388
(Constant)	-59.59	23.6	-2.48	.013

The results of the analysis on both the maximum change in heart-rate and the maximum heart-rate are (table 10):
- the values of the cardiac response (ZRES maximum heart-rate minus the minimum heart-rate) have more variance than the maximum heart-rate (ZRESMAX);
- the mean and the maximum change in pre-stimulus period do not exhibit large variations except for a few outliers. It is therefore shown than the selected pre-stimulus values represent a quiescent part before the occurrence of a stimulus;
- the cardiac response (ZRES) is not dependent upon the pre-stimulus values (very low values of the coefficient). Therefore the response seems to be an effect of the stimulus instead of a result of normally occurring changes in the heart-rate at the time of occurrence of the stimulus;
- for the variable heart-rate increase (ZRESMAX) the coefficient of the regression equation had a high value. It is however possible that this is a result of low variation of both the maximum heart-rate (ZRESMAX) and the pre-stimulus values.

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- for the variable heart-rate increase (ZRESMAX) the coefficient of the regression equation had a high value. It is however possible that this is a result of low variation of both the maximum heart-rate (ZRESMAX) and the pre-stimulus values.

Table 12. Mean, standard deviation and paired sample t-test of the cardiac variables for each source of noise in the three sound level conditions.

	Source	Variable	Pre-stimulus controle Mean (St.dev.)	Post-stimulus response Mean (St.dev)	Paired samples t-test t	p	df
45 dB(A)	Airplane	Z_{res}	4.01 (0.60)	7.69 (7.90)	3.62	0.001	61
		Z_{resmax}	2.14 (0.75)	5.53 (7.02)	4.04	0.000	70
	Train	Z_{res}	4.09 (0.58)	7.28 (5.80)	6.79	0.000	149
		Z_{resmax}	2.01 (0.63)	4.35 (5.52)	5.86	0.000	164
	Truck	Z_{res}	4.03 (0.71)	7.48 (7.15)	4.79	0.000	100
		Z_{resmax}	2.09 (0.77)	5.84 (8.00)	5.06	0.000	116
65 dB(A)	Airplane	Z_{res}	4.02 (0.58)	5.45 (2.02)	2.52	0.033	9
		Z_{resmax}	1.92 (0.61)	2.76 (1.84)	1.76	0.109	10
	Train	Z_{res}	3.86 (0.87)	7.76 (5.07)	5.11	0.000	41
		Z_{resmax}	1.99 (0.68)	4.44 (3.83)	4.42	0.000	43
	Truck	Z_{res}	4.21 (0.66)	6.46 (3.34)	2.69	0.017	15
		Z_{resmax}	2.07 (0.47)	3.97 (3.09)	2.66	0.016	17
75 dB(B)	Airplane	Z_{res}	4.18 (0.96)	10.17 (7.89)	5.44	0.000	52
		Z_{resmax}	2.24 (1.05)	7.07 (7.07)	5.17	0.000	58
	Train	Z_{res}	4.04 (0.93)	6.08 (3.33)	4.33	0.000	49
		Z_{resmax}	2.07 (0.72)	3.62 (2.55)	3.90	0.000	50
	Truck	Z_{res}	4.21 (0.66)	6.46 (3.34)	2.69	0.017	15
		Z_{resmax}	2.07 (0.47)	3.97 (3.09)	2.66	0.016	17

Comparison between the noise sources

Figures 5 to 7 illustrate possible differences between noise sources.

In the 45 dB(A) condition the differences between the noise sources were not consistent for the two variables ZRES and ZRESMAX.

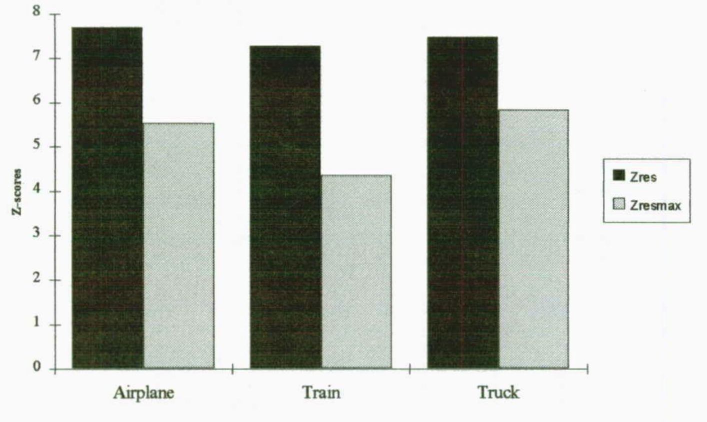

Figure 5. Values of ZRES and ZRESMAX after stimuli from the three noise sources in the 45 dB(A) level.

It is clear from figure 6 that also in the 65 dB(A) condition the differences between the noise sources were not consistent for the two variables ZRES and ZRESMAX.

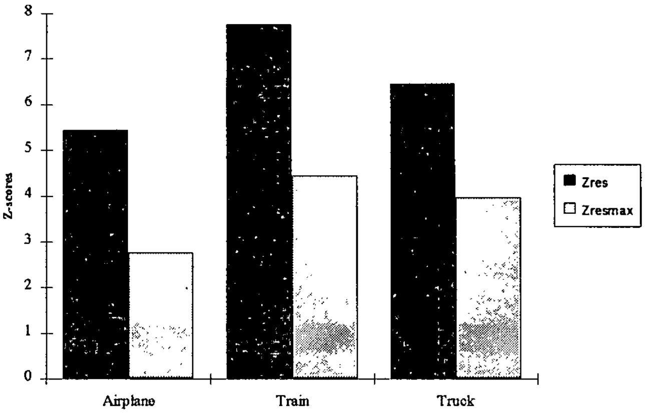

Figure 6. **Values of ZRES and ZRESMAX after stimuli from the three noise sources in the 65 dB(A) level.**

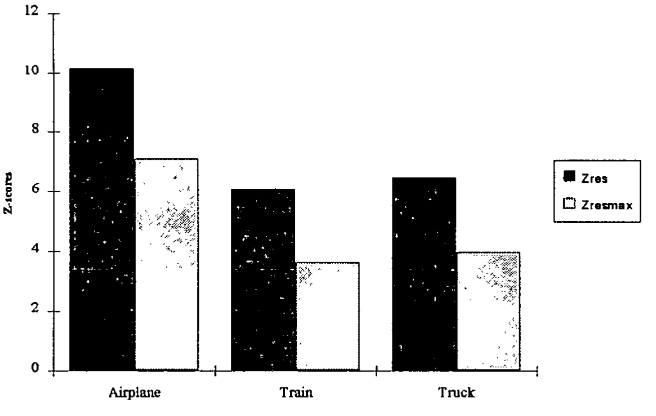

Figure 7. **Values of ZRES and ZRESMAX after stimuli from the three noise sources in the 75 dB(B) level.**

In the 75 dB(A) condition (figure 7) for both ZRES and ZRESMAX airplane noise elicited higher cardiac responses than truck noise and train noise, while the truck noise was more disturbing than train noise.

In general it has to be concluded that, although some difference was found between the three noise sources, this effect was not consistent over the sound level conditions and also hardly ever reached significance.

8. RESULTS OF THE SUBJECTIVE SLEEP QUALITY

The relative sleep quality scale asked about the sleep quality as compared with the preceding quiet night. As the scale was a 5 points scale the value of zero means 'the sleep quality is not different from the preceding night'. The values one and two mean 'the sleep quality is better/much better than the preceding quiet night' respectively, while the values of minus one and minus two mean 'the sleep quality is worse/much worse than the preceding quiet night' respectively.

Comparison of sound levels

The differences between the sound levels are shown in table 13.

Table 13. T-values and corresponding p-values of the t-tests for related measures of the comparison between the three sound levels within each noise source. Significant p-values are given in Bold.

	Sleep Quality relative to the quiet nights				
Sound Level	**Airplane**		**Train**		**Truck**
	45 dB(A)	***65 dB(A)***	***45 dB(A)***	***65 dB(A)***	***45 dB(A)***
65 dB(A)	t=1.2, p<0.15	-	t=-2.5, **p<0.02**	-	t=3.5, **p<0.01**
75 dB(B)	t=1.9, **p<0.05**	t=1.2, p<0.15	t=0.0, p<0.5	t=1.7, p<0.07	t=3.5, **p<0.01**

Both in train and in truck noise there was a significant difference between the 65 db(A) condition (15 stimuli) and the 45 dB(A) condition (50 stimuli). However, after exposure to the 65 dB(A) train stimuli the sleep quality, as compared with the corresponding quiet night, was judged as *higher* than in the 45 dB(A) condition, while after the 65 dB(A) truck stimuli the sleep quality was judged as *lower* than in the 45 dB(A) condition.

Adjustment of the maximum sound level to a signal with B characteristics did, in both airplane noise and train noise, not result in a significant difference.

Comparison of noise sources

The differences between the noise sources are shown in table 14.

Table 14. **Means of the sleep quality scores relative to the quiet nights in the three sound level conditions and the results of the variance analysis between the three noise sources. Standard deviations are given between brackets.**

	Source	Sleep Quality rel. to Quiet	F-values	p-values
45 dB(A)	Airplane Train Truck	0.00 (0.82) -0.57 (0.54) 0.57 (0.98)	6.02	<0.005
65 dB(A)	Airplane Train Truck	-0.43 (0.79) 0.14 (0.69) -0.67 (0.82)	1.97	n.s.
75 dB(B)	Airplane Train Truck	-0.16 (0.90) -0.57 (1.14) -0.67 (0.82)	0.16	n.s.

In the 45 dB(A) condition a difference was found between the effect of the noise sources. Truck noise was regarded as most disturbing for the subjective sleep quality in comparison with the quiet night and train noise was regarded as least disturbing for the subjective sleep quality in comparison with the quiet night.

In the 65 dB(A) condition and the 75 dB(B) condition no difference was found between the noise sources.

9. DISCUSSION

9.1. GLOBAL EEG PARAMETERS

In the 45 dB(A) condition the global EEG parameters did not show any difference with the quiet condition. In the 65 dB(A) condition the variable Wake after sleep onset (WASO) was more and, to a lesser extent, the percentage of slow wave sleep (SWS) and total sleep time (TST) was less than in the quiet condition. In the 75 dB(B) condition only WASO was more after the exposure to train noise.

The effects of noise on the overall sleep parameters were not very strong. This can be due to a number of reasons:

1. the dynamics of sleep stages were disturbed only to a limited extent so that a compensation in periods without stimuli was still possible;
2. the intensity of the stimuli of 45 dB(A) was not strong enough to cause a substantial amount of disturbance. This should however be interpreted in combination with the number of stimuli. We showed that even the 45 dB(A) stimuli caused arousals. This means that when the number of stimuli increased there would be less chance that disturbance due to stimuli is compensated;
3. the number of 65 dB(A) and 75 dB(B) stimuli was not very high so that there was more time between the stimuli to compensate for the disturbance.

The lower frequencies, as measured in the 75 dB(B) condition were not an important factor in comparing the effects of different noise sources on the global EEG paramaters.

The total amount of REM sleep was in the 75 dB(B) condition less in the case of train noise than in the 65 dB(A) condition. The other parameters did not show any difference between the two sound levels.

The comparison of the effects of the three noise sources revealed that in general train noise and truck noise were more disturbing than airplane noise. Truck noise caused more disturbance than train noise.

9.2. TEMPORAL CHARACTERISTICS OF SLOW WAVE SLEEP AND REM-SLEEP

The temporal structure of SWS in 45 dB(A) showed a clear decrease of SWS accross the night in comparison with the quiet night. A similar effect was present in the case of REM sleep. In general REM sleep occurs for a short period and it has its own stable and strong periodicity. Therefore the effect is important because the chances that REM is disturbed are relatively low, as the stimuli may not occur in the REM periods at all.

The disturbance of the temporal structure, even if small, is important. The temporal relationship between slow wave sleep, REM sleep and light sleep is a manifestation of an interaction between different neurochemical substances (McCarley, 1992). This neurochemical activity has its own physical balance and homeostasis (metabolic rate, decay times etc.). A disturbance of the temporal relationship also disturbs the homeostasis. As a consequence the interaction between the activity of different substances is not optimal.

Patients with insomnia (a persistant sleep disturbance) show similar disturbances (Hofman, 1994). However, this does not imply that exposure to noise always leads to insomnia.

Contrary to our expectations, the 15 stimuli in the 75 dB(B) conditions (airplane and train) disturbed the temporal pattern of SWS more than the 50 stimuli in the 45 dB(A) condition. It seems that the increase of the sound level from 45 dB(A) to 75 dB(B) compensated for the fewer number of stimuli in the 75 dB(B) condition. This was also true for the temporal pattern of REM sleep in the case of train noise.

Not many differences were found between the three noise sources of comparable sound level. Where differences were found, the comparison of the noise sources revealed that in general train and truck noise disturbed sleep more than airplane noise. The comparison between train noise and truck noise gave mixed results. There was no difference between the disturbing effects of train and truck noise on the temporal structure of SWS sleep. Train noise disturbed the temporal structure of REM sleep. The lower frequencies, as measured in the 75 dB(B) condition, did not seem to be an important factor.

9.3. AROUSAL REACTIONS AND AWAKENINGS

In this study it was shown that noise stimuli caused both awakening reactions and EEG arousals. In most cases the awakenings and EEG arousals were of short duration (less than one minute), but there was a tendency towards an increase in the duration of the reaction as the duration of the stimuli increased. An increase in the duration of the stimulus did not result in more reactions. So, although the airplane stimuli had a longer duration than stimuli from the other two noise sources, this did not result in more reactions.

The 45 dB(A) maximum sound level caused less awakening reactions and less EEG arousals than the stimuli with 65 dB(A) and 75 dB(B) maximum sound level. The number of EEG arousals did not differ significantly between the 65 dB(A) and the 75 dB(B) condition.

In all sound levels we found a lower probability of awakening after a stimulus in deep sleep as compared to light sleep. A difference in reactivity to stimuli during sleep over the course of the night, as was found by authors like Eberhardt and Ohrstrom (1987) or Shapiro et al. (1963), could not be confirmed in this study. This can be either due to the limited number of stimuli or to the non-linear relationship between the reactivity to stimuli and the time of the night, which was found in this study.

The awakening reactions to stimuli with 45 dB(A) maximum level and 65 dB(A) maximum level did not show significant differences between the noise sources. In the 75 dB(B) condition the differences were significant: train noise caused 73% more awakening reactions than truck noise and 26% more reactions than airplane noise. Airplane noise caused 29% more reactions than the truck noise.

Field studies generally showed less annoyance from train noise than from airplane noise or truck noise. However, the density of train traffic was also generally less than that of truck or airplane noise indicating that the number of stimuli was also important. For example: Vernet and Simmonet (1983), looking at the total number of reactions, reported less reactions to train noise than to road traffic. This result could be explained, however, by the lower number of train passages. When the number of stimuli was taken into account, Vernet and Simmonet showed that the percentage of awakening reactions to train stimuli was higher than to truck stimuli.

It can be concluded from our study that, as far as arousal and awakening reactions are concerned, sound level and number of stimuli may be more important than the source of the noise.

The probability of occurrence of awakening reactions was more sensitive to differences between noise sources than the probability of occurrence of EEG arousals. One reason may be that during the awakening reactions the subject might be more aware of the source of the disturbing stimulus than during the arousal reactions.

Another possible explanation of the low sensitivity of EEG arousals is the choice of frequency bands. The EEG also contains frequencies higher than the beta-frequency band, called beta-2. It is possible that the changes in beta-2 are more sensitive to the noise sources.

9.4. ECG PARAMETERS

In this study we compared the cardiac response to a stimulus with the cardiac values before the occurrence of the stimulus. Therefore we could be certain that the changes in the cardiac parameters were real responses to the stimulus. By using this method it could be proved that the cardiac responses were directly related to stimuli.

In the lowest sound level condition of 45 dB(A) the airplane stimuli, train stimuli as well as truck stimuli caused a highly significant disturbance of the ECG. These results agree with other findings. For example, Hofman et al. (1994a) showed that passing vehicles in the case of continuous traffic noise caused cardiac disturbances which were not dependent on the peak level.

Also in the highest sound level condition of 75 dB(B) all noise sources caused cardiac disturbances. This effect was however not so clear in the 65 dB(A) condition. Although the trends were all in the same direction, not all of the effects (like the effects of the airplane stimuli) reached statistical significance. One of the reasons may be that in the high sound level conditions the number of stimuli was lower (15) than in the 45 dB(A) sound level conditions (50). Also, more stimuli had to be rejected because body movements did not allow reliable ECG detection.

Differences between noise sources were not consistent over the sound level conditions. It has to be concluded that the source of the noise is not important enough to induce differences in cardiac disturbance.

No difference was found between the 75 dB(B) sound level condition and the 65 dB(A) sound level condition. This means that the adjustment of the sound level to the characteristics of the B-weighted measurement (with a better representation of the lower frequencies) did not result in differences of the cardiac responses.

9.5. SUBJECTIVE SLEEP QUALITY AS COMPARED WITH THE QUIET NIGHT

In the case of airplane and truck noise the 15 stimuli with a higher sound level caused more deterioration of the subjective sleep quality in comparison with the quiet night than the exposure to 50 stimuli of a lower sound level. Only in the case of train noise the number of stimuli was judged subjectively as more important than the sound level, as the exposure to 50 train stimuli of a lower sound level caused more deterioration of the subjective sleep quality in comparison with the quiet night than the exposure to 15 train noise stimuli of a higher sound level.

Adjustment of the maximum sound level to a signal with B characteristics did, in both airplane noise and train noise, not result in a significant difference.

In the 45 dB(A) condition truck noise was regarded as most disturbing and train noise was regarded as least disturbing, with airplane noise in the middle. In the 65 dB(A) condition and the 75 dB(B) condition no difference was found between the noise sources.

10. CONCLUSION

Summarizing it can be concluded that the exposure to 50 stimuli of 45 dB(A) sound level resulted in:

- a decrease of SWS in the first hour of sleep, causing a flattening of the normal declining course of SWS over the night;
- a decrease in the amount of REM-sleep per hour and a disturbance of the temporal characteristics of REM-sleep over the night;
- awakening reactions and EEG arousals;
- an increase in heart rate;
- a decrease of the subjective sleep quality.

The exposure to 15 stimuli of 65 dB(A) resulted in:

- more Wake after sleep onset and, to a lesser extent, less percentage of SWS and a shorter total sleep time;
- a disturbance in the temporal characteristics of slow wavae sleep over the night, resulting in a decrease of SWS in the first hour of sleep and causing a flattening of the normal declining course of SWS over the night;
- a decrease in the amount of REM-sleep per hour;
- awakening reactions and EEG arousals;
- an increase in heart rate, but not in all noise sources;
- some decrease in subjective sleep quality.

The exposure to 15 stimuli of 75 dB(B) peak level did not result in more disturbance than the exposure to 15 stimuli of 65 dB(A) peak level. It can be concluded that low frequencies (B-weighting) in the noise during sleep are not an important disturbing factor.

The comparison of the three noise sources did not result in large differences in all three conditions (45 dB(A), 65 dB(A) and 75 dB(B)), except for train noise and truck noise. In these two noise sources more disturbing effects were found on the global EEG parameters and on the temporal characteristics of SWS and REM-sleep than in airplane noise.

The physiological quality of sleep is reflected mainly in:

- the temporal structure of slow wave sleep and REM-sleep;
- awakening and arousal reactions.

All of these measures were disturbed by the noise in this study. The fact that the cardiac system does always react on the noise, even in the lowest sound level condition, can have an impact on health when subjects are exposed to many noise stimuli during a prolonged period.

For the subjective sleep quality the sound level was the most important factor. In the 75 dB(B) sound level condition the subjective sleep quality was judged as lower than in the quiet night in all noise sources, in the 65 dB(A) sound level condition in two of the three noise sources, while in the 45 dB(A) sound level condition not much difference was found with the quiet night.

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Datum

VERZONDEN 21 NOV. 1994

MBG 10N94001

Onderzoek vergelijkend effect op de slaap
zaaknummer : 93130150
dossiernummer: 9370023

Bij brief van 9 augustus 1993, kenmerk MBG 11393009 is aan u voor het bovengenoemde project een bedrag toegezegd van maximaal ƒ 86.057,-- (inclusief 17,5% BTW).

Ten aanzien van de ingediende facturen van 24/10/94 en 27/10/94 met als kenmerk FCT.F059 en FCT.F060 het volgende:

- De factuur van 27/10/94 vermeld werkzaamheden over de periode januari 1993. Deze moet volgens mij januari 1994 zijn.
- Twee urenbriefjes van de factuur van 24/10/94 zijn getekend in december 1994. Dit klopt niet.

Volgens de gestelde voorwaarden in de toezeggingsbrief is de einddatum van het project 30 november 1993. Dit betekent dat het project afgelopen is en ik een einddeclaratie mag verwachten. In plaats van een einddeclaratie ontvang ik twee facturen over een periode die na de einddatum van het project zijn. Ik heb geen verzoek mogen aantreffen over verlenging van de einddatum. Gaarne toelichting hier omtrent.
De declaraties dienen na afloop van iedere maand te worden ingediend. Na ongeveer een jaar ontvang ik twee declaraties, waaruit ik kan concluderen dat dit project nog niet is afgelopen. Gaarne toelichting.
De urenbriefjes dienen wekelijks opgestuurd te worden. Deze ontvang ik samen met de facturen. Gaarne toelichting.

Ik verzoek u aan de gestelde voorwaarden te houden. Mocht u van de voorwaarden willen afwijken dan moet u dit schriftelijk doen.

Gezien de bovenstaande opmerkingen en toelichtingen stuur ik de facturen retour en verwacht ik binnen twee weken na ontvangst van deze brief een reactie van U.

Bijlagen

Mocht vragen hebben over deze brief dan kunt U zich wenden tot dhr. R. Oemar
tel: 070-3394164.

Hoogachtend,

de directeur van de directie Geluid en verkeer,
voor deze;
het hoofd van de afdeling Verstoring en
Geluidkwaliteit,

drs. J.A. Verspoor

Bijlage: 2

COMPARATIVE EVALUATION OF SLEEP DISTURBANCE DUE TO NOISES FROM AIRPLANES, TRAINS AND TRUCKS*

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Client: Ministry of Housing, Planning and Environment

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