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EFFECTS OF TEMPORARILY LIMITED NOISE CALMING PERIODS DURING SLEEP

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Abstract

As traffic density will increase in the forthcoming years, more during the shoulder hours and during the night than during the day and due to the deleterious effects of noise on sleep this paper evaluates 3 models of temporary quiet periods during the night. As the times of these periods are oriented to the sleep behaviour of the majority of the adult population persons with different bedtimes are concerned.

Twenty-four healthy young persons (12 women, 12 men, 21 – 27 yrs) slept in 2 consecutive weeks, four nights each week in the laboratory while during one week each exposed to road or railway noises. Three models of temporary quiet periods were realized: two starting at 11 pm and lasting 4 or 6 hours and one starting at 3 am and lasting until 7 am. Eight normal sleepers went to bed at 11 pm, eight early sleepers at 10 pm and eight late sleepers at 12 pm, wake-up call was eight hours later. The overall 9 exposure patterns were reduced to three main exposure patterns, defined by the quiet period in the beginning, in the middle or at the end of the subjective night. During all nights polysomnograms were recorded continuously, sleep was evaluated subjectively every morning.

Noise in the beginning of the night caused disturbances before and shortly after noise onset. If the night is terminated by a quiet period only, the initial disturbances are fully compensated. However, whenever the subjective night is terminated with an even short noise period, sleep structure and subjective evaluation of sleep are significantly impaired. Thus, whenever a temporary quiet period during the night is considered, it is strongly recommended to locate this period at the end of the subjective night. In any case late sleepers profit less from such regulations.

1. INTRODUCTION

Though noise emission of the various means of transport (road and rail vehicles, aircraft) has been significantly reduced within the last decades the overall noise load in terms of equivalent noise levels day-evening-night levels, etc. became nevertheless higher due to the considerable increase of traffic density. Though the actual load is already critical for numerous residents living along busy roads, railway tracks and in the vicinity of airports traffic density is expected to increase further but as neither the road nor the railway networks will be extended accordingly traffic density will increase more during the shoulder hours and during the night than during the day. Thus noise abatement is a major challenge and as the effects of noise are relevant for health essential for public health care.

Concerning noise abatement priority must be given to the reduction of noise emission at the source itself. However, the success of these measures might become evident only after years or even decades because aircraft and trains operate up to 30 and even 40 years and road vehicles on average up to 8-10 years. Even the exchange of tyres does not happen earlier than after 2 to 3 years. It is therefore essential to introduce organisational measures as well that are effective at short term.

Concerning the avoidance of noise-induced sleep disturbances the complete prohibition of any traffic during the night is certainly desirable but scarcely possible. It is therefore discussed to reduce or to avoid traffic for at least several hours during a night.

The present study focuses on the question of a suitable time period for traffic reduction (prohibition) during the night. Twenty-four persons were observed during sleep in two consecutive weeks in the laboratory while exposed to road or rail traffic noise. Three models of temporary quiet were tested. As the beginning and the end of these models are oriented to the sleep behaviour of the largest part of the population it is assumed that persons who have habitually or due to their profession earlier or later bedtimes will profit less from such a regulation as the quiet periods for them are partially reduced or embedded into an initial and a final noise exposure.

2. MATERIALS AND METHODS

2.1 Participants

Twenty-four healthy and normal hearing persons (12 women, 12 men, 21 – 27 years of age, 23.0 ± 1.9 yrs) participated in the experiments that were approved by the Local Ethics Committee.

2.2 Experimental Design

The participants slept after a habituation night in two consecutive weeks, each week four consecutive nights in the laboratory. Eight persons went to bed at 11 p.m. (normal sleepers), eight persons at 10 p.m. (early sleepers), and eight persons at 12 p.m. (late sleepers). They stood up eight hours later at 7 a.m., at 6 a.m. and at 8 a.m., respectively. The participants were in a permuted sequence one week exposed to road and the other week to rail traffic noise. The four nights of each week consisted of a random sequence of a quiet and three noisy nights, with equivalent noise levels of 39.4 and 41.7 dBA, respectively.

2.3 Recordings

Physiological recordings. The polysomnogram that provides information on the beginning and the end of sleep as well as on the amount and distribution of the various sleep stages was continuously recorded throughout each night. It consists of 2 electroencephalograms (EEG), 2 electrooculograms (EOG) and 1 electromyogram (EMG).

Subjective evaluations. Every morning the participants judged their sleep. Using 6 ten-point scales (ranging from 0 to 10) they were requested ('Please estimate your sleep') to estimate their difficulties in falling asleep (very easy – very difficult), calmness of sleep (very calm – very restless), sleep depth (very sound – very shallow), sleep duration (very long – very short), restoration (very high – very low), body movements (very little – very much).

According to a factor analysis all these scales loaded on a single factor and were summed up and subtracted from the maximum achievable number (60) and the result was labeled as 'Sleep quality'. Another 10-point scale was used to estimate actual fatigue (alert – tired).

2.4 Noise loads

Three models of temporary quiet periods were chosen for the experiments: There were two 'evening' quiet periods starting at 11 p.m. and lasting 6 hours until 5 a.m. (E6) or 4 hours until 3 a.m. (E4) and one 'morning' quiet period starting at 3 a.m. and lasting until 7 a.m. (M4). The times 11 p.m. and 7 a.m. were oriented to the average sleep behaviour of adult persons who go to bed at 11 p.m. and rise at 7 a.m. The 3 models are shown for normal sleepers in the upper part of Figure 1.

These three models result in overall 9 exposure patterns when early and late sleepers are considered. These patterns can, however, summarized to 3 main patterns, determined by a quiet period in the beginning of the (subjective) night (Q N), at the end of the (subjective) night (N Q) or embedded into an initial and a terminal noise period (N Q N).

A pink noise of 28 dBA was continuously applied during all nights (even during quiet nights). In the noisy nights 241 to 248 pass-bys of road vehicles or 154 to 160 passages of rail vehicles were superimposed with maximum levels between (L_{Amax} = 56 to 68 dB). The equivalent noise level varied between 39.4 and 40 dBA. Higher noise loads resulted for early and for late sleepers (41.2 to 41.7 dBA), as the evening quiet period was reduced for early sleepers an the morning quiet was prolonged for late sleepers by one hour.

Concerning the pattern noise increased after the 4 hours period in the evening gradually within the following 2 hours, and decreased accordingly before the 4 hours quiet period at the end of the night. In the other cases an abrupt increase or decrease was assumed.

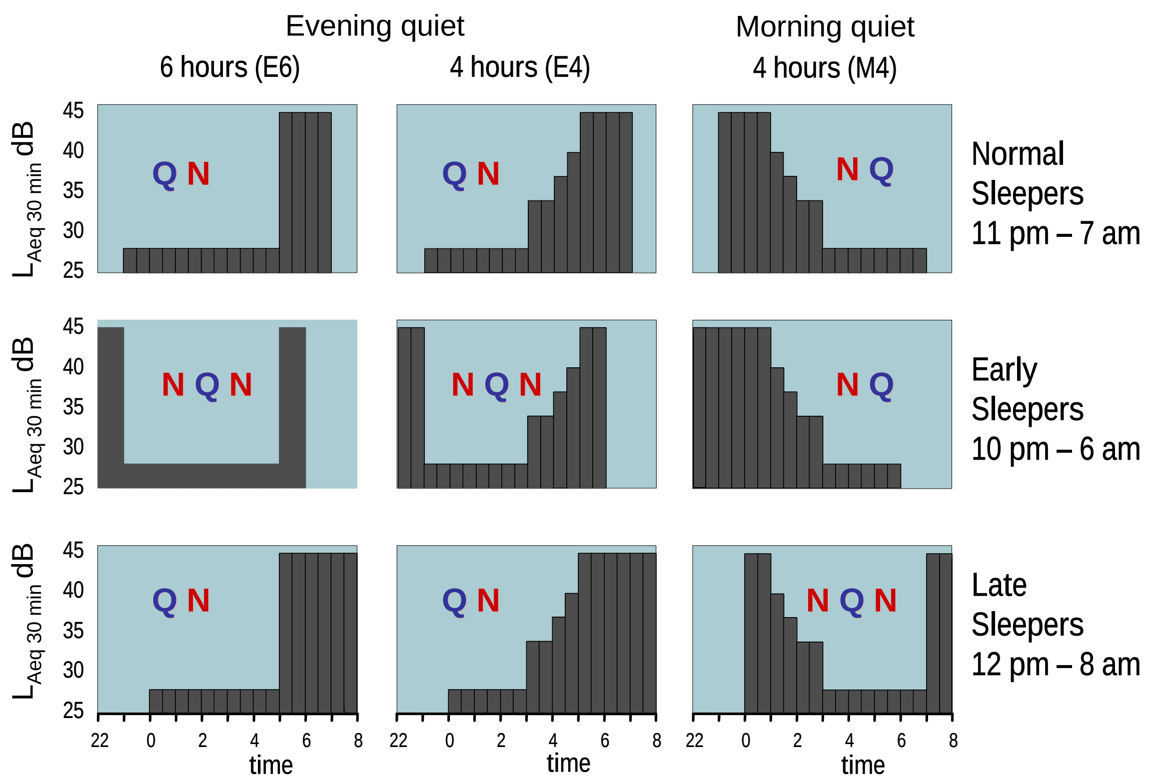

Figure 1: Exposure patterns. Three quiet periods (from left to right) and three groups defined by different bedtimes.

3. RESULTS

3.1 Comparison between exposure patterns

Concerning the quiet nights there were no differences between early, normal and late sleepers neither for the physiological data nor for subjective evaluation of sleep thus allowing the calculation of averages across groups and to reduce the exposure patterns to 3 main patterns mentioned above with the quiet period in the beginning, in the middle and at the end of the subjective night (Q N – N Q N – N Q).

Beginning of sleep. Table 1 shows for the 3 main exposure patterns the data calculated for the beginning of sleep as defined by the time period between the extinction of the lights and the end of the first REM-period. As compared to quiet nights and the situations where the nights started with a quiet period sleep onset latency, the latency to slow wave sleep (SWS, deep sleep) and the time awake including the time in sleep stage S1 (the transitional stage between wake and sleep) was longer whereas the duration of SWS was shortened.

Concerning those exposure patterns where the subjective night started with a quiet period and was terminated by a noise period, there were no indications of alterations at the beginning of sleep.

Table 1: Alterations of sleep parameters at the beginning of sleep as compared to the quiet nights during the main exposure patterns (yellow: $p < 0.05$, orange: $p < 0.01$)

Exposure pattern	**N Q**	**N Q N**	**Q N**
	mean± s.d.	mean± s.d.	mean± s.d.
Sleep onset latency (SOL)	2.0 ± 8.7	12.7 ± 19.4	1.7 ± 7.6
Latency to slow wave sleep (SWS)	4.6 ± 13.7	2.0 ± 7.1	0.3 ± 3.7
Awake and stage S1 of 1st sleep cycle	1.8 ± 7.1	1.8 ± 3.0	0.8 ± 3.1
Duration of SWS of 1st sleep cycle	-12.1 ± 14.3	-7.2 ± 10.7	-0.4 ± 9.2

Table 2 presents selected parameters of the physiological structure of the total sleep period, i.e. the time between sleep onset and final awakening and of the subjective evaluation of sleep, separately for the three main exposure patterns. Figure 2 shows the differences of these parameters to the quiet nights.

Concerning the nights that began with noise exposure and was terminated with a quiet period (N Q), none of these parameters was, as compared to quiet nights significantly altered. As sleep in these nights was found to be disturbed in the beginning (see Table 1), the lack of alterations during the total sleep period indicates a compensation.

If the quiet period was embedded into an initial and a final noise period (N Q N), where the beginning of sleep was already significantly disturbed, total sleep time was due to the prolongation of intermittent wakefulness significantly reduced as well as the Sleep Efficiency Index (SEI) that relates the total sleep time (the time from sleep onset to final awakening minus the intermittent time awake) to the sleep period time (the time from sleep onset to final awakening) while the Sleep-Disturbance-Index (SDI) was reduced. In addition, both subjective parameters, the evaluation of sleep quality and of fatigue were as well significantly impaired.

The same alterations occurred in those nights where a quiet period was located in the beginning of the night and followed by noise exposure. All the physiological parameters and the subjective evaluation were altered significantly with a p-value of less than 0.01.

Table 2: Selected sleep parameters related to the three exposure patterns with the quiet period in the beginning, in the middle and at the end of the subjective nights; comparison to quiet nights (orange: $p \leq 0.01$, yellow $p \leq 0.05$).

Exposure pattern	N Q	N Q N	Q N
	mean ± s.d.	mean ± s.d.	mean ± s.d.
Total sleep time	434.0 ± 13.1	408.3 ± 33.1	423.9 ± 21.6
Intermittent time awake	22.3 ± 6.3	36.1 ± 16.7	35.2 ± 17.1
Sleep efficiency-Index	0.95 ± 0.01	0.92 ± 0.04	0.92 ± 0.04
Sleep-Disturbance-Index	-0.18 ± 0.72	0.38 ± 0.94	0.32 ± 0.72
Subjective Sleep Quality	36.0 ± 6.6	30.0 ± 6.5	31.4 ± 5.8
Fatigue	3.9 ± 2.0	5.1 ± 2.0	6.0 ± 1.4

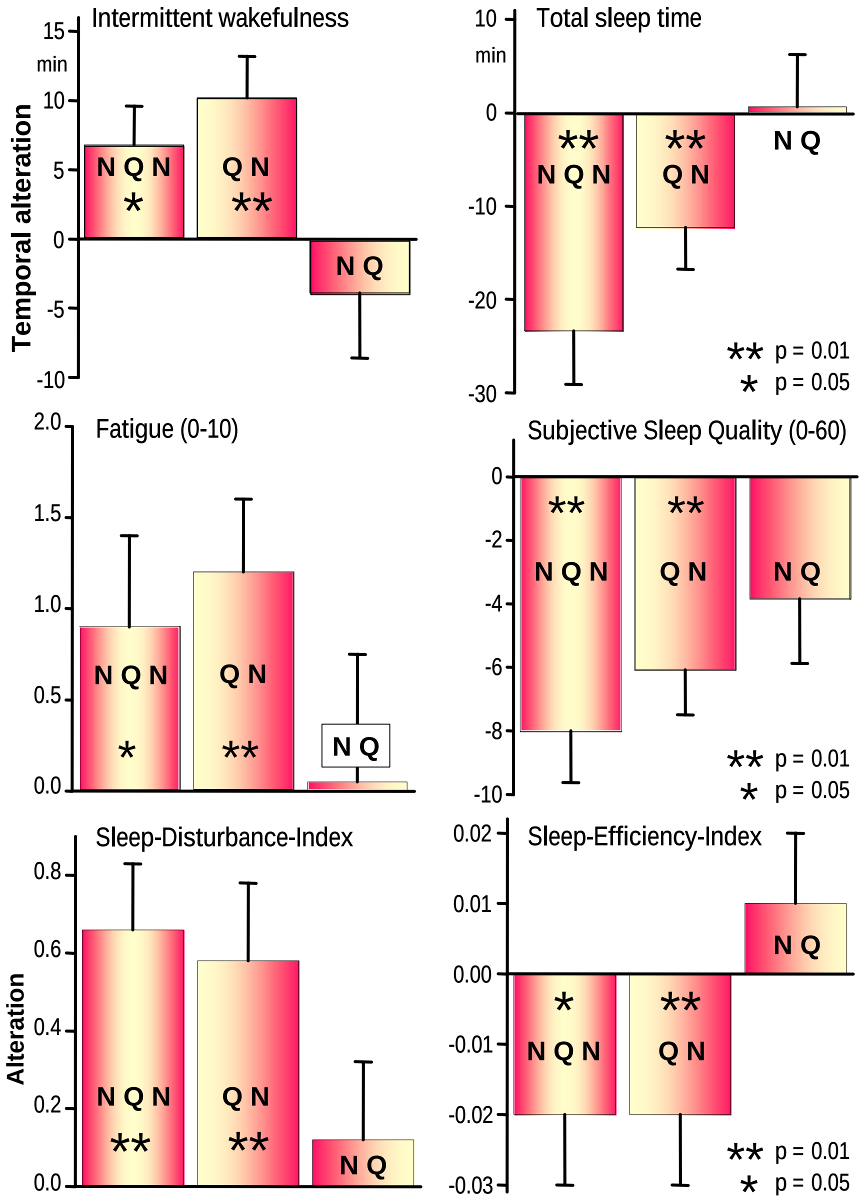

Figure 2: Alterations as compared to quiet nights for the three main exposure patterns Noise – Quiet – Noise (N Q N), Quiet – Noise (Q N), and Noise – Quiet (N Q).

3.2 Comparison between persons with different sleep times

Figure 3 shows the alterations of the Sleep-Disturbance-Index, separately for normal sleepers, for early and for late sleepers for situations where the quiet period was located in the beginning of the night and at the end of the night. Thereafter, it becomes clear, that normal sleepers profit most from temporally limited quiet periods during the night. Early sleepers, for whom the initial quiet period was embedded into two noisy periods and for whom the quiet period in the morning was shorted by one hour, were more impaired than normal sleepers but this was not significant. Late sleepers, however, for whom the quiet period in the evening was shortened and the quiet period in the morning was followed by an hour with high traffic density, were much more disturbed than normal sleepers.

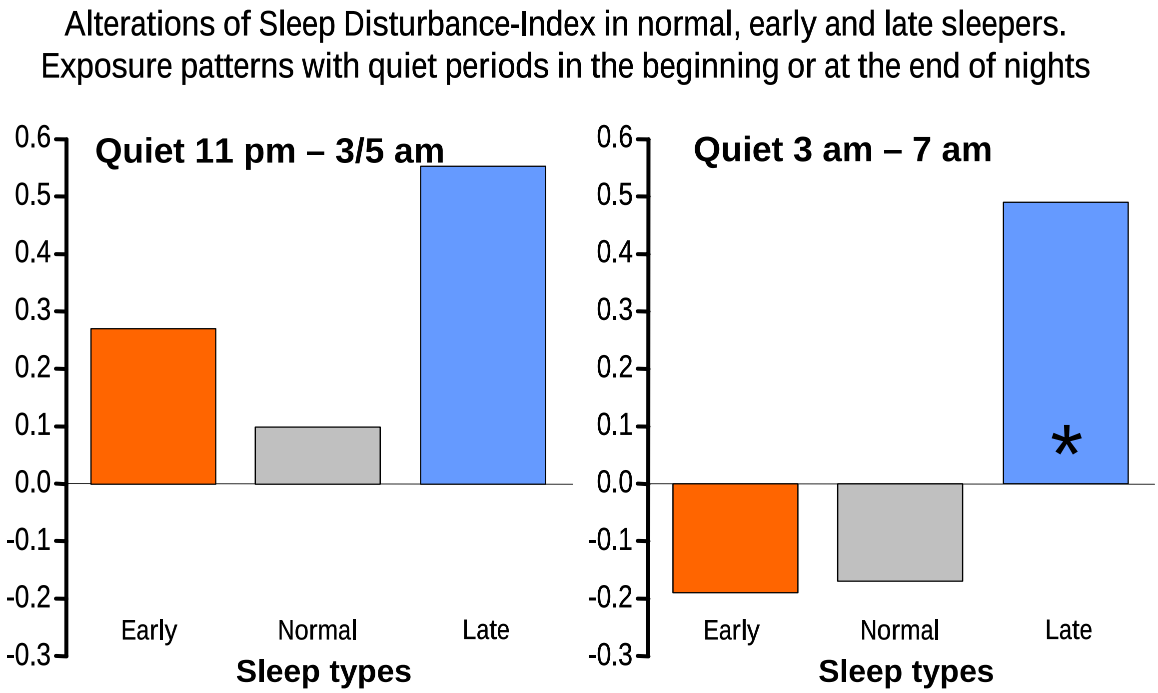

Figure 3: Alterations of the Sleep-Disturbance-Index in persons with different sleep times and with the quiet period in the beginning and at the end of the night.

4. DISCUSSION

Residents living along busy roads, railway tracks and in the vicinity of airports, usually assess sleep disturbances as the most deleterious effect of noise. As these disturbances are not restricted to the physiological processes of sleep but might consecutively impair mood and performance and are even suspected to contribute in the long run to the genesis of multi-factorial chronic diseases, it is essential to protect the exposed persons. A complete prohibition of traffic is as a rule not possible. Apart from noise abatement at the source which becomes effective only at medium or long term, operational measures have to be considered. The latter are effective at short term though regionally limited.

Possible operational measurements are, among others, the temporally limited reduction of traffic noise either by the complete prohibition for several hours, by the partial prohibition of selected noisy vehicles (motor cycles, trucks), by reductions of speed etc. The present study focused on the question of suitable time periods with the utmost beneficial effects. As these times are as a rule oriented to the sleep behaviour of the majority of the adult population. The present study considers, in contrast to previous studies [1-3] persons who habitually or due to their profession have earlier or later bedtimes.

It was expected that noise that occurs in the beginning of the subjective night would impair the physiological processes at that time. This proved to be true. Sleep onset latency, latency to slow wave sleep as well as the time awake and in the lightest sleep stage S1 were prolonged, whereas the first period of slow wave sleep in the first cycle was reduced. However, concerning the physiological structure of sleep over the entire night, these disturbances were no longer demonstrable; moreover subjective evaluation of sleep in terms of sleep quality and fatigue did not differ from quiet nights. This unequivocally indicates a complete compensation meaning of the disturbances experience in the beginning of the nights. If a noise period is followed by a quiet period that lasts until awakening, the deep sleep can be caught up and the time awake is reduced. According to the results of the early sleepers a three-hour period at the end of the subjective night seems to be sufficient for a complete compensation. The effect of compensation is, however, strongly reduced if the quiet period is followed by an even short noise period.

Any noise exposure at the end of the subjective night, whether preceded by an initial or intermittent quiet period caused significant disturbances not only on the physiological level but concerning the subjective evaluation of sleep as well.

Apart from compensation a differentiated analysis first performed here, where sleep impairments were determined for each consecutive hour indicated that even during noise exposure adaptations are possible: even with persistent and further increasing noise load the extent of disturbances decrease gradually. Overall it can be assumed that the frequently described moderate structural alterations of total sleep are due to two mechanisms, firstly to adaptations during noise and secondly if the noise period is followed by a quiet period up to the end of the subjective night by compensation.

As expected normal sleeper profited most from the temporary quiet periods as the respective times were oriented at the sleep behaviour of the major part of the adult population. Irrespective of the model tested here early sleepers who are due to their early bed times more exposed to noise in the early night were only marginally more impaired, whereas late sleepers were significantly more impaired because they were exposed in all their nights to a noise period at the end of their sleep period.

5. CONCLUSIONS

The study performed here showed

- that a temporarily limited quiet period is only useful, if the exposed persons have the possibility to terminate their sleep in quiet, where a three-hour quiet period is sufficient. Each noise exposure at the end of a night leads to a prolongation of intermittent time awake and reduced sleep efficiency, an increase of the Sleep-Disturbance-Index and a reduction of subjective sleep quality and greater fatigue.
- The prolongation of the initial quiet period from four to six hours is therefore not useful, if this quiet period is followed by noise exposure.
- During exposure to noise adaptations are expected where the reaction of the single noises are gradually reduced, where in case of a consecutive quiet period compensation mechanisms occur as well.

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