Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise

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Abstract

In order to determine the influence of noise sensitivity on sleep, subjective sleep quality, annoyance, and performance after nocturnal exposure to traffic noise, 12 women and 12 men (age range, 19-28 years) were observed during four consecutive nights over a three weeks period. After a habituation night, the participants were exposed with weekly permuted changes to air, rail and road traffic noise. Of the four nights, one was a quiet night (32 dBA), while three were noisy nights with exposure to equivalent noise levels of 39, 44, and 50 dBA in a permuted order. The traffic noise caused alterations of most of the physiological parameters, subjective evaluation of sleep, annoyance, and performance. Correlations were found between noise sensitivity and subjective sleep quality in terms of worsened restoration, decreased calmness, difficulty to fall asleep, and body movements. The results suggest that alterations of subjective evaluation of sleep were determined by physical parameters of the noise but modified by individual factors like noise sensitivity.

Keywords: *Noise sensitivity, performance, polysomnogram, subjective sleep quality, traffic noise*

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The effects of noise on sleep can be categorized into primary, secondary, and tertiary or long-term effects based on their temporal occurrence. [1] The primary effects occur during bedtime with pronounced alterations of sleep (arousals, sleep stage changes, and awakenings) and autonomous functions. The secondary effects are the consequences of disturbed sleep such as annoyance and impairment of subjective sleep quality, well-being, and performance. [2],[3],[4],[5] In the long run, these primary and secondary effects are suspected to contribute to the genesis of multi-factorial chronic diseases, particularly, to cardiovascular diseases.

The effects of traffic noise are determined by a variety of moderating factors. [6] Apart from the acoustical characteristics such as sound pressure level and frequency spectra, the situation (e.g., a familiar surrounding or laboratory) as well as individual factors such as noise sensitivity might play a decisive role. [4],[7],[8],[9]

Noise sensitivity and annoyance

Noise sensitivity is regarded as a stable personality trait that reflects the individual's attitude to noise in general. [9],[10],[11],[12],[13] Individuals who are repeatedly annoyed by noise in different situations characterize themselves as noise sensitive. [14],[15] This sensitivity indicates the vulnerability to a wide range of noises, which moderates the degree of noise annoyance, and thus, explains partly the inter-individual variance of reactions to noise. [13]

Laboratory and field studies on the effects of transportation noise have shown that sensitive individuals are more annoyed than those who are rather resistant against the impact of noise, and up to one-fourth of the variance of annoyance is explained by this trait. [16],[17],[18]

Noise sensitivity and subjective evaluation of sleep

With regard to night time annoyance, several studies have shown strong negative correlations between noise sensitivity and subjectively evaluated sleep quality or the number of recalled awakenings in residents exposed to transportation noise. [7],[8],[19],[20],[21]

Öhrstrom *et al* . confirmed this for laboratory studies where subjective sleep quality after noisy nights was reduced by 12% in rather noise resistant individuals and by 25.4% in noise sensitive individuals. [4],[14],[15] These authors identified the number of noise events (25.8% explained variance) as the most important and noise sensitivity as the second most important factor (12.7% explained variance) for subjective evaluation of sleep quality.

Noise sensitivity and performance

The relevance of noise sensitivity for performance was, as a rule, studied under the direct influence of noise in the laboratory. Zimmer and Ellermeier [22] found impairments of a serial-recall task during exposure to irrelevant speech but an almost negligible influence of noise sensitivity with correlation coefficients ranging between $r = 0.084$ and $r = 0.232$ depending on the instrument used for measuring noise sensitivity. Similar results were reported for ventilation and road traffic noise. [23],[24] A field study revealed that subjects with high sensitivity scores made more daily errors than those with low sensitivity scores. [25]

Studies concerning the relationship between noise sensitivity and performance after noise disturbed nights are rare and the results are inconsistent. Whereas Öhrstr φm and Rylander [4] could not determine an association between noise sensitivity and performance decrements after nocturnal traffic noise, Öhrstr φm and Bj φrkman [14],[15] found prolonged reaction times in a simple-reaction-time task in the non-sensitive individuals compared to the sensitive ones.

Noise sensitivity and physiological functions

A very few studies have focused on the influence of noise sensitivity on physiological responses. With regard to daytime exposure, Stansfeld *et al* ., [26] apart from decelerated heart rates in sensitive women, found no further physiological distinctions between sensitive and non-sensitive individuals concerning blood pressure, skin conductance, and hearing thresholds. Similarly, Waye *et al* . [24] did not observe significant influence of noise sensitivity on the release of cortisol during several tests performed under the impact of ventilation noise. However, the ventilation noise with a lower frequency spectrum was accompanied by an attenuation of the circadian rhythms and decline of cortisol levels in sensitive individuals as compared to rather resistant individuals. Griefahn and Di Nisi [27] found stronger reactions in terms of acute annoyance, decrease of peripheral blood flow, and acceleration of heart rate in sensitive than in non-sensitive individuals exposed to various types of noise.

Concerning the physiological effects of nocturnal noise, the results reported in the literature are contradictory. Where Öhrstr φm *et al.* , [14],[15] reported fairly larger event-related increases of heart rates in sensitive individuals as compared to non-sensitive individuals, Di Nisi *et al* . [28] as well as Brink *et al* . [8] found same noise-induced vegetative alterations in sensitive as well as rather resistant individuals.

Öhrstrom and Bjorkman, [14],[15] Öhrstrom and Rylander [4] as well as Brink *et al* ., [8] who recorded body movements as an indicator of sleep disturbances, could not ascertain more movements in sensitive than in non-sensitive individuals. Basner *et al* . [29] recorded the polysomnogram, which is the only measure that clearly differentiates between the awake and sleep states and provides information about sleep depth. However, many large laboratory and field studies on the effects of nocturnal aircraft noise have determined more awakenings in sensitive individuals than in non-sensitive individuals. Griefahn [19] found no influence of nocturnal road traffic noise on the polysomnogram.

Aim of the study

The aim of the present study was to investigate the effects of traffic noise exposure on sleep, subjective sleep quality, annoyance, and performance and to explore whether these reactions are associated with noise sensitivity, which is determined with the newly developed Noise Sensitivity Questionnaire (NoiSeQ). [30] According to the literature, noise sensitivity is expected to influence the subjective sleep quality and night time annoyance, less markedly performance, but probably not the physiological parameters of sleep that are indicated by the polysomnogram.

Materials and Methods

Participants

Twenty-four healthy and normal hearing individuals (12 women and 12 men; mean age, 23.1 ± 2.5 years) gave their written consent to the study, which was approved by the local Ethics Committee.

Design and procedure

The participants slept in the laboratory for 13 nights (three consecutive weeks). After a habituation night, from Sunday to Monday, they spent four consecutive nights, each week, from Monday evening to Friday morning in the laboratory. They were exposed with weekly permuted changes to noises emitted from road, rail, and air traffic, respectively. Of the four nights, one was a quiet night where a pink noise with an L_{Aeq} = 32 dB was applied continuously, while three were noisy nights with exposure to equivalent noise levels of 39, 44, and 50 dBA in a permuted order.

The participants arrived at the laboratory two hours prior to bedtime; here, the electrodes for the derivation of the polysomnogram were fixed. After the completion of performance tests and the evaluation of the actual situation, the subjects went to bed. The lights were switched off and the recordings were started at 11 p.m. The participants slept in separate sound-insulated rooms with air temperature adjusted to 20°C. After waking up at 7 a.m., the participants completed a short questionnaire to evaluate their sleep and then executed a performance test.

Materials

Noise sensitivity

Noise sensitivity was measured using the Noise-Sensitivity-Questionnaire (NoiSeQ), [30] which determines the global noise sensitivity with seven items each for five different areas, namely, work, sleep, communication, leisure, and habitation. Each item consists of a statement where the participants used a four-point rating scale to indicate their agreement from strongly agree (0) to strongly disagree (3). These scores were summed up and divided by the number of statements so that global sensitivity potentially varies between 0 and 3.

Additionally, the subjects completed several other questionnaires to determine their personal traits such as neuroticism, introversion, and anxiety. Individuals with high scores in the neuroticism and anxiety scales were excluded from the experiments.

Polysomnogram

The polysomnogram, i.e., two electroencephalograms (EEG), two electrooculograms (EOG), and one electromyogram (EMG), was continuously recorded throughout all nights and evaluated according to Rechtschaffen and Kales. [31] The parameters derived from each polysomnogram were sleep onset latency (SOL: time elapsed between lights off and sleep onset), sleep period time (SPT: sleep onset until final awakening), wakefulness after sleep onset (WASO), total sleep time (TST = SPT-WASO), sleep efficiency index (SEI = TST/SPT), and the time spent in each sleep stage. Sleep stage 2, which usually amounts about 50%, remained unaffected by noise and was, therefore, not listed in the tables. Additionally, the times spent in stages 3 and 4 were summed up to SWS (slow-wave-sleep) and time spent awake was combined with stage 1, i.e., the transition between wake and sleep (time in S0 and 1).

Subjective evaluation of sleep

Sleep was subjectively evaluated every morning using short questionnaires with six scales ranging from 0 to 10. The participants were requested ("Please estimate your sleep") to estimate their difficulty to fall asleep just after going to bed as well as after intermittent awakening (both scales reaching from very difficult to very easy), calmness of sleep (very restless-very calm), sleep depth (very shallow-very sound), restoration (very low-very high), and body movements (very much-very little). These six items were first analyzed separately. Six scores were also summed up to "subjective sleep quality," where 0 indicated very poor and 60 indicated excellent sleep quality. Three further questions concerned sleep latency (in minutes), number of recalled awakenings, and estimated duration of intermittent awakenings (in minutes).

Annoyance

Every morning annoyance was assessed by a single question "How strongly have you been disturbed or annoyed by traffic noise during the night?" A ten-point scale reaching from "not at all" to "extreme" was used to estimate the degree of annoyance.

Performance test (switch)

A two-figured number was presented for 170 minutes in a corner of a virtual square in the centre of the screen of a personal computer. By using two correspondingly arranged keys, the participants had to indicate the position of the even figure for numbers occurring above the centre, and the position of the greater figure for numbers occurring below the centre accordingly. After a total of 240 stimuli were presented clockwise, the participants could prepare for the following task, i.e., repetition (non-switch) or changes (switch). The reaction-stimulus interval was 1000 minutes. The reaction time and errors were calculated separately for switch and non-switch; the differences between both were labelled as switch costs.

Statistics

The statistical analyses were based on the means calculated over the nine noisy nights of each participant irrespective of the type and the level of noise and on the means of the three quiet nights concerning polysomnographic data, subjective sleep quality, annoyance, and performance. The Wilcoxon test for related samples was used to test for differences between quiet and noisy nights.

Pearson correlations were calculated between noise sensitivity and physiological sleep parameters, subjectively evaluated sleep parameters, annoyance, and performance as averaged over the nine noisy nights. P -values < 0.05 were considered as significant and P -values < 0.10 indicated a trend. Analyses were performed with SPSS 12.0 for Windows.

Results

Noise sensitivity

Within the possible range from 0 to 3, noise sensitivity as determined with the NoiSeQ ranged between 0.37 and 1.77 (median = 1.2, mean = 1.08) indicating that the samples studied here were rather less sensitive.

Noise effects

The three quiet nights were compared with the nine noisy nights. Where sleep latency and sleep period time were not affected by noise, significant alterations in the expected direction were identified for WASO, TST, SEI, time in S0 and 1, in SWS-sleep and in REM-sleep [Table - 1]. Concerning subjective evaluation, apart from the number of recalled awakenings that only revealed a trend, the estimated parameters of sleep showed highly significant impairments ($p < 0.001$). Annoyance was also significantly greater after noisy nights rather than after quiet nights. Regarding performance reaction, time showed a strong trend towards prolongation after noisy nights, but neither the number of errors nor the switch costs revealed effects of noise.

Correlation analyses with noise sensitivity

Correlation coefficients were calculated between NoiSeQ-scores and those variables that were significantly altered respectively after noisy nights with *p* -values of at least 0.01. The respective coefficients with *p* -values of at least 0.1 are listed in the last columns of [Table - 1],[Table - 2].

None of the other physiological sleep parameters were associated with noise sensitivity. Concerning subjective evaluation, the difficulty to fall asleep (initially) and subjectively evaluated sleep depth were not related to noise sensitivity. Calmness and restoration showed a significant trend, where the difficulty to fall asleep after intermittent awakening, estimated body movements as well as the sum of these six variables, labelled as "sleep quality" were significantly associated with noise sensitivity. However, neither annoyance, the estimated time to fall asleep, the recalled number of awakenings, the estimated duration of wakefulness after sleep onset, nor reaction time were significantly related to noise sensitivity.

Discussion

Methodological aspects

As the participants were expected to spend 13 nights over a three weeks period in the laboratory, they were carefully selected. They completed several questionnaires that focused on personal traits. Applicants with high neuroticism- and anxiety-scores were excluded from participation. As both these traits correlate with noise sensitivity, these selection criteria implicitly reduced the number of noise sensitive individuals. [7],[13],[22] In addition, self-selection had to be taken into account. Since the requirements of the study that the participants could be exposed to transportation noise during nights were clarified, sensitive individuals who probably anticipated (severe) sleep disturbances did not apply for participation. As a result, the NoiSeQ-scores (which were not used for selection) varied in a rather narrow range, namely between 0.37 and 1.77, indicating that the participants in this study were rather resistant than sensitive to noise.

Despite the small range of the NoiSeQ-scores in the actually studied sample, this analysis was performed to test the applicability of the newly developed NoiSeQ. Significant correlations of NoiSeQ-scores with at least a few subjective alterations were expected to reveal a higher predictive power in samples with larger variance of sensitivity.

Noise effects

Apart from sleep latency and sleep period time with a trend towards degraded sleep, all the physiological sleep parameters were significantly impaired during noisy than that during the quiet nights. These alterations were expected and supported by other studies. [5],[29]

The physiological alterations were followed by significant after-effects. In line with other studies, annoyance and each of the six items, which constitute subjective sleep quality, were significantly worsened. [9],[14],[15],[32] Moreover, nocturnal noise exposure was followed by prolonged reaction times, while the error rate remained unaffected. The effects on performance are supported by studies on executive functions (that are essential for the execution of the switch task applied here) that were impaired even after partial sleep deprivation or led to an attenuation of event-related potentials. [33],[34],[35]

The influence of noise sensitivity

Inter-individual differences were ascertained during noisy nights for physiological sleep parameters, and consecutively, for subjective sleep quality and performance by a great variety of individual and situational influences. Noise sensitivity is considered as a major contributor to the extent of responses to noise. However, none of the physiological parameters of sleep were significantly related to this personality trait and the same was true for performance, whereas several items of subjective evaluation of sleep were clearly related to noise sensitivity.

This discrepancy between physiological responses and performance data on one hand and subjective evaluation on the other hand is well in line with the literature. The noise-induced alterations of physiological functions were occasionally related to noise sensitivity. Stansfeld *et al* . [26] as well as Smith and Rich, [36] who have studied galvanic skin resistance and cardiovascular effects, respectively, state that these vegetative responses are independent from noise sensitivity. However, a strong association was reported by Griefahn and Di Nisi [27] who found clearly enhanced cardiovascular and emotional responses to short periods of gunfire, traffic noise, and pink noise in sensitive individuals than in the resistant individuals.

However, where emotional reactions might contribute, via stress-related release of cortisol, to the physiological response during consciousness, this is less likely during sleep, and there is scarcely a study that reveals the relationship between physiological responses and noise sensitivity. Di Nisi *et al* . [28] as well as Brink *et al* . [8] did not record larger cardiovascular responses in sensitive individuals than in the less-sensitive individuals. The same was true for body movements, as reported by Brink *et al* ., [8] Öhrstrom and Bjorkman., [14],[15] and Öhrstrom and Rylander, [4] and for sleep disturbances as verified by the means of a polysomnogram. [37],[38] Only Basner *et al* ., [29] who identified event-related awakenings with the polysomnogram in large laboratory and field studies, reported more noise-related awakenings in sensitive individuals than in rather resistant individuals; however, this was observed only in the laboratory.

Similar to the noise-induced physiological alterations, the prolongation of reaction times after noisy nights was also not related to noise sensitivity. This is supported by an experimental study performed by Öhrstr φm and Rylander [4] and a field study done by Smith and Stansfeld. [25]

However, noise sensitivity plays a significant role for subjective evaluation. The difficulty to fall asleep after intermittent awakening, calmness, restoration, estimated body movements, and sleep quality turned out to be influenced by noise sensitivity with *p* -values of approximately 0.08 for the correlation coefficients. These findings are supported by other studies. [4],[7],[8],[14],[15],[21]

Concerning annoyance, large-scale social surveys and carefully performed meta-analyses have clearly shown the impact of noise sensitivity on annoyance. [12],[39],[40] However, the situation for night time annoyance is more complex, since this feeling results from noise experienced during consciousness, i.e., during sleep onset latency and intermittent wakefulness, and from subjective evaluation of sleep, which at the time of evaluation belongs to the past and constitutes a qualitatively different state of consciousness. [41] The time to fall asleep and intermittent wakefulness were only moderately prolonged by 2 and 9 minutes, respectively, which was sufficient to elevate annoyance as compared to quiet nights, but again rather moderately, from 1.1 to 4.8 on a scale from 0 to 10. Both the small ranges, within which noise sensitivity and annoyance vary, might have masked the hypothesized relation. The influence of noise sensitivity on night time annoyance is also determined in other studies. [8],[9],[12],[16],[17],[40],[42]

However, the present results are in accordance with a study performed by Heinonen-Guzejev *et al* ., [43] who have analyzed 1495 questionnaires from Finnish adults. Annoyance was determined with 10 items and noise sensitivity with a single question. According to a factor analysis, one factor labelled as "night time annoyance," included annoyance items concerning sleep problems, becoming nervous, and disturbances of rest; a second factor labelled as "daytime annoyance," included annoyance items about disturbances of conversation and listening to radio/TV; and the third factor included self reports of traffic noise exposure. None of these factors correlated significantly with noise sensitivity.

With respect to these repeatedly reported discrepancies between physiological and performance data and subjective evaluation [44] noise sensitivity can be viewed as an independent variable, which may be directly related to the subjective evaluation of sleep quality without the detour over night-time annoyance. Additionally, this might be specifically related to the definition and the instruments used for the determination of noise sensitivity. None of these instruments (questionnaires) developed and applied so far predicts individual differences in the effects of noise but predicts them for subjective emotional outcomes. Another major problem with these measures is that they reflect general sensitivity rather than something specific to noise. [40],[45] If so, it can be speculated that the unfamiliar environment in the laboratory may have a stronger influence on sleep, thus, masking the influence on noise effects.

Conclusion

The results of the present study suggest that noise sensitivity is an important non-acoustical factor concerning the subjective reactions to nocturnal traffic noise exposure. After noisy nights, subjective evaluation of sleep was rated worse by noise sensitive individuals than by the non-sensitive individuals.

Noise sensitivity seems to be a suitable predictor for subjectively evaluated sleep but not for physiological alterations of sleep. Further research with noise sensitivity directed pre-selections, i.e., a greater sample with a wider range of noise sensitivity, are necessary to reveal a higher prediction power for noise-induced alterations of subsequent annoyance and performance.

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