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Aircraft noise effects in vulnerable populations

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ABSTRACT

Vulnerable population groups (e.g. children, elderly people, shift workers) have not been the focus of investigations into the effects of transportation noise for a long time. In two field studies in the vicinity of Cologne/Bonn Airport, we therefore investigated the effects of nocturnal aircraft noise on sleep as recorded with polysomnography and self-reported sleep quality as well as short-term annoyance in 51 primary school children (8-10 years) and 44 elderly people (55 - 76 years). In a laboratory study, the effects of aircraft noise on the same outcome variables were compared between 17 participants who slept during the day (19 - 36 years) and 16 participants who slept at night (18 - 35 years). This article provides an overview of the results of these studies in vulnerable groups. Noise effects were more pronounced in participants who slept during the day than in those who slept at night. The findings for children and older people were less consistent and showed effects of nocturnal aircraft noise either on sleep (children) or on self-reported sleep quality and annoyance only

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(elderly people). Results of the vulnerable groups are discussed in comparison to findings in middle-aged adults.

1. INTRODUCTION

Disturbed sleep at night is the most serious short-term consequence of traffic noise. They can manifest themselves in wake-up reactions, changes in sleep depth and sleep patterns [1]. Secondary effects may include impairment of subjective sleep quality as well as increased fatigue and annoyance during the day [2]. Long-term tertiary effects may include the development of health disorders (particularly cardiovascular diseases, e.g. an increased risk of high blood pressure or stroke) [3]. There are numerous laboratory and field studies on the effect of different types of traffic noise on primary and secondary reactions in (young) healthy adults. Exposure-response models for the assessment of noise-induced sleep disturbances as well as noise-induced annoyance in the morning have been derived from these studies. However, population groups that are more sensitive to the psychological and physiological effects of (traffic) noise (so-called "vulnerable groups" [4, 5]) have hardly been systematically investigated to date. Older people are counted among the vulnerable groups for noise effects alongside children, people with previous illnesses or people working in shifts [4, 5].

The sleep of older people is considerably susceptible due to its inherently increased fragmentation. The proportion of deep sleep phases is reduced, sleep efficiency is reduced [6] while sensitivity to external disturbance factors (e.g. noise) is increased. It can be assumed that elderly people are, thus, more to adverse traffic noise effects [5].

Children are seen to be more at risk to the negative effects of noise due to a sensitive developmental period [4] and they have less-developed coping strategies [4, 7] Moreover, especially those of primary school age, have longer sleeping times including shoulder times of the day, i.e. the late evening and the early morning with high traffic density [4]

Around 15 % of the population in Germany work night shifts [8]. Night workers often work between 23:00 and 07:00 h and consequently have to sleep at daytime [9]. Due to the circadian misalignment associated with shift work sleep is more fragile in terms of fragmented sleep, longer waking time, and subjective poor sleep quality [10, 11].

This paper is intended to significantly expand the current state of knowledge on the effects of noise on the three mentioned vulnerable populations. An overview is given over three studies from the recent past conducted at the Institute of Aerospace Medicine of the German Aerospace Center and its main results on the effect of aircraft noise during bedtime on a) sleep quality and b) on short-term annoyance due to aircraft in the morning.

2. Methods

2.1. Sample

Children and elderly participants were examined in the field, i.e. in their home environments. All participants were residing under or beneath flight paths within a radius of approximately 20 km around the Airport Cologne/Bonn that shows a continuous 24/7 operation scheme without a night curfew. We included 51 children aged 8 to 10 years, 23 were females, (study 1) and 44 elderly participants aged 55 to 76 years, 30 females (study 2). Participants of both studies have lived at least 12 months in their current district or a district that was comparable with regard to its aircraft noise exposure. All participants were healthy in terms of sleep and other chronic diseases. They were screened for hearing impairment by audiometric screening as well as for age-adequate normal bedtimes, sleep and health disorders, and medication which have the potential to confound result interpretation.

In a laboratory study (study 3), we included 33 participants, 18 females (study 3). Participants were allocated by random to either a night sleep group (n=17, aged 18-35 years) or a day sleep group (n=16, aged 18-35 years). Participants were screened for comparable inclusion and exclusion criteria as mentioned above.

2.2. Study protocol

Both children and elderly participants were examined for one (preceding) adaptation night followed by three (children, study 1) or four (elderly, study 2) consecutive test nights at home. The first night served as adaptation to the protocol and to the measurement instruments. During all nights, non-invasive electrophysiological methods, (so-called polysomnography) were applied for the objective measurement of sleep quality. Naturalistic aircraft and ambient noise exposure were recorded via a class1-sound level meter placed next to the participant's ear (Figure 1). Sound pressure levels were continuously recorded with a frequency weighting "A" and a time weighting "slow". In addition, an audio file (wav format) was recorded throughout the night to identify the sounds and to assign categories, such as "aircraft", "car", "participant. Study nights comprised workdays and week-ends with varying air traffic and corresponding exposure. Every morning after getting up, annoyance and self-rated sleep quality was assessed.

Figure 1: Participant of study 2 in the field sleeping with polysomnographic instruments. Next to the bed, a sound level meter records aircraft and ambient sounds.

In the laboratory (study 3), participants also slept for one preceding adaptation night and afterwards during two visits composed of two consecutive sleep episodes, each in the sleep laboratory of the DLR Institute of Aerospace Medicine. As mentioned above, participants slept during all visits (except the adaptation night) during night-time (23:00 -07:00, referred to as "night sleepers") or during daytime (09:00-17:00, referred to as "day sleepers"). The two laboratory visits, during one of which participants were exposed to aircraft noise during both sleep episodes, were separated by a recovery break of at least seven days. During the sleep episodes with aircraft noise exposure, we played back an aircraft noise of 81 aircraft fly-over sounds from eight different aircraft types in the bedrooms. The noise scenario produced an energy-equivalent sound pressure level across the time in bed of Leq = 46.8 dB(A) and was based on aircraft sounds recorded in an apartment with tilted windows located six km away from the airport and directly under the flight path.

2.3. Prediction variables

Aircraft noise exposure was considered as prediction variable. In the field studies (study 1 and 2), we determined the maximum sound pressure level of each aircraft noise event. In addition, we derived the number of aircraft noise events above a maximum sound pressure level of 30 dB(A) per Time in Bed as a total night exposure metric. For both studies, a median split was applied, assigning all study nights to lower exposure vs. higher exposure. The median split in study 1 (children) was at 37.5 aircraft noise events per Time in Bed. The median split in study 2 (elderly) was at 20 aircraft noise events per Time on Bed.

In the laboratory study (study 3), we differentiated between noise nights as described above with 81 aircraft noise events vs. a quiet night without any noise event played back.

2.4 Outcome variables

2.4.1 Sleep

Sleep recordings were scored according to [12] differentiating between 6 stages: “wake”, “stage 1” to “stage 4” and “REM sleep”. The present paper focusses on the following sleep parameters:

- Wake time after sleep onset during Sleep Period Time [min]: Sleep Period Time is defined as the time between the first epoch spent in sleep stage 2 to the last sleep stage prior to the final awakening
- Duration of sleep stage 1 [min] indicating light sleep and considered as less restorative
- Duration of deep sleep [min]: total time spent in stage 3 or stage 4, considered as particularly important for recovery.

In the field studies with children and elderly participants (study 1 and 2), in addition, we analyzed noise-associated sleep stage changes from stage 2, 3, 4 or REM sleep to stage 1 or wake occurring within a window of 90 seconds after an aircraft noise event. These sleep stage changes are referred to as “noise-associated awakenings” in the following.

In the two studies that examined adults (study 2 and 3), self-rated sleep quality was assed using 6 items and a numerical scale from 0 to 10 [13] with a sum score of 60 indicating good sleep. In the children sample (study 1), a global singe-item question was asked that could be answered with verbal five-point scale from 1=“very good” to 5=“very poor” sleep.

2.4.2 Annoyance

Annoyance during the past night was assessed via the annoyance question recommended by [14] adapted to the rating for the past night in all three studies. For the field studies (study 1 and 2), we used a verbal five-point scale as recommended by [15]. The annoyance rating was dichotomized according to [16]: 1 =“not” and 2= “a little annoyed“ were set to 0 (“no annoyance”), and 3=“moderately”, 4=“quite” and 5=“very annoyed” were set to 1 (“moderate to high annoyance”). The laboratory study used the verbal five-point scale recommended by [14] ranging from 1 =”not at all annoyed” to 5=”extremely annoyed”. No dichotomization was applied.

2.5 Statistical analyses

For the field studies, we compared sleep and annoyance scores between night with higher vs. lower aircraft noise exposure. The comparison was achieved via linear mixed models with a random intercept for the participant. In the laboratory study, we also applied linear mixed regression models with a random intercept for the participant and compared the same outcome values between the noise and the quiet nights. This comparison was conducted separately for day sleepers and night sleepers, i.e. while noise exposure was a within-subject factor, day vs. night sleep was the between-subject factor.

For the field studies with children and elderly participants, we also applied mixed logistic regression models with a random intercept to predict a) the probability for an awakening by the maximum sound pressure level of an aircraft noise event and b) the probability for moderate to high annoyance in the past night by the number of aircraft noise events per Time in Bed. In order to interpret the effect of noise exposure on the probability for awakenings and annoyance, we pooled data with data from 44 randomly selected participants in the age of 18 to 55 years from a previous field study with adults [16, 17].

3. Results

3.1. Comparison between higher and lower exposed nights in children and elderly participants examined in the field

In study 1 (children), in lower exposed nights the average number of aircraft noise events per Time in Bed was M = 17.3 aircraft noise events, whilst in the higher exposed nights, on average M = 65.6 events occurred. Higher exposure was associated with a longer wake time during Sleep Period Time (lower exposure: M = 21.2 min, higher exposure: M = 28.5 min, p = .016) and a reduction of deep sleep (lower exposure: M = 251.1 min, higher exposure: M = 234.4 min, p=.010). Duration in stage 1 was not affected by aircraft noise exposure (lower exposure: M = 13.6 min, higher exposure: M = 14.3, p = .399). Neither annoyance (lower exposure: M = 1.7, higher exposure: M = 1.9, p = .309) nor self-rated sleep quality (lower exposure: M = 2.06, higher exposure: M = 2.03, p = .854) showed any effect of the noise exposure.

In study 2 (elderly participants), in lower exposed nights the average number of aircraft noise events per Time in Bed was M = 10.3 aircraft noise events. The average number of events in the higher exposed nights was M = 43.5. Neither sleep stage 1 duration (lower exposure: M = 23.4 min, higher exposure: M = 21.9, p = .226) nor wake time during Sleep Period Time (lower exposure: M = 52.7 min, higher exposure: M = 59.3 min, p = .190) was affected by nocturnal aircraft noise exposure. Contrasting our expectations, deep sleep duration was significantly higher in higher exposed nights (lower exposure: M = 79.6 min, higher exposure: M = 86.3 min, p = .030). Annoyance was more pronounced after higher exposed nights (M = 2.2) than in lower exposed night (M = 1.6, p = .005). Self-rated sleep quality was decreased with higher exposure (M = 34.3) compared to lower exposure (M = 36.8, p = .023).

3.2 Comparison among children, elderly and middle-aged adults

The effect of noise on the fragmentation of sleep in terms of awakenings was compared between study 1 (primary school children, aged 8-10 years), study 2 (elderly participants ≥ 55 years) and a random sample of participants aged 18 < 55 years taken from a previous study at the same airport [17]. At the same maximum sound pressure level of an aircraft noise event, the probability for a noise-associated awakening (= stage change to wake or stage 1) was lower for children aged 8-10 years and participants at an age of 55 years or older than for the reference sample in the age range 18 < 55 years. Figure 2 presents the exposure-response curves predicting the probability for a noise associated awakening based on the maximum sound pressure level and further variables as recommended by [18] applying a mixed logistic regression with a random intercept. In order to plot the exposure-response curves, the following variables were set to the medians of each study: the equivalent sound pressure level 1 min before the aircraft noise event [dB(A)], the duration of the noise event [s], the velocity of level increase [dB(A)/s]. The elapsed sleep time was held constant at 5 h across all studies and the preceding sleep stage was set to stage 2.

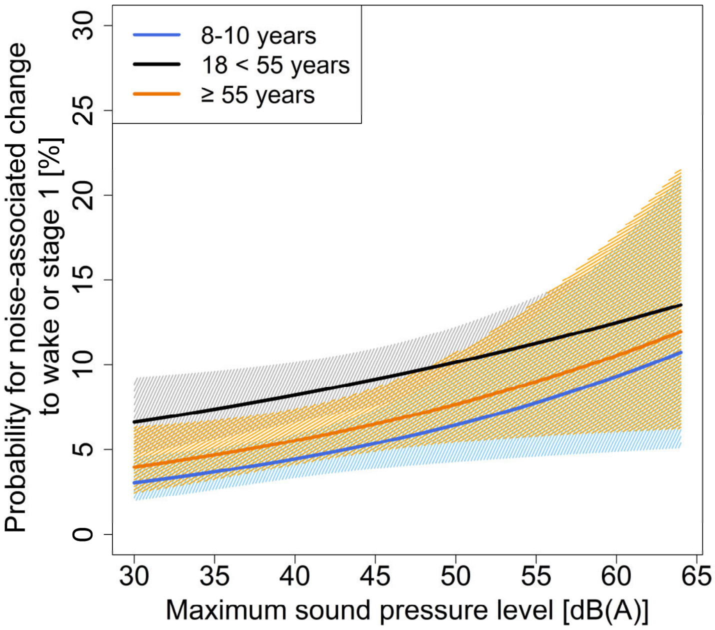

Figure 2: Probability for noise-associated change to wake or stage 1 predicted by maximum sound pressure level of the aircraft noise event and depending on age.

Similarly, we compared the effect of aircraft noise represented by the number of aircraft noise events per Time in Bed on the probability for moderate to high aircraft noise annoyance in the morning between study 1 (primary school children, aged 8-10 years), study 2 (elderly participants ≥ 55 years) and a random sample of participants aged 18 < 55 years [17]. Figure 3 depicts the exposure-response curves predicting the probability for moderate to high annoyance based on the number of aircraft noise events per Time in Bed.

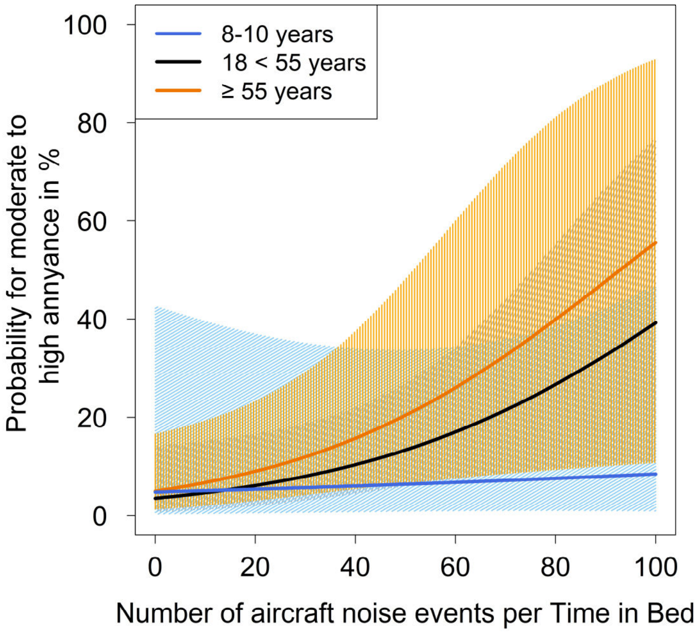

Figure 3: Probability for moderate to high annoyance based on the number of aircraft noise events per Time in Bed and depending on age.

3.3 Comparison between night-time and day-time sleep

We computed the effect of noise on the selected sleep and annoyance parameters via separate linear mixed regression models with a random intercept for the participants. Table 1 presents the mean values of the selected parameters obtained in sleep episodes with aircraft noise exposure ("noise") and without aircraft noise played back ("quiet") for both night sleepers and day sleepers. P-values are reported for the mean differences.

Table 1: Mean values of the selected sleep and annoyance parameters depending on the noise condition ("quiet" vs. "noise") and the timing of the sleep episode ("night sleeper" vs. "day sleeper").

	Night sleeper			**Day sleeper**		
	M_{quiet}	M_{noise}	p	M_{quiet}	M_{noise}	p
Wake time during Sleep Period Time [min]	19.0	22.3	.438	60.2	63.9	.704
Stage 1 duration [min]	11.9	11.8	.882	15.3	19.9	.009
Deep sleep duration [min]	124.3	117.9	.187	105.7	95.3	.059
Aircraft noise annoyance in the past night	1.0	3.0	<.001	1.1	3.4	<.001
Self-rated sleep quality	38.9	31.5	<.001	41.1	29.8	<.001

4. Discussion

The present paper gives an overview over the adverse effects of aircraft noise during sleep on groups of the population assumed to be particularly vulnerable to noise effects: children, elderly people and people forced to sleep during daytime, such as night-shift workers.

We have focused on two adverse effects that may be part of the causal pathway from exposure to long-term health risks, i.e. sleep disturbance and fragmentation as well as noise-induced annoyance. We examined both parameters assessed via electrophysiological measurements and self-reports.

Field examinations of primary school children (study 1) showed that childhood sleep can be affected by nocturnal aircraft noise in terms of a reduction of deep sleep duration and an increase of wake time. Although these disturbances of sleep seem rather small, the magnitude is similar to deteriorations found for the same sleep parameters in children suffering from obstructive sleep apnoe representing an intrinsic sleep disturbance [19]. In contrast, no effects of nocturnal noise could be observed in self-report of sleep quality and annoyance. The probability for moderate to high aircraft noise-induced annoyance assessed in the morning was not related to the number of aircraft noise events during the Time in Bed. Children were less annoyed than adults at middle age in a comparison with data randomly selected from a previous dataset obtained in the same airport vicinity.

In contrast to children, elderly people show adverse significant effects of nocturnal aircraft noise exposure in self-reported sleep quality and annoyance assessed in the field (study 2). The probability for moderate to high annoyance was significantly related to the number of aircraft noise events during the time in bed. Annoyance probabilities were higher than those for middle-aged adults at the same number of events. A reason may be the longer wake times of elderly than middle-aged adults [6] so that elderly participants consciously perceive more noise events during the night and, as a consequence report more often annoyance. No significant adverse deteriorations in terms of an increase of wake time and stage 1 duration were observed between lower and higher exposed nights. Contrary to our expectations, deep sleep duration was even prolonged in higher exposed nights. This effect is not easily explainable and warrants further analyses of sleep data, e.g. via spectral analyses to detect the spectral power density of sleep electroencephalogram and in particular the actual amount of slow delta waves. This information cannot fully be obtained by conventional sleep scorings based on 30 sec epochs [20].

Both children and elderly people showed a lower probability for noise-associated awakenings than middle-aged adults at the same maximum sound pressure level. For children, similar results have been found before for road traffic noise events [21]. A lower sensitivity in the elderly is again contra-intuitive and needs further investigation of sleep data beyond scoring of 30 s epochs, for instance via already mentioned spectral analysis.

The systematical examination of noise effect on night vs. day sleeping participants in the laboratory showed more pronounced effects in participants who slept during the day than in those who slept at night. A significant increase in the non-restorative sleep stage 1 under noise exposure was found in day sleepers but not in night sleeper. Moreover, a trend for a noise-induced reduction of deep sleep duration was found in participants who slept during daytime but not in those sleeping during the night. Aircraft noise exposure significantly evoked annoyance and reduced self-rated sleep quality in both day and night sleepers. However, the differences between noise an quiet nights were slightly larger in participants who slept during the day.

5. Conclusion

Aircraft noise effects differ between vulnerable populations. While people forced to sleep during daytime show more pronounced effects both with regard to physiological and self-reported outcomes, effects in children and elderly people are less consistent. Based on the current findings, children seem to be less affected in terms of perceived annoyance during the night as well as conscious and reportable disturbance of their sleep, but they show changes in their sleep depth and in their wake time. Children awake with lower probability following an aircraft noise event than middle-aged adults at the same sound pressure level. Thus, children are not more vulnerable regarding *single* noise events, but because of longer bed times corresponding to the exposure to more events. Elderly people in contrast show a higher probability for annoyance than middle-aged adults at the same noise exposure, presumable because of longer wake times during their bedtimes and, thus, more time of conscious perception of noise events. Results in the sleep parameters wake time, stage 1 and deep sleep duration as well as regarding the probability for noise-associated awakenings suggest that nocturnal aircraft noise exposure does not further deteriorate sleep structure and depth beyond age-related changes. However, for a comprehensive conclusion, more results, in particular for the spectral power density of noise exposed sleep in the elderly is necessary.

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