Temporally limited nocturnal traffic curfews to prevent noise induced sleep disturbances

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ABSTRACT

This study aimed at the identification of a time frame suitable for the prevention of noise induced sleep disturbances. Curfews at the end of nights were expected to provide the best protection; further persons with corresponding bed times were expected to profit most.

Subjects and methods. 24 students (12 women, 12 men, 21-27 yrs) slept two consecutive weeks four nights each in the laboratory being exposed one week each to rail or road traffic noise. The 4 nights each week consisted of a quiet night and three noisy nights with different curfews (23–3 h, 23–5 h, 3–7 h). Eight persons each went to bed at 22, 23, and 24 h and got up 8 h later. The resulting 9 exposure patterns were condensed to 3 patterns with curfews at the beginning, in the middle or at the end of the night. Polysomnograms were recorded each night and the participants evaluated their sleep every morning.

Results and conclusions. Traffic curfews are beneficial only at the end of the night and disturbances experienced in the beginning of the night are then compensated. Even short periods of subsequent noise cause sleep disturbances. Thus late sleepers whose nights always end with a noisy period profit scarcely from these regulations.

INTRODUCTION

Sleep disturbances are considered as the most deleterious effects of noise. Acute event related effects are cortical and autonomic arousals, sleep stage changes, awakenings and body movements that are determined by the temporal acoustical microstructure of the single vehicles (temporal variation of levels and frequencies, rise time, duration, type of noise etc.), the macrostructure of the whole noise scenario (sequences of vehicles, noise-free intervals etc.) as well as by the actual situation (sleep depth etc.) (Basner et al. 2006; Brink et al. 2008; Griefahn 1989; Marks et al. 2008). These primary reactions cause eventually alterations of whole nights' sleep (Basner et al. 2004; Griefahn et al. 2006), followed by worse ratings of sleep quality and impaired performance the next day (Basner 2008; Marks & Griefahn 2005; Öhrström & Björkman 1988; Öhrström et al. 2006). In the long run nocturnal noise is even suspected to contribute to the genesis of cardiovascular diseases (Babisch 2006). Thus sleep disturbances are undoubtedly relevant for health and noise abatement becomes an essential element of public health care.

Though the actual noise load is already critical for numerous residents living along busy roads, railway tracks and in the vicinity of airports traffic volume is expected to increase further. But as neither the road nor the railway networks will be enlarged accordingly traffic density and thereby transportation noise will increase more during the shoulder hours and during the night than during the day. This will consequently increase and aggravate noise induced sleep disturbances.

Concerning noise abatement suitable measures are traffic curfews for all or at least for the noisiest vehicles (motorcycles, trucks, high speed trains, freight trains), for the whole night or for defined sections of the night. Concerning the latter it is not yet clear whether these curfews should be established at the beginning, in the middle or at the end of the night. But as the noises in these studies were more or less evenly distributed over the night and as the reaction to a distinct stimulus depends on the reactions to previous stimuli it is not justified to set the time frames for traffic curfews without adequate tests.

This study aimed at the identification of a time frame for traffic curfews that provide a sufficient protection. It was hypothesized that noise induced sleep disturbances are best prevented by traffic curfews in the late night. Noise in the beginning of the subjective night (that indicates the individual noise load of a person due to his/her individual bed time) affects the process of falling asleep but subsequent curfews provide the opportunity to compensate these disturbances. Curfews at the beginning of the night will, however, not affect sleep onset but subsequent noise exposure causes sleep disturbances that cannot be compensated thereafter. Further, as the time frames of curfews are fixed (e.g. to the sleep behavior of the majority of the adult population) persons with corresponding bed times are probably sufficiently protected. But persons with earlier or later bed times profit less from such regulations as for them the quiet periods are either reduced or embedded into an initial and a terminal noise exposure.

This study evaluated three temporally limited curfews where the respective time frames are oriented to the sleep behavior of the majority of the German population. Most people go to bed around 23 h and get up at around 7 h. Two evening curfews started at 23 h and lasted 4 or 6 hours until 3 or 5 h, respectively, a morning curfew started at 3 h and lasted until 7 h. Persons with normal, early, late bed times were observed during two consecutive weeks in the laboratory while exposed to road and rail traffic noise.

MATERIALS AND METHODS

Participants

24 healthy and normal hearing students (12 women, 12 men, 21-27 yrs) gave their written informed consent to the study that was approved by the Local Ethics Committee. 8 persons each had normal, early or late bed times (23, 22, 24 h).

Experimental Design

After a habituation night the participants slept two consecutive weeks, each week four consecutive nights from Monday night to Thursday night in the laboratory. Bedtimes were 23, 22 and 24 h for normal, early and late sleepers respectively. Time in bed (TIB) was terminated eight hours later at 7, 6 and 8 h, respectively. The participants were exposed in a balanced order to rail and to road traffic noise during the first or the second week, respectively. The four nights of each week consisted of a random sequence of a quiet and three noisy nights with different traffic curfews.

Noise load

A 10 hours noise scenario from 22 to 8 h was created with lower traffic density in the middle of the night. It consisted of recordings of real traffic pass-bys. The road traffic scenario consisted of a mixture of private cars and trucks and the rail traffic scenario of a mixture of passenger and freight trains. The maximum levels varied between 56 to 68 dBA at the sleepers' ears. The hourly equivalent noise levels were L_{Aeq} = 45 dB with 48 road and 30 rail pass-bys per hour. The levels decreased to L_{Aeq} = 38 dB from 1 to 2 h and from 4 to 5 h with 33 and 24 pass-bys per hour. The L_{Aeq} from 2 to 4 h was 34 dB with 16 road and 10 rail pass-bys per hour. Three traffic curfews were applied to this scenario. Two evening curfews started at 23 h, one lasting 6 hours until 5 h, the other 4 hours until 3 h. A morning curfew started at 3 h and lasted until 7 h. The three bed times and three curfews resulted in nine different exposure patterns (Fig. 1) which were then grouped to three patterns with the curfew in the beginning (Q N), in the middle (N Q N) and at the end (N Q) of the subjective night. To achieve for the 6 hours traffic curfew the same equivalent noise level the number of pass-bys was elevated to 62 and 40 for road traffic and rail traffic, respectively. A 28 dBA red noise was continuously applied throughout all nights, even during quiet nights.

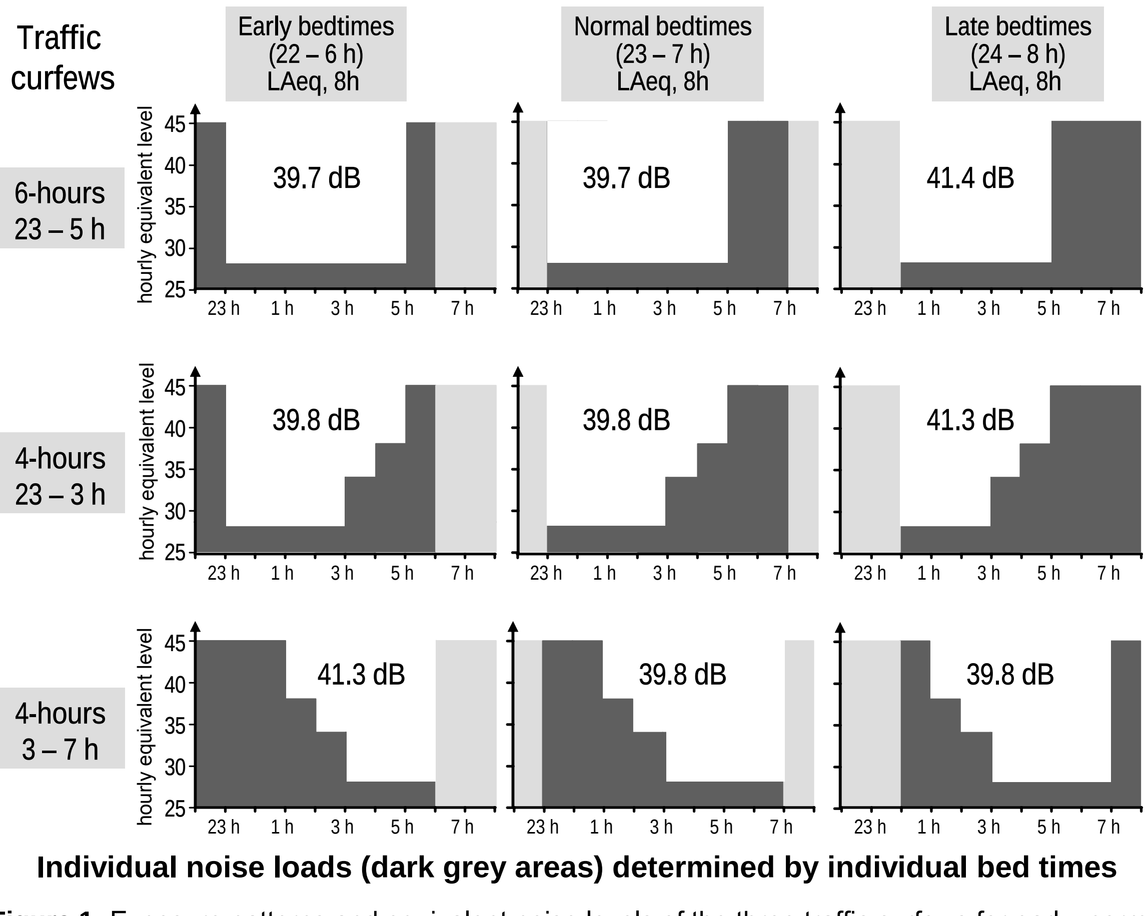

Figure 1: Exposure patterns and equivalent noise levels of the three traffic curfews for early, normal, and late sleepers

Equivalent noise levels over the 8 hours in bed varied in most nights between 39.7 and 39.8 dBA but increased to 41.3 to 41.4 dBA for early and late sleepers whose individual morning and evening curfew, respectively lasted 3 instead of 4 hours.

Equipment. The participants slept in separate sound shielded rooms with room temperature adjusted to 20 °C. All rooms were equipped with two loudspeakers. An intercom system provided the possibility to contact the experimenter at any time.

Recording of physiological parameters and subjective evaluation

Polysomnogram. The polysomnograms (2 EEG, 2 EOG, 1 EMG) were continuously recorded throughout each night and rated according to Rechtschaffen and Kales (1968). The parameters derived from each polysomnogram were sleep onset latency (SOL, sleep onset: the first occurrence of 3 successive epochs of stage S1), sleep period time (SPT = sleep onset until final awakening), wakefulness after sleep onset (WASO), total sleep time (TST = SPT–WASO), Sleep-Efficiency-Index (here, as bed times were fixed to 8 h, defined as SEI = TST/SPT), and the time spent in each sleep stage (separately for SPT and for the first sleep cycle). Sleep stages S3 and S4 were combined to slow-wave-sleep (SWS) and the times awake and in stage S1 were for the first sleep cycle combined to S0&1.

Seven parameters that are typically though moderately affected during nocturnal noise exposure were condensed to a 'Sleep-Disturbance-Index' (SDI, Griefahn et al. 2008a). These were: SOL (sleep onset latency), SWSL (latency from sleep onset to the first epoch of slow-wave-sleep), WASO (wakefulness after sleep onset until final awakening), W>3min (number of awakenings >3 min), sleep stages S1, SWS (time in sleep stages S3 + S4) and REM (time in rapid-eye-movement sleep).

Subjective evaluations. Using 6 ten-point scales (ranging from 0 to 10) the participants evaluated their sleep every morning, the difficulty to fall asleep (very easy – very difficult), calmness of sleep (very calm – very restless), sleep depth (very deep – 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' (SQ).

RESULTS

Comparison between groups and traffic modes

There were no significant differences between the three groups defined by normal, early and late bed times during quiet nights. Concerning road and railway noise there was a tendency ($p \leq 0.1$) for shorter TST, less REM-sleep, prolonged WASO, reduced SEI and increased SDI during nights with railway noise than during nights with road traffic noise. But as none of the various sleep parameters revealed a significant ($p \leq 0.05$) difference the corresponding situations defined by the temporal location of the curfews were averaged across nights with rail and road traffic noise for further statistics.

Effects of traffic curfews

Table 1 shows the differences between quiet nights and noisy conditions with different curfews, where positive numbers indicate higher values in noisy than in quiet nights.

Concerning SOL and the first sleep cycle curfews in the beginning of the subjective night (Q N) did not, as compared to entirely quiet nights, cause significant alterations. In contrast noise in the beginning of the subjective night (N Q, N Q N) was associated with a significant reduction of SWS during the first sleep cycle and non-significant prolongations of SOL, SWSL and S0&1.

Table 1: Means and standard deviations (SD) of the differences between quiet and noisy conditions for three curfews (positive values indicate longer times in noisy nights). **: p ≤ 0.01, * p ≤ 0.05 in columns 2-4 indicate significant within-subject differences between noisy and quiet nights. Kruskal-Wallis and Wilcoxon tests concern the differences between conditions (temporal position of curfews).

	Exposure pattern Temporal position of curfews during nights						Kruskal -Wallis	Wilcoxon test		
	Q N (1)		**N Q N (2)**		**N Q (3)**			**1:2**	**1:3**	**2:3**
	mean ±	SD	mean ±	SD	mean ±	SD	p	p	p	p
			SOL and first sleep cycle							
SOL	1.7	± 7.6	12.7	± 19.4 **	2.0	± 8.7	0.06	0.02	0.46	0.06
SWSL	0.3	± 3.7	2.0	± 7.1 *	4.6	± 13.7	0.27	0.05	0.29	0.41
S0&1	0.8	± 3.1	1.8	± 3.0 *	1.8	± 7.1	0.41	0.12	0.46	0.27
SWS	-0.4	± 9.2	-7.2	± 10.7 **	-12.1	± 14.3 **	0.02	0.03	<0.01	0.52
			Whole nights sleep							
TST	-12.2	± 17.8 **	-23.3	± 23.0 **	0.7	± 22.6	0.27	0.28	0.06	<0.01
WASO	10.2	± 12.2 **	6.8	± 11.3 *	-3.9	± 18.9	0.06	0.44	0.01	0.06
SEI	-0.02	± 0.03 **	-0.02	± 0.03 *	0.01	± 0.05	0.08	0.72	0.02	0.05
SDI	0.58	± 0.79 **	0.66	± 0.68 **	0.12	± 0.90	0.20	0.84	0.09	0.05
SQ	-6.0	± 5.7 **	-7.9	± 6.3 **	-3.8	± 7.9	0.32	0.26	0.36	0.09

Concerning the whole night none of the physiological parameters or subjective evaluation differed significantly from the entirely quiet nights when the subjective nights were terminated with a curfew (N Q). But noise periods at the end of the nights were irrespective of the temporal position of the (Q N, N Q N) associated with worse sleep. WASO was then prolonged at the expense of TST, the SEI was lower and the SDI was higher; sleep quality was rated worse (see Fig. 2). The between-conditions tests confirm this, i.e. no significant differences between both the situations with noise at the end of the subjective night but these conditions differed from nights with a traffic curfew at the end.

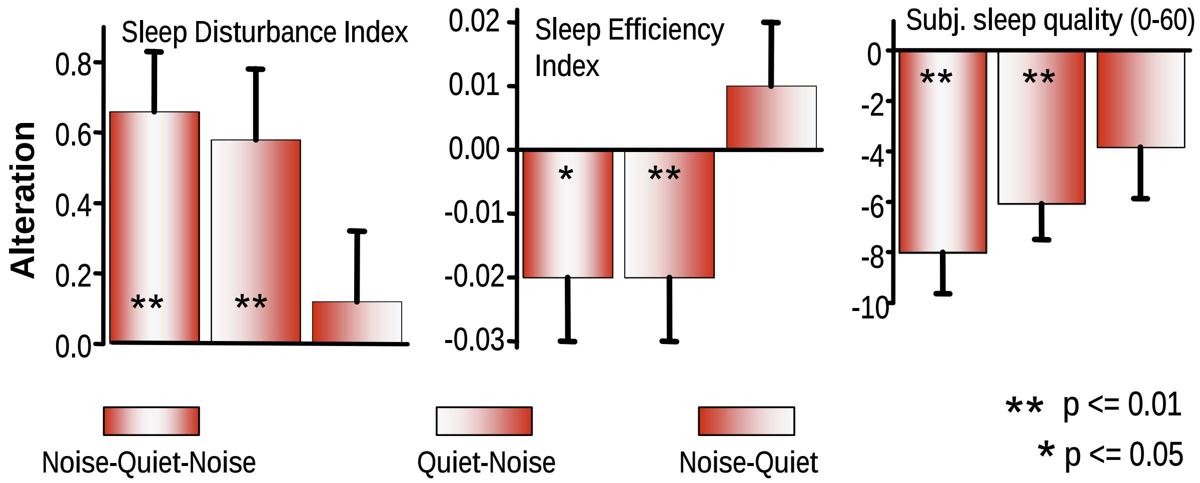

Figure 2: Alterations of the SDI, the SEI and subjective sleep quality during noisy nights with differently terminated curfews as compared to entirely quiet nights.

Comparison between persons with different bed times

The time frames of the curfews applied to 'normal' bed times (23–7 h). The assumption that persons with earlier or later bed times profit less from these regulations was tested for both the 4 hour curfews at the beginning and at the end of the night (Q N, N Q). The respective means and standard deviations of normal, early and late sleepers are listed in Table 2. The parameters of early and late sleepers were, using the Wilcoxon test, compared to those of normal sleepers. Figure 3 shows the alterations of the SDI.

Table 2: Means and standard deviations (SD) of selected sleep parameters of early, normal and late sleepers, separately for nights with evening or morning curfews. Wilcoxon-test for the comparison between early or late sleepers vs. normal sleepers: **: p ≤ 0.01, * p ≤ 0.05.

	Early sleepers		Normal sleepers		Late sleepers		
	mean	± SD	mean	± SD	mean	± SD	
			Curfew 23 – 3 h				
TST	410.5	± 37.0	433.6	± 8.3	414.3	± 26.8	
WASO	36.7	± 19.7	27.8	± 9.1	42.7	± 20.4	
SEI	0.92	± 0.04	0.94	± 0.02	0.91	± 0.05	
SDI	0.27	± 1.17	0.10	± 0.60	0.55	± 0.79	
SQ	30.3	± 5.9	32.6	± 6.7	30.2	± 4.8	
			Curfew 3 –7 h				
TST	430.1	± 16.6	437.9	± 7.7	406.0	± 31.2	**
WASO	21.4	± 8.4	23.3	± 3.6	35.5	± 14.6	*
SEI	0.95	± 0.02	0.95	± 0.01	0.92	± 0.04	**
SDI	-0.19	± 0.91	-0.17	± 0.52	0.49	± 0.70	*
SQ	35.8	± 5.0	36.2	± 8.2	29.7	± 7.5	

The evening curfew (23–3 h) was preceded by one hour in noise in early sleepers and reduced by 1 hour for late sleepers. But this did not cause a further worsening of sleep than in normal sleepers.

The morning curfew (3–7 h) was reduced to 3 hours for early sleepers. But none of the sleep parameters (Table 2) deviated significantly from those of the normal sleepers. But late sleepers for whom this curfew was followed by a single noisy hour had a significantly longer WASO, a lower SEI, a greater SDI and lower sleep quality.

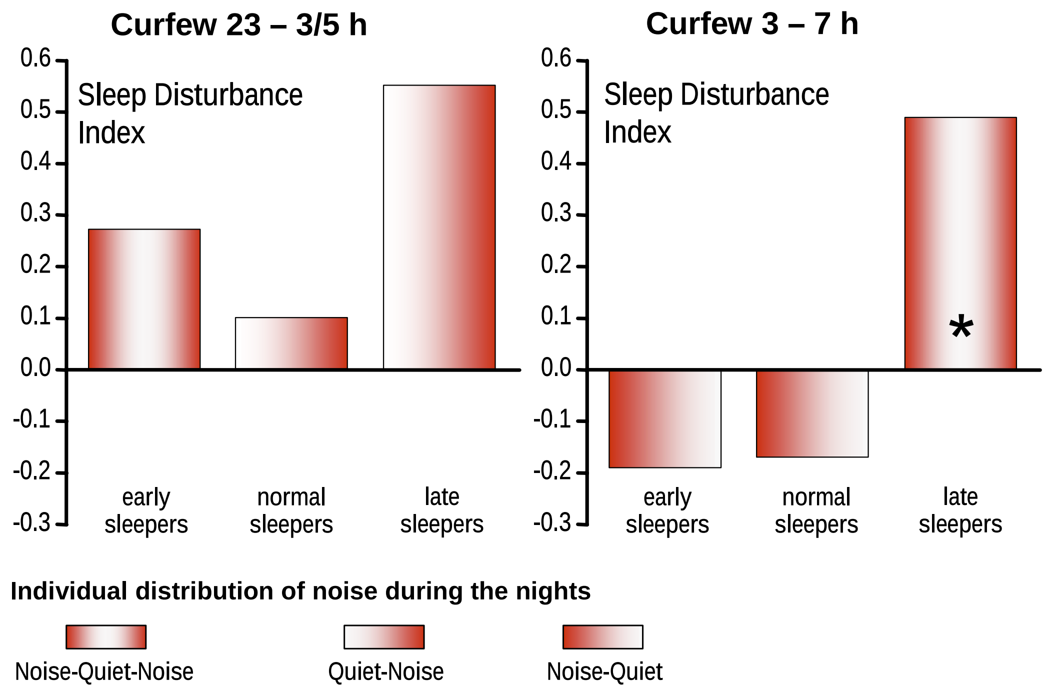

Figure 3: Alteration of the SDI in nights with different curfews as compared to entirely quiet nights in persons with different bed times.

DISCUSSION

Concerning noise abatement significant short-term alleviations are expected by the establishment of traffic curfews. This study focused therefore on the identification of time frames that provide the best relief. A few studies where noise was applied only in the early or in the late night dealt with noise from aircraft (Maschke 1992) and from military training camps (Griefahn 1989). The present study is the first that focused on the most frequent noise source, i.e. on noise from surface transportation (rail and road traffic). Further, as these time frames are oriented to the sleep behavior of the majority of the adult population this study considered in contrast to previous studies also persons who have habitually or due to their profession earlier or later bed times.

Noise in the beginning of the subjective night caused as expected a delay of sleep onset and deep sleep, a prolongation of the time awake and of sleep stage S1 on the costs of the time in deep sleep of the first sleep cycle. But these disturbances were obviously compensated when sleep was terminated in quiet. Then neither the physiological indicators of sleep nor the subjective evaluation of whole nights' sleep differed significantly from that of entirely quiet nights. Similar observations were already reported for the effects of sonic booms, noises from military training camps or aircraft (Griefahn 1989; Maschke 1992). As indicated by the data of the early sleepers a three hours quiet at the end of the subjective night is probably sufficient for complete compensation. But as soon as this period was followed by an even short noise exposure none of the curfews was beneficial.

Evening curfews that are irrespective of the individual bed times followed by a noise period were associated with considerable disturbances. Concerning the morning curfew, however, persons with normal and with early bed times did not sleep worse than during entirely quiet nights. But persons with late bed times, for whom this curfew was followed by one hour in noise slept then significantly worse. Thus temporally limited curfews are only useful when the subjective night is terminated in quiet. The greater vulnerability during the late night is certainly related to the lower sleep depth and the then elevated sympathetic tone.

There are of course some limitations. The participants were young and healthy. It is conceivable to assume that the differences in the beneficial effect of morning and evening curfews are smaller in older persons whose sleep becomes flatter (Bliwise 2005; Griefahn 1985). The differences might also be less when these curfews are established in the field because reactions in the field are usually less than in the laboratory (e.g. Basner et al. 2004).

CONCLUSIONS

This study concerns the value of different time frames of traffic curfews to avoid sleep disturbances due to noises emitted from rail and road vehicles. It has shown that traffic curfews are beneficial only at the end of the subjective night, where a 3 hours period would be sufficient. Only then whole nights' sleep deviates scarcely from that of entirely quiet nights. Any, even short noise periods at the end of the subjective night cause prolongations of intermittent wakefulness, reduced sleep efficiency, increases of the SDI and a reduction of subjective sleep quality. This implies that late sleepers benefit scarcely from these regulations as their subjective night always ends with a noisy period.

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