Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Journal of Sound and Vibration 277 (2004) 453–457
JOURNAL OF SOUND AND VIBRATION
www.elsevier.com/locate/yjsvi

Cortisol response and subjective sleep disturbance after low-frequency noise exposure

K. Persson Waye[a,*], A. Agge[a], A. Clow[b], F. Hucklebridge[b]

[a]*Department of Environmental Medicine, Göteborg University, Box, 414, 40530 Gothenborg, Sweden*
[b]*Department of Psychology, University of Westminster, London, UK*

Accepted 25 March 2004
Available online 27 July 2004

Abstract

A previous experimental study showed that the cortisol response upon awakening was reduced following nights with low-frequency noise exposure. This study comprised a larger number of subjects and an extended period of acclimatisation nights. In total, 26 male subjects slept during five consecutive nights in a sleep laboratory. Half of the subjects were exposed to low-frequency noise (40 dBA) on the 4th night and had their reference night (24 dBA) on the 5th night, while the reverse conditions were present for the other half of the group. Subjective sleep disturbances were recorded by questionnaires and cortisol response upon awakening was measured in saliva. The results showed that subjects were more tired and felt less socially orientated in the morning after nights with low-frequency noise. Mood was negatively affected in the evening after nights with low-frequency noise. No effect of noise condition was found on the cortisol secretion. There was a significant effect of group and weekday, indicating that further methodological developments are necessary before saliva cortisol secretion can be reliably used as an indicator of noise-disturbed sleep.

1. Introduction

Little is known of how low-frequency noise (<200 Hz) affects sleep, but reports from case studies indicate that persons exposed to low-frequency noise had difficulties of falling asleep and

*Corresponding author: Tel.: +46-31-7733604; fax: +46-31-825004.
E-mail address: kerstin.persson@envmed.gu.se (K. Persson Waye).

0022-460X/$ - see front matter
doi:10.1016/j.jsv.2004.03.004

that they felt very tired in the morning. In a previous study, increased levels of cortisol in urine were found among children chronically exposed to heavy vehicle traffic noise [1]. A previous experimental study showed that the cortisol response upon awakening was reduced following low-frequency noise exposure during the night [2]. The present study is an extension of the experimental study, comprising a larger number of subjects and an extended number of acclimatisation nights.

2. Materials and methods

Twenty-six male, normal hearing students with an average age of 26 years (SD = 4.3) slept in a sleep laboratory for five consecutive nights. Half of the subjects were exposed to low-frequency noise on the 4th night and had their reference night with no exposure on the 5th night while the reverse conditions were present for the other half of the group (Table 1).

Saliva samples for cortisol determination were taken immediately after wake up, and after 15, 30 and 45 min. Subjective evaluations of sleep and mood were obtained using questionnaires in the morning and in the evening. During the acclimatisation nights and reference nights, the A-weighted sound pressure level from the normal ventilation was 24 dB. The low-frequency noise was a recorded wide-band ventilation noise to which was added a dominant 50 Hz tone, sinusoidally amplitude modulated (100%) with a modulation frequency of 2 Hz. Fig. 1 shows the average values and standard deviations of the third octave band sound pressure level of the low-frequency noise in relation to the normal background sound from ventilation and the normal hearing threshold [3]. The values for the low-frequency noise are based on measurements at five positions on the pillow in each bedroom, in total 15 measurement positions. The low-frequency noise had an A-weighted sound pressure level of 40 dB. The low-frequency noise was played continuously with two interruptions at 00.30h to 01.00h and 04.30h to 05.00h. During these interruptions the low-frequency noise was reduced to the background sound level.

3. Statistical treatment

The amounts of cortisol were analysed as the square root of the measurements in order to normalise initially skewed distributions. Responses after nights with low-frequency noise were analysed in relation to the reference night by a 4 (sampling periods) $\times$ 2 (exposure conditions) $\times$ 2 (groups) analysis of variance (ANOVA). The first two conditions were within-subject factors and group was a between-subject factor. Subjective data were analysed using non-parametric statistical tests. All tests were carried out two-sided and a p-value of less than 0.05 is reported as statistically significant.

Table 1
Design of the study (Accl = acclimatisation nights, Ref = reference night, LFN = nights with low-frequency noise exposure)

Group	Night 1	Night 2	Night 3	Night 4	Night 5
I	Accl 1	Accl 2	Accl 3	LFN	Ref
II	Accl 1	Accl 2	Accl 3	Ref	LFN

4. Results

The median values of sleep quality (ranges 0 = good to 10 = bad) over the week for all subjects were 5.4, 3.7 and 3.6 during the three acclimatisation nights, 3.8 after the reference nights and 4.7 after nights with low-frequency noise. After the initial acclimatisation night, the sleep quality was thus rather stable and no significant differences between nights and hence noise conditions were found ($\chi^2 = 3.481$, df = 4, $p = 0.48$). No difference was found between groups. Tiredness in the morning was reported to a significantly higher degree after nights with low-frequency noise exposure ($z = -2.185$, $p = 0.029$, Table 2). No difference was found for estimated tiredness in the afternoon and in the evening, and no significant differences was found between groups. Subjective irritation followed the same pattern with a borderline significantly higher rating in the morning following nights with low-frequency noise exposure ($z = -1.943$, $p = 0.052$).

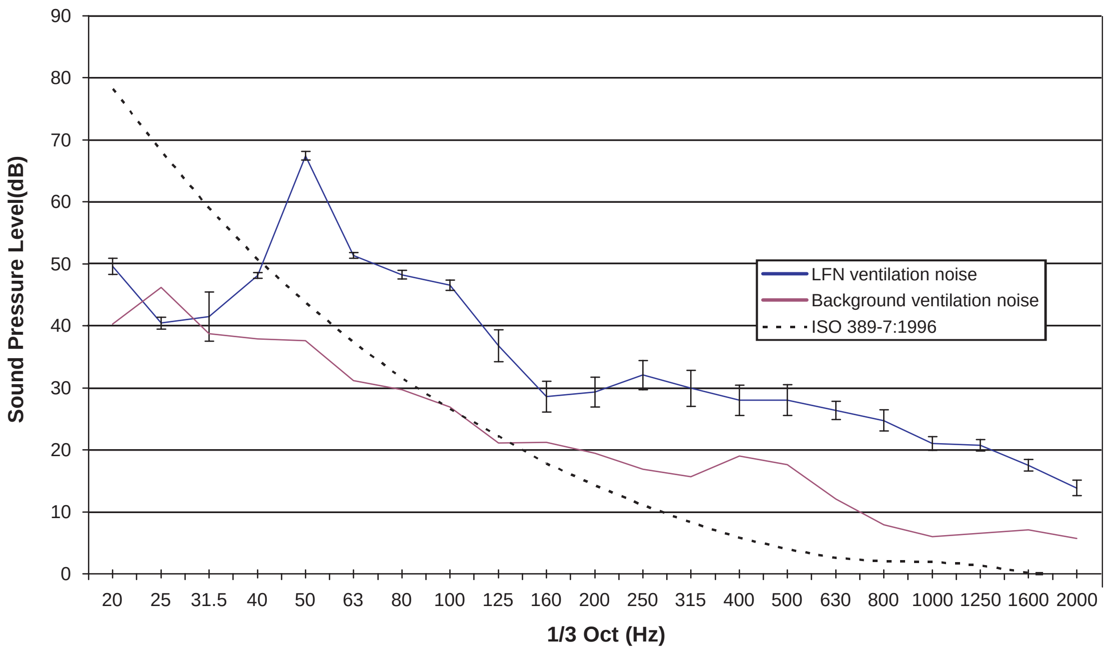

Fig. 1. Third octave band sound pressure levels of the low-frequency noise and the background sound from the normal ventilation in relation to the normal hearing threshold (ISO 389-7:1996). Vertical bars represent ±standard deviations.

Table 2
Median values of reported tiredness in the morning and evening after reference nights (Ref) and nights with low-frequency noise exposure (LFN)

Tiredness	Ref	LFN	Significance value
Morning (0–10)	4.8	6.5	$p = 0.029$
Afternoon (0–10)	4.8	5.5	NS
Evening (0–10)	5.7	6.8	NS

Table 3
Median values of reported mood in the evening after reference nights (Ref) and nights with low-frequency noise exposure (LFN)

Mood evening (1–4)	Ref	LFN	Significance value
Activity	3.00	2.43	NS
Extroversion	2.81	2.63	$z=-2.243$, $p=0.015$
Hedonic tone	3.08	3.00	$z=-2.208$, $p=0.027$
Social orientation	3.09	2.91	$z=-2.263$, $p=0.024$
Security	3.18	3.00	NS
Relaxation	3.00	3.00	$z=-1.959$, $p=0.05$

Of the mood dimensions, social orientation in the morning was rated lower after nights with low-frequency noise exposure compared to the reference night (median value 2.86 vs. 3.0, $z = -1.959$, $p=0.051$). No difference was found for the other mood dimensions reported in the morning. The median values of rated mood in the evenings after the reference nights and nights with low-frequency noise are given in Table 3. As can be seen extroversion, hedonic tone, social orientation and relaxation were rated significantly lower in the evenings following nights with low-frequency noise as compared to evenings after reference nights.

No significant differences were found between exposure conditions for time to fall asleep, number of times waking up during the night, and reported tension in the morning.

For the total group, the expected cortisol response after awakening with levels reaching a peak at 30 min was found and the main effect of sampling time after wake up was significant ($F(3)=24.8$, $p<0.001$). No significant main effect for noise condition or significant interaction between noise condition and sampling time was found. The response pattern varied between the two groups, and a significant interaction between noise, time and group was found ($F(1.492)=9.3$, $p = 0.001$, Fig. 2). The data indicated that the cortisol response pattern for group I after low-frequency noise was similar to group II after reference nights and that the response pattern for group II after low-frequency noise was similar to group I after reference nights. As the responses after low-frequency noise were obtained at different weekdays (Thursday vs. Friday) for the two groups, the influence of weekday was added to the analysis. A significant interaction between the day of the week and response of cortisol ($F(1.492)=9.3$, $p = 0.001$) was found while no significant effect was found between groups.

5. Concluding comments

This study found that certain subjective sleep parameters were affected by low-frequency noise, which is largely in accordance with a previous study [2]. No effect was found of low-frequency noise exposure on the cortisol response upon wake up. Data indicate that the response was influenced either by group or weekday. We could not detect any group-related differences that could explain the difference in cortisol response, however a recent study measuring cortisol in urine over a period of 40 nights [4] found a weekday rhythm in cortisol secretion, which supports

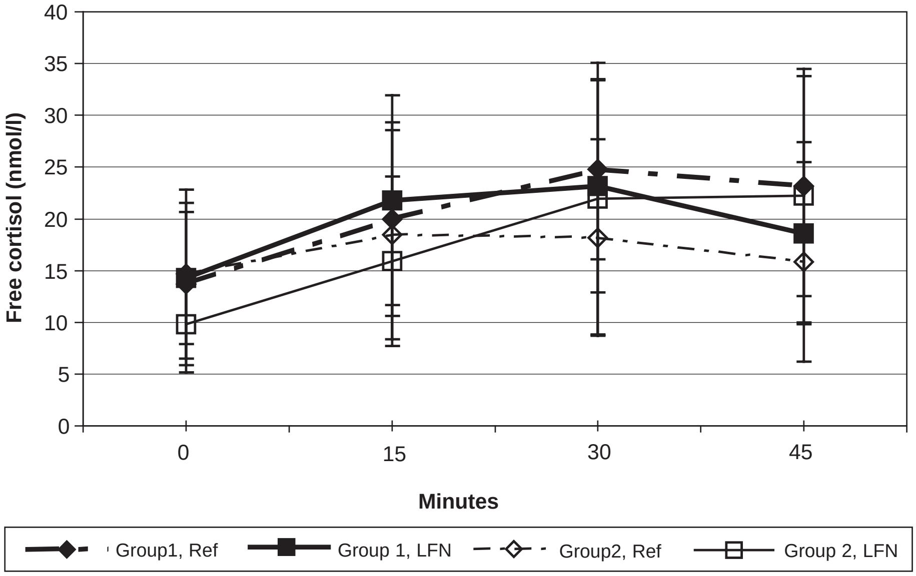

Fig. 2. Cortisol response for the two groups in the morning after the reference night and the night with low-frequency noise exposure. Cortisol response after nights with low-frequency noise are marked with unbroken lines. Diamonds are used for group I and squares for group II. Vertical bars represent standard deviations. For clarity only positive or negative values are shown.

an hypothesis of a weekday variation. The interference with different response pattern for weekdays may be one explanation for the inconsistent results between this and the previous study. These results emphasises the need to further study methodological aspects related to cortisol response upon awakening as an indicator of noise-disturbed sleep.

Acknowledgements

The study was funded by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), Grant number 2001-0502.

References

[1] H. Ising, M. Ising, Chronic cortisol increases in the first half of the night caused by road traffic noise, *Noise and Health* 4 (2002) 13–21.

[2] K. Persson Waye, A. Clow, S. Edwards, F. Hucklebridge, R. Rylander, Subjective symptoms and saliva cortisol response after wake up after exposure to low frequency noise and traffic noise during sleep, *Life Sciences* 72 (2003) 863–875.

[3] ISO 389-7, Acoustics reference zero for the calibration of audiometric equipment Part 7: reference threshold of hearing under free-field and diffuse-field listening conditions, 1996.

[4] C. Maschke, J. Harder, H. Ising, K. Hecht, W. Thierfelder, Stress hormone changes in persons exposed to stimulated night noise, *Noise and Health* 5 (2002) 35–45.