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EFFECTS OF NOISE ON SLEEP IN SHIFT WORKERS

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ABSTRACT

Introduction. This study focused on the effects of noise on sleep at night and day and on after-effects i.e. sleepiness and impaired performance during a following 8-h work shift.
Methods. Forty-eight persons (23 male, 25 female; 19-30 yrs) slept in a balanced order four consecutive nights (23-7 h) and four consecutive days (14-22 h) in the laboratory and performed thereafter 8-h work shifts in the morning or in the night, respectively. Sleep was indicated by the Sleep Efficiency Index (SEI) and the Sleep Disturbance Index (SDI). Sleepiness was rated after awakening and hourly during work shifts, and during the latter followed by four performance tests. The first and another randomly chosen sleep period were noise-free. During the six other sleep periods the participants were exposed to railway and to road traffic noise with equivalent noise levels between 41 and 56 dBA.
Results. SEI and SDI indicated worse sleep during days than during nights but were only moderately affected by noise. Sleepiness was the only variable where noise and shift type showed an interaction. Soon after awakening sleepiness was rated higher after night than after day sleep and higher after noise exposure during sleep. Sleepiness was after sleep in noise throughout the work shifts higher than after sleep in quiet and reaction times were then prolonged.
Conclusion. The same noise had the same effect on day sleep and on night sleep. In the real life situation noise is about 8 to 15 dBA higher during the day than during the night suggesting stronger sleep disturbances of day sleep.

INTRODUCTION

Night work is an essential prerequisite for the functioning of human societies. Yet this type of work is critical as work is done when performance capacity is low and sleep is scheduled for a time when performance capacity is high. The consequences of night work are sleep disturbances with dramatically reduced sleep duration due to intermittent and premature awakening. Sleep deficits accumulate over successive night shifts thus causing increasing sleepiness and performance decrements during work [Åkerstedt 2007]. The main reason for sleep disturbances is related to the disturbed circadian phase but likely enhanced by environmental noise that is by 8 – 15 dB higher during the day than during the night.

Most studies performed so far focused exclusively on the effects of nocturnal noise on sleep. Moreover, after-effects such as sleepiness and impaired performance were mainly ascertained shortly after awakening. Observations during the following work periods were not yet done. The present study focuses therefore on sleepiness and on cognitive performance during 8-hour work shifts in the morning and in the night after the participants had spent 8 hours in bed during the night or during the day respectively, either in quiet or in noisy conditions.

MATERIAL AND METHODS

Participants. Forty-eight healthy and normal hearing students (23 male, 25 female; 19 – 30 yrs) participated and gave their written informed consent to the study which was approved by the local Ethics Committee. They were according to the Pittsburgh Sleep Quality Index good sleepers (PSQI [Buysse et al. 1989]).

Experimental design. The participants worked in a balanced order four consecutive early shifts (8-16 h) and four consecutive night shifts (23-7 h). Each shift was preceded by 8 hours in bed (23-7 h before early shifts, 14-22 h before night shifts). The first and another randomly chosen sleep period were noise-free. During the six other sleep periods the participants were three times each exposed to railway and to road traffic noise with the restriction that each person was exposed once to the conditions Rail4 and Road4 (see below).

Experimental procedure. The participants arrived at the institute two hours before bedtime. After the fixation of the electrodes for the registration of the polysomnogram (PSG) they went to bed and were woken up 8 hours later. They then estimated their actual sleepiness. Work shifts started 1 h after the wake- up call by the experimenter. During that 8-h work shifts the participants completed performance tests every hour for about 25 minutes. They were allowed to read, to write or to communicate between the tests.

Technical equipment, noise load. Participants slept in separate sound shielded rooms that were equipped with two loudspeakers each. The background noise produced by the air conditioning was 28 dBA and was during six sleep periods superimposed by noise scenarios. The latter were recorded along three railway tracks at three distances each and in three roads at two distances each (see Table 1). Recordings were then filtered and attenuated by at least 15 dB to simulate tilted windows. Thus, this paper refers to indoor levels at the sleepers' ears.

Table 1. Equivalent noise levels for the rail and road scenarios at the ear of the sleeper.

Recording distance	Number of train pass-bys (2200 – 0600 h)		
	n = 20	n = 40	n = 58
100 m	41.9 dB Rail 1	46.3 dB Rail 3	
50 m	44.9 dB Rail 2	49.4 dB Rail 4	50.5 dB Rail 5
25 m		53.5 dB Rail 6	54.3 dB Rail 7
	Number of road vehicles (2200 – 0600 h)		
	n = 1 300	n = 4 300	n = 8 600
32 m		41.2 dB Road 1	
26 m			49.1 dB Road 6
20 m	42.3 dB Road 2	44.6 dB Road 4	
15 / 14 m	43.1 dB Road 3	(44.6+4)dB Road 5*	55.9 dB Road 7

Data collection and evaluation

The polysomnogram (PSG) was recorded throughout the time in bed. Parameters derived from each PSG were

- Sleep Efficiency Index (SEI = TST/SPT, where SPT denotes the time between initial sleep onset and final sleep offset and TST i.e. the difference of SPT – intermittent wakefulness) and the
- Sleep Disturbance Index (SDI [Griefahn et al. 2008]) that integrates seven sleep parameters (sleep onset latency [SOL], latency to slow wave sleep [SWSL], intermittent wakefulness [wakefulness after sleep onset = WASO], times spent in sleep stages S1, SWS [stages S3 plus S4], SREM, number of awakenings longer than 3 minutes) and allows a reliable and valid estimate of alterations of sleep structure.

Saliva sampling. Beginning with work onset saliva samples were collected hourly during work shifts using cotton wool swabs (Salivette™) that were moved within the mouth until soaked. The swabs were then centrifuged and saliva was stored at -20 °C until assayed. Analysis was performed with a luminescence immunoassay (LIA, IBL) where the detection limit was 0.16 ng/ml saliva.

Sleepiness was rated after awakening as well as hourly during each work shift while using the Karolinska Sleepiness Scale (KSS).

Performance tests. Four performance tests that were trained 7 days prior to the experiments were hourly performed in a random order. Three tests (GN, DAT, WMT) were taken from the test battery of attentional performance (TAP [Zimmermann & Fimm 2002]). These were:

- **Selective Attention Test (Go/Nogo).** The test consists of five differently patterned squares that occur in a random sequence in the centre of the screen for 150 ms each. A key must be pressed if either of two previously shown squares (the target stimuli) occurs. Pressing the key on presentation of a non-target stimulus is counted as an error. A total of 200 trials (33 targets, 67 non-targets) were given.
- **Divided Attention Test (DAT).** A visual and an auditory task are given simultaneously. On the visual task (DATv), a series of 10x10 cm squares are displayed in the centre of the screen for 1 500 ms each. A matrix consists of a regular array of sixteen dots (4x4) with seven randomly superimposed "x". A key must be pressed whenever four "x"s form a small square. The auditory task (DATa) consists of a series of alternating high (2 000 Hz) and low (1 000 Hz) tones (Di – Da – Di – Da). A key must be pressed in case of any deviation from this regular sequence (e.g. Di – Di or Da – Da). From overall 150 stimuli, 20 are visual and 21 auditory targets.
- **Working Memory Test (WMT).** This task is a two-back task, where the participant monitors a series of digits and has to press a button whenever a digit is the same as the penultimate digit. Every of the 100 numbers is presented for 1 500 ms. 15 numbers are targets.
- **Psychomotor Vigilance Task (PVT).** The PVT runs for a period of 10 minutes. The participants must press a key as soon as a millisecond counter starts to count after random intervals of 1 to 10 seconds. After the key is pressed, the counter displays the last number, thus giving a feedback before the counter restarts. Lapses are defined by reaction times < 150 ms or > 500 ms.

RESULTS

A 2x2 ANOVA, where shift type and noise conditions were considered, was done first with all sleep parameters (including the 9 parameters that contribute to the sleep efficiency and to the sleep disturbance index) and with all after effects. There was only one significant interaction between noise and shift type. Sleepiness as measured with the KSS was after sleep in noise almost the same after day and after night sleep but higher after night sleep than after day sleep ($p = 0.041$). Thus, the data were combined for further analyses.

Table 2 presents SEI, SDI and KSS averaged over sleep in respectively after sleep during nights and days as well as averaged over sleep in respectively after sleep in quiet and sleep in noise. Table 3 shows sleepiness and performance data ascertained hourly during day shifts and during night shifts, as well as during shifts after sleep in quiet and after sleep in noise. Figures 1 and 2 depict the courses of sleepiness and reaction times as measured with the PVT during the day shifts and during the night shifts as well as during work shift after sleep in quiet and after sleep in noise.

Night sleep vs day sleep

Both sleep parameters SEI and SDI indicated worse sleep during the day than during the night (Table 2) and sleepiness was higher after night sleep than after day sleep. Only SEI and KSS revealed a tendency for significance. As shown in Table 3 sleepiness was significantly greater and performance

Table 2. Sleep parameters and sleepiness. Left: noise free sleep during night and day. Right: sleep in quiet vs sleep in noise. SEI: Sleep efficiency index, SDI: Sleep disturbance Index, KSS: Karolinska sleepiness scale

Dependent variables	Type of shift			Effect of noise		
	night sleep	day sleep	Signifi-cance	sleep in quiet	sleep in noise	Signifi-cance
SEI	0.96 ± 0.03	0.92 ± 0.07	+	0.94 ± 0.06	0.93 ± 0.06	
SDI	-0.66 ± 0.85	-0.54 ± 1.26		-0.60 ± 1.07	-0.09 ± 1.10	**
KSS	3.9 ± 1.2	3.2 ± 1.1	+	3.5 ± 1.2	3.9 ± 1.1	+

Table 3. Sleepiness and performance during day- and night shifts, respectively during shifts after sleep in quiet and sleep in noise. Means and standard deviations calculated for the whole shifts. rt: reaction time in ms, noe: number of errors

	Type of shift			Effect of noise		
	Day shift after night sleep	Night shift after day sleep	p-value	Shift after sleep in quiet	Shift after sleep in noise	p-value
Sleepiness,	2.7 ± 0.8	3.0 ± 0.9	**0.010**	2.6 ± 0.8	2.9 ± 0.9	**0.002**
Go-Nogo, rt	612.3 ±114.9	630.8 ±141.3	0.188	601.4 ±108.7	628.3 ±134.6	0.084
Go-Nogo, noe	1.4 ± 1.6	1.6 ± 1.9	0.893	1.3 ± 1.31	1.5 ± 1.9	0.292
DAT, audit., rt	1477.3 ± 87.9	1479.5 ±102.8	0.847	1500.6 ± 83.6	1471.0 ± 98.3	**0.010**
DAT, audit., noe	1.3 ± 1.5	2.1 ± 2.4	**0.003**	1.4 ± 1.8	1.7 ± 2.1	0.199
DAT, visual, rt	594.8 ± 72.2	610.3 ±101.8	0.245	599.7 ± 67.9	603.5 ± 94.7	0.245
DAT, visual, noe	0.5 ± 0.5	0.7 ± 0.9	0.313	0.6 ± 0.5	0.6 ± 0.8	0.774
WMT, rt	748.2 ±173.1	770.2 ±212.4	0.355	725.9 ±166.6	770.3 ±200.9	0.057
WMT, noe	2.0 ± 2.0	2.8 ± 2.7	**0.018**	2.0 ± 2.1	2.5 ± 2.5	0.097
PVT, rt	285.9 ± 56.5	320.7 ±120.4	**0.004**	280.3 ± 65.2	311.2 ±103.1	**0.006**

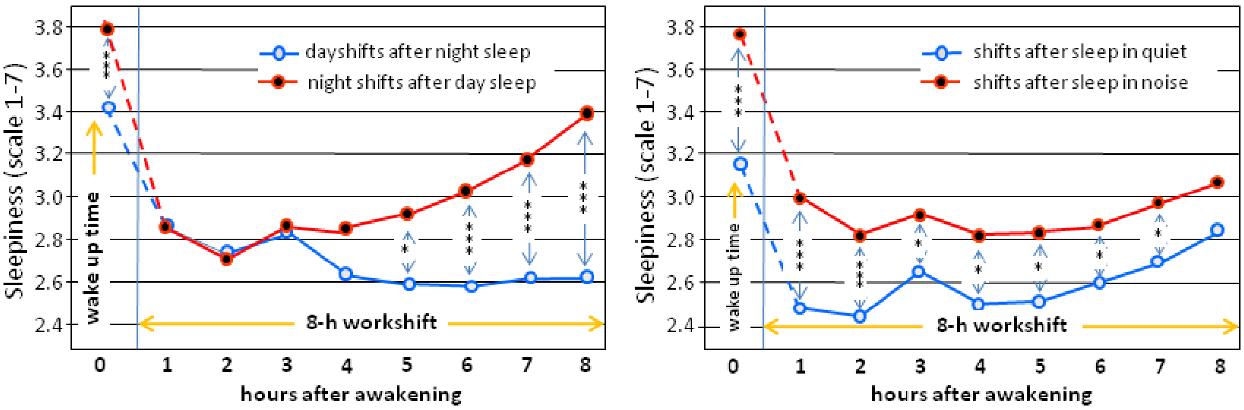

Figure 1. Courses of hourly ascertained sleepiness. Left panel: during day and night shifts. Right panel: after night and after day sleep. $p \leq 0.05$: *, $p \leq 0.001$: ***

was worse during night shifts than during day shifts. Reaction time in the PVT was longer and the number of errors in the DATa and in the WMT was higher during night than during day shifts. According to Figure 1 sleepiness was immediately after the wake-up call significantly higher but decreased steeper after night than after day sleep. Sleepiness was then similar during the first three hours of the day and of the night shifts. Thereafter it remained on a low level during day shifts but increased gradually during night shifts. Similarly to sleepiness reaction times were almost the same during the first three hours of both shifts. Thereafter error rates increased moderately during the day but considerably steeper during the night shifts thus revealing as shown in Figure 2 a tendency for a gradually increasing difference.

Effects of noise

The SDI was significantly greater during noisy as compared to noise-free sleep periods. Sleepiness after awakening was significantly higher after noisy than after quiet nights. In both situations sleepiness decreased within the next hour and increased again gradually but slightly towards the end of the work shifts. Apart from the last hour sleepiness remained significantly greater after noisy than after quiet nights.

Concerning performance the quantitative aspects of performance (reactions times) were more associated with noise during sleep than the qualitative aspects (number of errors).

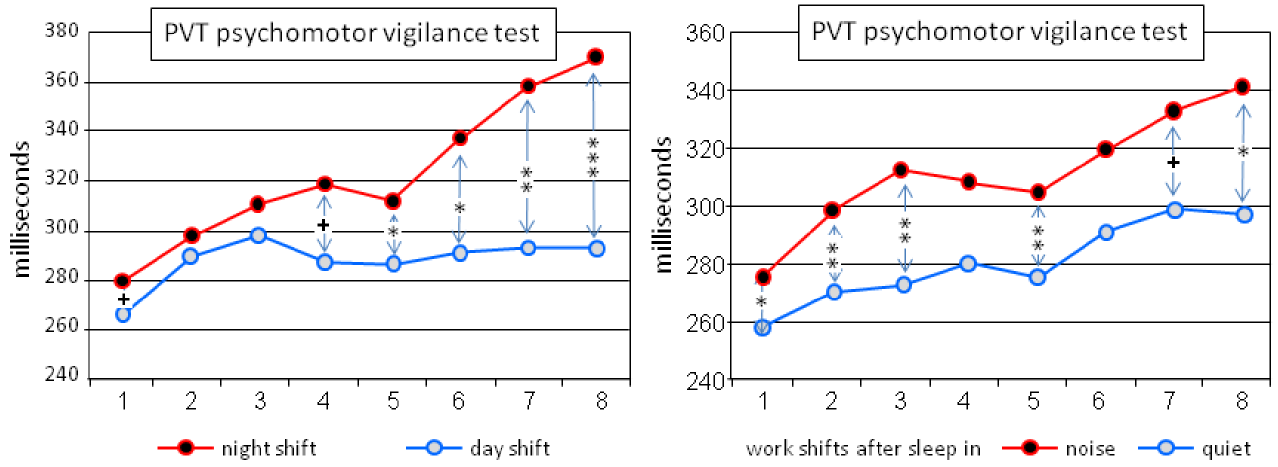

Figure 2. Courses of hourly ascertained reaction times in the PVT. Left: during day and night shifts. Right: after night and after day sleep. $p \leq 0.05$: *, $p \leq 0.1$: +, $p \leq 0.05$: *, $p \leq 0.01$: **, $p \leq 0.001$: ***.

Performance impairment was almost equally spread over the eight hours of the shift. Reaction times after sleep in noise were significantly longer in the PVT, the GN and the WMT but significantly shorter for the auditory part of the DAT. The number of errors in the WMT revealed a tendency for more errors after noisy than after quiet nights.

DISCUSSION

Though up to 20 % of the work force is involved in shift work, the effects of noise on day sleep were only occasionally studied. This study is the first that concerned the simultaneous influence of both factors on sleep, on sleepiness and on performance during the following work shift. For this, 48 persons worked four consecutive 8-h work shifts each during the day and during the night in a balanced order. Each shift was preceded by an 8-h period in bed, during which the participants slept in quiet or were exposed to traffic noise with equivalent noise levels between 41.9 and 55.9 dBA.

A few studies on the effects of noise on day sleep were done in the early 70s and in the late 90s with a rather limited number of participants [Knauth & Rutenfranz 1972, Nicolas et al. 1993]. Due to these early studies it was expected that noise has a stronger effect on day sleep than on night sleep. In the real situation the equivalent noise levels are by 8-15 dBA higher during days than during nights. But as the reagibility per se was to be studied it was decided to expose the participants to the same noise scenarios during the day as during the night. As the extents of sleep disturbances were the same stronger reactions are expected in the real situation due to the higher noise levels. In addition daytime noise scenarios contain several noises that are kown to be particularly disturbing such as telephone and door bells, noises from the neighbourhood and from children.

As expected, sleep was disturbed during daytime and by intruding traffic noise. The extent of the disturbances was less than expected and there were – most surprisingly – apart from sleepiness no interactions between the temporal location of sleep (the shift type) and the influence of noise. This leads to the conclusion that noise had, at least in this experiment, the same effect on day sleep as on night sleep. Therefore, the sleep parameters ascertained during night and during day sleep and the data ascertained during day and during night shifts were combined for the presentation of the effects of traffic noise.

Effects of the temporal location of sleep and of noise on sleep structure

Concerning the temporal location of sleep that is a consequence of the shift type both of the integrated physiological sleep parameters, the SEI and the SDI, revealed worse sleep during the day than during the night. The impact of the shift type on sleep was repeatedly reported by numerous studies performed in the laboratory and in the field. In fact sleep disturbances are an almost essential concomitant of shift work [e.g. Åkerstedt et al. 2002]. Extended polysomnographic studies performed in the field have additionally shown that total sleep time, sleep stage 2, sleep stage REM and/or slow wave sleep were significantly reduced during day as compared to night sleep [Åkerstedt et al. 1995, Tilley et al. 1982].

These variables, the SEI and the SDI, were however much less affectd by noise during sleep than expected though the detailed analysis has shown a significant dose-response relation for the probability of event-related awakenings due to railway noise. Such a discrepancy between event-related awakenings and integrated measures is verified by other studies and indicates the ability of the organism to recover soon from acute sleep disturbances [Basner et al. 2004, Griefahn et al. 2006, Marks et al. 2008].

Effects of shift type and of noisy sleep on sleepiness

Concerning the shift type sleepiness was immediately after awakening significantly higher after night than after day sleep. This is most likely due to the 'sleep inertia' i.e. a state of disorientation and dizziness that occurs after awakening and lasts several minutes up to half an hour and is associated with reduced vigilance and impaired performance [e.g. Tassi and Muzet 2000]. The higher sleepiness after night work is explained by the fact that the participants woke up more frequently before the official wake-up call by the experimenter after day sleep than after night sleep. This means the participants were longer awake and thereby less sleepy when they evaluated their sleepiness than after night sleep where less time elapsed between awakening and the evaluation of sleepiness. Sleepiness decreased then considerably and reached similar values at the beginning and during the first two hours of the day and of the night shift. Thereafter sleepiness remained then on a level during day shifts but increased gradually during night shifts leading to an increasing difference of sleepiness between day and night shifts. These observations are in line with other studies [e.g. Baulk 2009, Spencer et al. 2006].

Concerning noise exposure sleepiness was soon after awakening rated higher after sleep in noise than after sleep in quiet. This is supported by the results of several other studies where sleepiness was not only evaluated higher after nocturnal noise exposure but where sleepiness was objectively verified by an increased pupillary unrest index [Basner et al. 2008, Bonnefond et al. 2008, Griefahn et al. 2006].

Further to other studies sleepiness was ascertained hourly during the following eight hours of the work shift. The data revealed that sleepiness remained to be higher after sleep in noise than after sleep in quiet throughout the entire 8 hours of work shifts.

Effects of shift type and of noise exposure during sleep on performance

Performance tests soon after awakening were done in numerous studies. The results were, however, ambiguous. Where only a few researchers found impairment, most researchers did not find any alterations. This might be due to the following reasons:

- The extent of sleep disturbances is too small to impair cognitive performance.
- The tests are not sensitive enough or not adequate to reveal performance decrements.
- The extent of the decrement can be compensated by motivation.
- Sleep inertia interferes with performance tests shortly after awakening.

Moreover, the relevance of tests performed immediately after awakening is questionned. Impairments are of concern if they persist over a longer time period, e.g. a work shift. Therefore performance in this study was ascertained hourly over a full 8-hour experimental work shift that started one hour after awakening.

As performance decrements in former studies primarily concerned executive functions the performance tests were chosen under this aspect [LeVere et al. 1972, 1975, Öhrström 2000], and because they had been shown to be affected by circadian disturbances [e.g. Wilkinson & Houghton 1982] and by noise [e.g. Elmenhorst et al. 2010].

Concerning the type of shift sleepiness was similar during the first two hours of the work shifts irrespective of the daytime. Thereafter, however, sleepiness remained on a level during day shifts but increased gradually towards the end of the night shifts. The decrease of performance which concerned more the qualitative aspects, namely the number of errors, than the quantitative aspects, namely reaction time that was only degraded for the PVT, showed a similar course as for sleepiness (see Figures 1 and 2). These alterations are supported by several other studies.

Each of the four tests applied here revealed performance decrements. In contrast to the daytime effects these impairments concerned the quantitative aspects, i.e. the reaction time rather than the qualitative aspects, i.e. the number of errors or missings. In addition the impairments due to noise exposure were spread over the whole shift. This applied for the reaction times ascertained for the vigilance-, the Go/Nogo- and the working memory task which were prolonged during shifts after sleep in noise as well as the error rate which increased for the memory test. These results are confirmed by former studies [Basner et al. 2008, Bonnefond et al. 2008, Elmenhorst et al. 2010,Griefahn et al. 2006, Marks & Griefahn 2005, Öhrström 1995] that were, however restricted to the first hour post-awakening. The study performed here revealed that the after effects of noise-disturbed sleep carries on for the entire work shift.

The shortening of the reaction time of the auditory part of the DAT surprises at the first glance. That a sensitization to auditory stimuli might have taken place is a rather speculative assumption which is, however, not entirely excluded. Several studies have shown that the brain is even during sleep able to perceive external stimuli, to analyse them and to react adequately [see Bastuji et al. 2002]. It might be that this leads to an increased readiness to react to acoustic stimuli during the consecutive time awake.

CONCLUSIONS

Overall noise exposure during sleep caused, irrespective of the temporal location of sleep (night, day), alterations of sleep structure, increased sleepiness and impaired performance during the consecutive work shift. However, as day sleep was worse than night sleep, the effects of noise are regarded as relatively worse. In the real life situation noise effects are expected to be much stronger as the equivalent noise levels are by about 8 to 15 dBA higher during the day than during the night. Moreover, daytime noise scenarios contain a lot of particularly disturbing noises such as doorbells, telephone bells, refuse collection etc.

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