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Effects of nocturnal air and rail traffic noise on sleep

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Abstract

Undisturbed and sufficiently long sleep is a prerequisite for a healthy life as well as for the prevention of fatigue-induced accidents. Especially the increasing air and freight rail traffic is more and more shifted to shoulder and night-time hours due to missing capacity and infrastructure during daytime. Thus, the sleep of residents near airports or railway tracks is increasingly affected by traffic noise. Only very few main airports, such as Frankfurt (Germany), implemented a night flight ban in order to countervail this trend. Since 1999 the Institute of Aerospace Medicine of the German Aerospace Center (DLR) has investigated these night time noise effects in several field studies in which the sound pressure levels L_{AS} and L_{AF} and sound files were continuously measured with class one sound level meters at the sleeper's ear. Sleep structure was recorded with polysomnography (simultaneous measurement of brain waves, eye movements, and muscle tone), the gold-standard to quantify sleep objectively. The results on sleep quality and additional awakening reactions due to traffic noise from former studies performed at Cologne/Bonn airport (high night time traffic) and a busy railway track in the Rhine valley (high night time freight traffic) are compared with the results of the recently completed NORAH (Noise-Related Annoyance, Cognition, and Health) study at Frankfurt airport. In the latter study data were collected both before as well as after the implementation of a ban of night flights between 11 p.m. and 5 a.m.. Sound exposure distributions, average sound levels and sound level rise time distributions at the sleepers' ear are presented for all three studies.

Keywords: Aircraft Noise, Rail Noise, Sleep, Polysomnography

1 Introduction

Transportation noise has become a major source of sleep disturbances and this situation will worsen as traffic density is predicted to increase considerably within the next years, more so during the night than during the day. Therefore, more and more residents' sleep will be disrupted by traffic noise. Sleep is essential for human beings because it provides physical and mental recreation and therefore its disturbances are considered detrimental to mood, performance and health. Due to the fact that the magnitude of the effects depend on the acoustical features of the intruding noises (apart from its information content and situational and individual factors), the adequate metric is essential for predicting the effects on sleep. A series of integrated noise metrics have been developed, such as the equivalent noise level (L_{EQ}), the day-night level (L_{DN}) or the day-evening-night level (L_{DEN}) [1] whose underlying concept is the sound energy equivalence which is used to consider residents' annoyance and in the case of L_{Night} also sleep disturbances.

This concept, however, does not take into account further acoustical and psychoacoustical aspects of different noises. A meta-analysis from 1999, performed by Miedema and co-workers [2] [3] in which 55 social surveys with overall about 58000 interviews were analysed, clearly showed that noise annoyance was highest for aircraft and lowest for rail traffic, whereas road traffic was intermediate . The concept of “annoyance”, however, includes both acoustical as well as non-acoustical factors, like e.g. mistrust in authorities and information policy, procedural fairness of decision processes, fear of adverse health effects, uncertainty relative to future traffic movements etc.. This meta-analysis of annoyance studies strongly supported the implementation of bonus-malus-regulations that have been established in many countries and that allow higher equivalent noise levels for rail than for aircraft noise.

Newer laboratory studies until 2008 [4] [5], however, in which aircraft, rail and road traffic noise was played back during the night, indicated that bonus-malus-regulations as applied with respect to annoyance may not be applied to physiological measures of sleep at night time. In those studies, awakening probability was highest for road traffic noise, intermediate for freight rail noise and lowest for aircraft noise, thus diverging from the effects on annoyance. Another laboratory study from 2013 also quantified the adverse effect of vibration on sleep quality [6]. It is well known that undisturbed and sufficiently long sleep is a prerequisite for a healthy life as well as for the prevention of fatigue-induced accidents. Nonetheless, the laboratory findings have to be confirmed in field studies that are characterized by higher ecological validity. If these field studies confirm the above mentioned results, bonus-malus-regulations, especially for the night, should be reviewed.

The German Aerospace Center (DLR) investigated these night time noise effects on sleep in several field studies near Cologne/Bonn airport (high night time traffic), near a busy railway track in the Rhine valley (high night time freight traffic) and in the recently completed NORAH (Noise-Related Annoyance, Cognition, and Health) study at Frankfurt airport before and after the implementation of a ban of night flights between 11 p.m. and 5 a.m. Currently there are two ongoing DLR field studies on the effects of road traffic noise on adults' sleep and aircraft noise near Cologne/Bonn airport on children's sleep. Results of these two studies are expected to be available in 2018.

2 Study design and methods

Polysomnography, i.e. the continuous measurement of electrical brain activity (EEG), eye movements (EOG), and muscle tone (EMG) is the gold standard for measuring sleep, and currently the only method that provides detailed information on sleep structure (e.g., distribution of different sleep stages, EEG awakenings and arousals) [7]. However, this procedure is also somewhat invasive, time consuming and costly [8]. In our studies, the preparation of the technical equipment and electrode application/removal associated with each single recording took approximately 90 min in the evening and 40 min in the morning.

Sleep stages were determined on a 30-s basis by two experienced scorers according to standard criteria [9]. Sleep scorers were blind to noise exposure. The first night always served as a habituation night and was not evaluated.

In order to be able to reliably attribute any sleep stage change or awakening to a single noise event, the volunteer subjects were required to have normal hearing thresholds and to be free of any health condition that affects sleep. Daytime activities were not controlled except that daytime naps, and caffeinated beverages and alcohol after 3.00 p.m. were not permitted. Minimum age was 18.

Results of the following DLR studies are considered in this overview:

STRAIN (STudy on human Response on AIrcraft Noise), field study around Cologne-Bonn airport, 2001-2002, 64 subjects, age range 19-61 years, 28 male, 9 consecutive nights each [10].

AIRORA (Air, ROad, RAil), laboratory study, 2004-2007, 72 subjects, age range 18-71 years, 32 male, 11 consecutive nights each [11].

DEUFRAKO-RAPS (German French Cooperation in traffic research, Railway noise, Annoyance, Performance, Sleep), field study near highly frequented freight train track in the Cologne/Bonn area, 2007-2010, 33 subjects, age range 22-68 years, 11 male, 9 consecutive nights each [12].

NORAH (NOise-Related Annoyance, cognition and Health), field study around Frankfurt airport, 2011-2015, 49 subjects (2011), 83 subjects (2012), age range 18-78 years, 25 male (2011), 33 male (2012), 3 consecutive nights each [13] [14].

In order to assure a noise event-related evaluation of the electrophysiological data, in the field studies class-one sound level meters were placed near the sleeper's ear. They continuously measured the sound pressure levels (SPL) L_{AS} respectively L_{AF} and, in addition, also recorded the noise events. In STRAIN and DEUFRAKO the outside SPL was measured 2 m in front of the bedroom window according to German standards [15].

The acoustical data were analysed by investigators who marked and commented every noise event that had reached the sleepers ear.

In the laboratory study AIRORA noise events belonged to one of 5 maximum sound pressure level categories (A-weighted with time constant set to slow): 45, 50, 55, 60 or 65 dB. For every level category and traffic mode (Air, Road, Rail) 8 different noises, measured inside sleeping rooms with closed or tilted windows, were available. These were used to generate 9 different noise scenarios.

3 Conclusions and Outlook

The DLR sleep studies cited above as well as results from other surveys show that traffic noise disturbs sleep, leads to changes in sleep structure and an increase of awakenings and arousals. Changes in quantity and quality of sleep (total sleep time, sleep onset, sleep efficiency, wake after sleep) are usually moderate and, due to biologically plausible habituation effects, cannot be compared with clinical sleep disorders in general.

However, there is not a complete adaption since traffic noise effects on sleep can still be observed after many years of exposure. Besides, people react very differently to traffic noise.

Despite the moderate changes in sleep structure, studies have shown that as a secondary effect traffic noise leads to an increase of daytime sleepiness, a slowing of reaction time, and impairment of memory consolidation. As a consequence, this could result in an increased risk for accidents. However, compared with the impact of clinical sleep disorders, alcohol intake or lack of oxygen the effects are less pronounced [16] [17].

The most prominent effect of traffic noise on sleep is the awakening reaction. From our sleep studies we derived exposure-response curves that express the awakening probability for a single noise event mainly as a function of its maximum sound pressure level. Awakening probabilities for single events with a given maximum sound pressure level were highest for freight trains, followed by aircraft and passenger trains. Field studies dedicated to road traffic noise are not yet available. These exposure-response curves can be used for developing protection concepts for traffic noise-exposed residents.

A night ban for flights at Frankfurt Airport between 11 p.m. and 5 a.m. delivered relief for residents' sleep. The aircraft noise associated awakenings were reduced whereupon residents who went to bed early could benefit most from the night flight ban.

Conclusions about long-term health effects can only be drawn indirectly. Awakening reactions often go along with a noise associated increase of the heart rate. This acute effect could be one explanation for an increased risk for cardiovascular diseases after long-term noise exposure.

Up to now exposure-response relationships have been available only for residents who are free of disorders that affect their sleep. In the future, studies are needed that include also vulnerable groups (e.g. residents suffering from certain diseases, children). Still very little is known about a possible pathophysiological pathway between disturbed sleep and the development of diseases after long-term noise exposure that may eventually be reflected in epidemiological studies.

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