Inter-individual differences in the effects of aircraft noise on sleep fragmentation

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ABSTRACT

Environmental noise exposure has been shown to disturb sleep and impair recuperation, and may contribute to the increased risk for (cardiovascular) disease.[1] Noise policy and regulation are usually based on average responses, although substantial inter-individual differences in the effects of traffic noise on sleep have been demonstrated even in relatively homogeneous and healthy populations. In this analysis, we investigated what percentage of the total variance in noise-induced awakening reactions can be explained by stable inter-individual differences. It is based on 72 healthy subjects (age range 18-71 years, 32 male) who participated in a polysomnographic laboratory study on the effects of traffic noise on sleep and were investigated for 11 consecutive nights. This analysis concentrates on 4 exposure nights where subjects were exposed to 80 noise events from air, road, and/or rail traffic noise with maximum sound pressure levels varying between 45 and 65 dB(A). Mixed-effects models of variance controlling for age, gender, study phase, study night, and noise exposure in the previous night showed that 53.7% of the total variance in awakening probability corrected for awakening probability in noise-free nights was explained by inter-individual differences. The results thus demonstrate that a considerable amount of the variance observed in noise-induced sleep disturbance can be explained by inter-individual differences that cannot be explained by age, gender, or specific study design aspects. It will be important to identify those at higher risk for noise induced sleep disturbance. Furthermore, the custom to base noise policy and legislation on average responses should be re-assessed based on these findings.

INTRODUCTION

Environmental noise exposure has been shown to disturb sleep and impair recuperation, and may contribute to the increased risk for (cardiovascular) disease. Noise policy and regulation are usually based on average responses, although substantial inter-individual differences in the effects of traffic noise on sleep have been demonstrated even in relatively homogeneous and healthy populations (see Figure 1). Sleep spindles have been identified as a potential biomarker of the susceptibility of the organism to noise.[2] However, the magnitude of inter-individual differences in susceptibility to noise-induced sleep disturbance relative to within-subject variability observed during repeated exposure to noise has not been systematically investigated until now. In this analysis, we investigated what percentage of the total variance in noise-induced awakening reactions can be explained by stable inter-individual differences.

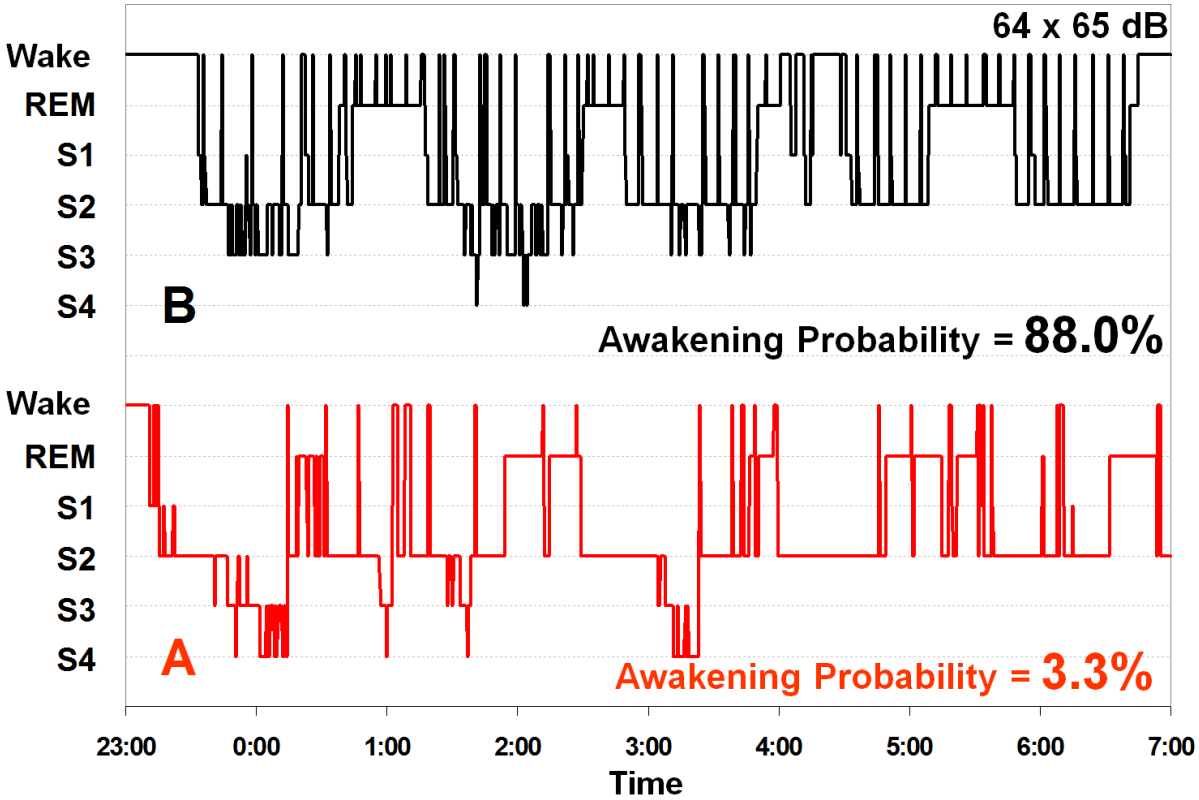

Figure 1: Differential noise sensitivity Hypnograms derived from polysomnography in two subjects participating in a laboratory study on the effects of aircraft noise on sleep are shown.[3] In this particular night, subjects were exposed to 64 identical aircraft noise events with a maximum sound pressure level of $L_{AS,max}$ 65 dB that were played back equidistantly in acoustically calibrated individual bedrooms. These two subjects represent extremes of the noise-sensitivity distribution: subject A (bottom) only woke up (i.e., polysomnographic sleep stage change to stage wake) in 3.3% of aircraft noise events, while subject B (top) woke up in 88.0% of noise events.

METHODS

Subjects were investigated for eleven consecutive nights. Night one served as adaptation. Nine different noise scenarios were played back during exposure nights two to ten. Night eleven served as a backup night, i.e. if signals of relevant electrodes were lost and sleep stage classification was impossible for one subject in nights two to ten, the respective noise scenario was presented in night eleven again.

There were nine different noise scenarios (see Table 1) with single, double and triple exposure nights. The three single exposure nights each consisted of 40 noise events from one traffic mode only, i.e. aircraft (AI), road (RO) or rail (RA). Noise events belonged to one of five maximum sound pressure level (SPL) categories: 45, 50, 55, 60 or 65 dB. SPLs were A-weighted with the time constant set to slow. Therefore, single exposure nights consisted of eight noise events from each of the SPL categories. For rail noise, each SPL category was divided into four noise events from freight trains and four noise events from passenger trains. For road noise, each category was divided into five noise events from passenger cars with dry roads, one noise event from passenger cars with wet roads, one noise event from motorcycles, and one noise event from trucks. Aircraft noise was not divided further.

There were three double exposure nights: Aircraft plus road noise (AIRO), aircraft plus rail noise (AIRA) and road plus rail noise (RORA). Each of the double exposure nights consisted of both 40 noise events from the respective single exposure nights, i.e. 80 noise events in total. There was one triple exposure night (AIRORA) consisting of all 120 noise events from the single exposure nights.

Table 1: Composition of exposure nights.

	Number of Noise Events				
Scenario	**Air**	**Road**	**Rail**	**Total**	$L_{A,eq}$
AI	40	0	0	40	39.7
RO	0	40	0	40	36.9
RA	0	0	40	40	39.7
RORO	0	80	0	80	39.7
AIRO	40	40	0	80	41.2
AIRA	40	0	40	80	42.5
RORA	0	40	40	80	41.2
AIRORA	40	40	40	120	43.3
NO	0	0	0	0	30.0

With this study design, exposures with different traffic modes were comparable according to number and maximum SPL of noise events. Additionally, the equivalent continuous sound levels $L_{A,eq}$ of the single exposure nights of aircraft and rail traffic noise were identical. Because of the shorter duration of road traffic noise events, the $L_{A,eq}$ of the road traffic single exposure night was lower than 39.7 dB. In order to get an $L_{A,eq}$ of 39.6 dB, the number of road noise events was doubled in exposure night RORO. In that way, it was possible to compare single exposure nights according to the $L_{A,eq}$ as well. Additionally, there was one night free of any traffic noise. Here, the $L_{A,eq}$ of 30 dB(A) was caused by the constant sound of the air-condition system.

Design of Study Periods

In order to be able to balance the study design, i.e. that each exposure was applied in each study night position once, there were nine study periods with eight subjects each. Therefore, 72 subjects (40+/-13 years, 32 male) were investigated polysomnographically in total. Electrophysiological signals included EEG, EOG, EMG, EKG, respiratory movements and finger pulse amplitude. Cortisol and noradrenalin were measured in nocturnal urine samples. Because sound insulation of sleep cabins was not absolute, in each study period, all eight subjects received the same noise pattern in the same night. Aside from one noise-free control night, there were no noise-free nights interposed between two exposure nights, i.e. there were no wash-out periods.

On the one hand, the noise strain of study participants should be high enough to be able to observe noise effects during the night and in the next morning, but, on the other hand, it should not be too high in order to prevent subjects from discontinuing the study early. Therefore, nights were divided into high exposure nights (AIRO,

AIRA, RORA, RORO, AIRORA) and low exposure nights (AI, RO, RA, NO), and the study was designed in a way that

(1) each exposure pattern was applied in every position (N2 to N10) once, and

(2) there were no more than two high exposure nights in a row.

The final design is shown in Table 2.

Table 2: Composition of study periods (abbreviations explained in the text).

	Study Night								
Period	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	AI	AIRA	AIRORA	RO	RORO	RA	AIRO	RORA	NO
2	AIRA	NO	RORA	AIRO	RO	AIRORA	RA	RORO	AI
3	AIRO	RORO	AI	NO	AIRA	RO	RORA	RA	AIRORA
4	AIRORA	AIRO	NO	AI	RA	RORA	AIRA	RO	RORO
5	RORA	AI	RO	AIRA	AIRORA	NO	RORO	AIRO	RA
6	RA	RO	AIRO	RORO	AI	AIRA	AIRORA	NO	RORA
7	RORO	RARO	RA	AIRORA	AIRO	AI	NO	AIRA	RO
8	RO	RA	RORO	RORA	NO	AIRO	AI	AIRORA	AIRA
9	NO	AIRORA	AIRA	RA	RORA	RORO	RO	AI	AIRO

Composition of single noise nights

The length of the time interval between the start of two noise events differed depending on the number of noise events per night and was otherwise randomly chosen using block randomization techniques. The length of the interval differed in nights with

- 40 noise events between 3 and 21 min,

- 80 noise events between 3 and 9 min and

- 120 noise events between 3 and 5 min.

In single, double and triple exposure nights playback of noise events started after twelve, six and four minutes, respectively. Playback always started at the beginning of a full minute, which coincided with the beginning of a 30-second sleep epoch. A more detailed description of the study can be found in Basner et al.[4]

This analysis concentrates on the 4 exposure nights where subjects were exposed to 80 noise events from air, road, and/or rail traffic noise (AIRO, AIRA, RORA and RORO in Table 1). Mixed-effects models of variance controlling for age, gender, study phase, study night, and noise exposure in the previous night with awakening probability in exposure nights corrected for awakening probability in noise-free nights were generated. Intra-class correlation (ICC) were calculated according to Van Dongen et al.[5] by dividing estimates of between-subject variance by the sum of between- and within-subject variance.

RESULTS

Mixed-effects models of variance controlling for age, gender, study phase, study night, and noise exposure in the previous night showed that 53.7% of the total variance in awakening probability in exposure nights corrected for awakening probability in noise-free nights was explained by inter-individual differences. This is illustrated in Figure 2. Intercept only models showed similar results (ICC=0.503).

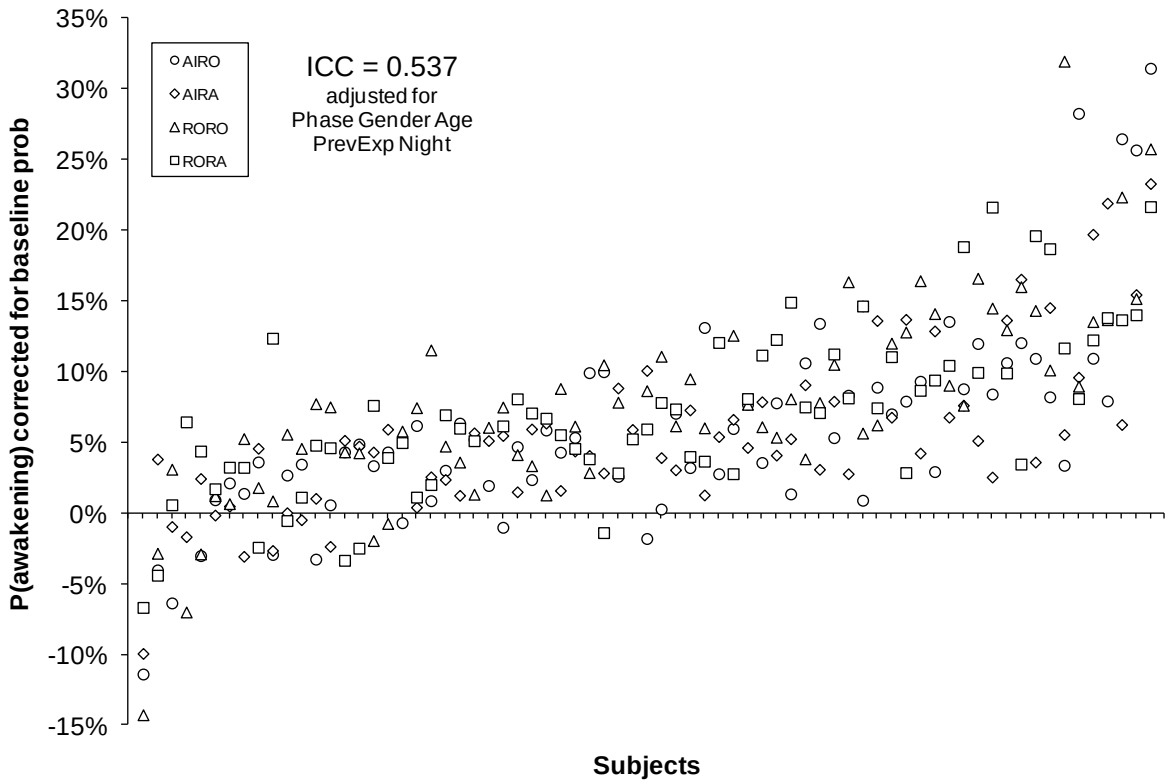

Figure 2: Awakening probability corrected for baseline probability (awakening probability in noise-free control nights was subtracted from awakening probability in noise exposure nights) is shown for each of the 72 subjects and for each of the 4 exposure nights (represented by different symbols). The subjects were ordered from smallest (left) to largest (right) average awakening probability. The figure illustrates that more than half of the variance was explained by stable inter-individual differences in awakening probability, indicating "moderate stability" according to conventional standards.[6]

DISCUSSION

The results demonstrate that a considerable amount of the variance observed in noise-induced sleep disturbance can be explained by inter-individual differences that cannot be explained by age, gender, or specific study design aspects. It will be important to identify those at higher risk for noise induced sleep disturbance. Furthermore, the custom to base noise policy and legislation on average responses should be re-assessed based on these findings.

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