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Single and Combined Effects of Air, Road and Rail Traffic Noise on Sleep

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ABSTRACT

INTRODUCTION: It is a well known fact that noise annoyance depends on the traffic mode. Much less is known about differences in physiological effects, especially on combined effects. Therefore, the German Aerospace Center (DLR) investigated the effects of air (AI), road (RO) and rail (RA) traffic noise on sleep in the AIRORA study.

METHODS: 72 subjects (40+/-13 years, 32 male) were polysomnographically investigated during 11 consecutive nights in the laboratory. Electrophysiological signals included EEG, EOG, EMG, EKG, respiratory movements and finger pulse amplitude. Cortisol and noradrenalin were measured in nocturnal urine samples. Each traffic mode consisted of five noise categories (maximum SPL 45, 50, 55, 60 and 65 dBA) with 8 different noise events, i.e. 40 noise events in total. Therefore, between 40 and 120 noise events were realistically played back during single (AI, RO, RA, RORO), double (AIRO, AIRA, RORA) and triple (AIRORA) exposure nights. The design was complemented with a noise-free control night and carefully balanced.

RESULTS: Although annoyance due to aircraft noise was stronger compared to both rail and road traffic noise, preliminary analyses of parts of the physiological data do not support the same order. Final results will be shown and discussed on the conference.

1 INTRODUCTION

It is a well known fact that noise annoyance depends on the traffic mode. Much less is known about differences in physiological effects, especially on combined effects. Therefore, the German Aerospace Center (DLR) investigated the effects of air (AI), road (RO) and rail (RA) traffic noise on sleep in the AIRORA study. This paper concentrates on methods and study design. Preliminary and some final results will are also shown.

2 STUDY DESIGN AND PROTOCOL

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 ten served as a backup night, i.e. if signals of relevant electrodes were lost and sleep stage

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classification was impossible for one subject in nights two to ten, the respective noise scenario was presented in night ten again.

Table 1: Composition of exposure nights.

	Number of Noise Events				
Scenario	Air	Road	Rail	Total	$L_{AS,eq}$
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

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 categories: 45, 50, 55, 60 or 65 dB. Sound pressure levels 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 in four noise events from freight trains and four noise events from passenger trains. For road noise, each category was divided in 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 lorries. 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.

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 $L_{AS,eq}$ of the single exposure nights of aircraft and rail traffic noise were identical. This was accomplished by cutting out middle pieces of two 65 dB freight trains. Because of the shorter duration of road traffic noise events, the $L_{AS,eq}$ of the road traffic single exposure night was lower than 39.7 dB. In order to get an $L_{AS,eq}$ of 39.6 dB, the number of road noise events was doubled in exposure night RORO (details shown in Table 2). In that way, it was possible to compare single exposure nights according to the $L_{AS,eq}$ as well.

Table 2: Composition of exposure night RORO with 80 noise events in total and an $L_{AS,eq}$ of 39.7, which is equal to the $L_{AS,eq}$ in exposure nights AI and RA. Number of noise events in each category are shown.

	Maximum SPL in dB(A)				
	45	50	55	60	65
Passenger Car (Dry Road)	1	2	2	3	2
Passenger Car (Dry Road)	1	2	2	3	2
Passenger Car (Dry Road)	1	2	2	3	2
Passenger Car (Dry Road)	1	2	3	2	2
Passenger Car (Dry Road)	1	2	3	2	2
Passenger Car (Wet Road)	1	2	3	2	2
Motorcycle	1	2	3	2	2
Lorry	1	2	3	2	2

Additionally, there was one night free of any traffic noise. Here, the $L_{AS,eq}$ of 30 dB(A) was caused by the constant sound of the air-condition system.

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

Archdeacon et al. [1] described a sequentially counterbalanced square for nine exposures, where each exposure is applied in every position once and is preceded by every other exposure once as well. There are 9!=362,880 possibilities of attributing the nine different noise scenarios to this square. All possible combinations were tested, but in every combination there was at least one study period with three high exposure nights in a row.

Therefore, all designs meeting both criteria (1) and (2) were calculated with a computer program, and one design was chosen. The final design is shown in Table 3.

Table 3: 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

Of the possible study designs the one was chosen with the best balance according to prior exposure (see Table 4). Low exposure nights were preceded by high exposure nights in six and by low exposure nights in two cases, allowing a direct comparability between single exposure nights and with the noise-free night according to prior exposure.

2.2 Composition of single noise nights

The length of the time interval between the start of to 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.

The night was divided into four blocks of 10 (single exposure nights), 20 (double exposure nights) or 30 (triple exposure nights) noise events. The detailed procedure will be exemplified for single exposure nights below. First, the time intervals between the start of two noise events were sorted in descending order. Each of the four longest intervals was randomly assigned to one of the four blocks. This method was repeated for compartments of four intervals, until the last compartment of the four shortest time intervals. This procedure guaranteed that time intervals of equal length were evenly distributed over the four blocks, and therefore over the night. Thus, clusters of short or long time intervals at the beginning or the end of the night were avoided. Next, the order of time intervals within blocks was randomly changed.

A similar procedure was applied for maximum SPLs of noise events. Two noise events of each maximum SPL category were randomly assigned to one of the four blocks. Then, the order of noise events within blocks was randomly changed. This procedure guaranteed that noise events with equal maximum SPL were evenly distributed over the four blocks, and therefore over the night. Thus, clusters of noise events with low or high SPLs at the beginning or the end of the night were avoided.

The sequence of time intervals in each study night was kept constant for single, double and triple exposure nights over the nine study periods, e.g. single exposure nights consisted always of the same sequence of time intervals in night three, irrespective of the type of exposure (AI, RO, RA).

The sequence of noise events was changed for each exposure pattern over the nine study nights, as the type of the noise events occurring before sleep onset play an important role for the evaluation of the whole night, especially in multi exposure nights.

The time intervals and types of the first ten noise events of exposure pattern AIRO are exemplarily given in Table 4.

Table 4: Noise pattern of the first ten noise events in study nights two to ten for exposure night AIRO. above: start time of noise event, below: maximum SPL (e.g. 45 = 45dB), type of noise event (e.g. AI = aircraft noise) and number of noise event in the SPL category (e.g. 5)

	Study Night								
Event	2	3	4	5	6	7	8	9	10
1	23:06 45AI4	23:06 50RO4	23:06 50AI8	23:06 50RO1	23:06 60AI8	23:06 65RO4	23:06 45AI7	23:06 60RO7	23:06 65AI8
2	23:12 50AI5	23:15 45RO8	23:10 60AI8	23:14 50RO8	23:12 55RO8	23:11 50AI7	23:13 45RO8	23:13 45AI1	23:12 55AI4
3	23:17 50AI3	23:23 50AI3	23:17 50RO6	23:23 55RO5	23:16 65RO4	23:20 45AI6	23:20 50AI1	23:19 45AI2	23:21 60AI6
4	23:20 45RO2	23:31 65AI8	23:23 65AI5	23:31 50AI5	23:21 60RO2	23:24 50RO5	23:28 45RO5	23:24 45RO7	23:24 65RO4
5	23:26 45RO4	23:35 60AI4	23:30 45AI6	23:35 55RO4	23:24 45AI4	23:31 55AI8	23:34 45AI2	23:28 50RO4	23:33 45RO2
6	23:30 60RO7	23:43 55RO1	23:39 65RO6	23:39 65AI3	23:31 65AI3	23:34 55AI8	23:40 60RO1	23:33 45RO5	23:37 55AI1
7	23:39 55RO1	23:47 55RO8	23:43 60RO4	23:42 65AI8	23:35 60RO5	23:39 65RO1	23:44 60RO6	23:41 55RO4	23:46 50RO3
8	23:47 55RO6	23:54 60RO5	23:48 45RO1	23:48 65RO8	23:41 55RO7	23:48 55RO1	23:47 55AI5	23:49 65AI8	23:51 45AI4
9	23:52 65RO6	23:57 45AI8	23:51 65RO4	23:52 50AI4	23:50 65AI6	23:56 55RO7	23:50 55RO3	23:53 50AI5	23:55 60RO4
10	23:55 50RO4	00:03 50RO6	23:56 50RO8	23:59 60RO2	23:54 45AI8	00:03 65AI6	23:58 55RO6	23:57 60AI8	23:59 50AI2

3 PRELIMINARY RESULTS

3.1 Sleep quality

Questionnaires were filled out by study participants about 10 minutes after wake up time. Subjects were asked about their sleep quality on a five-point scale. The percentage of subjects choosing the upper two categories depending on traffic pattern are shown in Figure 1.

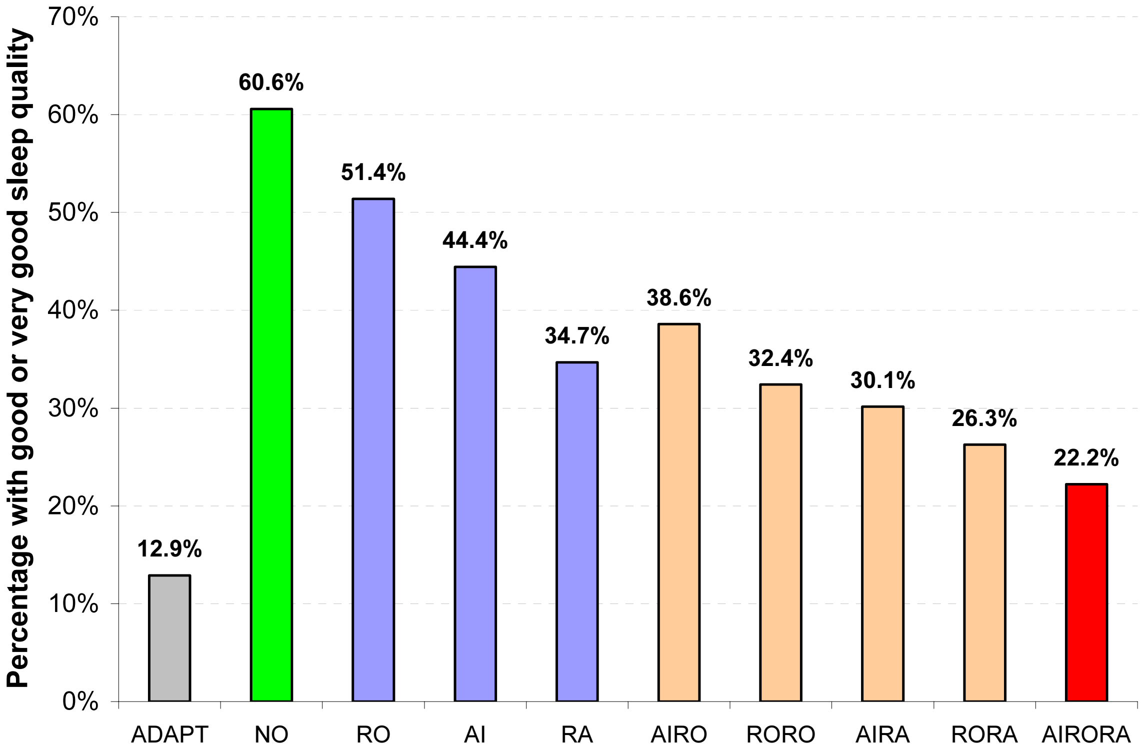

Figure 1: Sleep quality depending on traffic noise pattern (ADAPT = adaptation night #1, NO = noise free night, AI = air traffic, RO = road traffic, RA = rail traffic).

Only 12.9% of the subjects rated the sleep quality of the adaptation night as good or very good, whereas 60.6% of the subjects evaluated the noise-free night as good or very good. Sleep quality decreased in single exposure nights in the order road (51.4%), air (44.4%) and rail (34.7%) traffic noise. Sleep quality in double exposure nights was generally perceived worse than in single exposure nights, except for nights with rail traffic noise only, which was perceived worse than nights with road and air traffic noise. Sleep quality in the triple exposure night AIRORA was perceived worst and only a little better compared to the adaptation night.

3.2 Annoyance

Subjects were asked whether they perceived air, road or rail traffic noise during the night. If they perceived noise of two sources, they were asked by which they felt more annoyed. If they perceived all three traffic modes, they were first asked which annoyed them most, and then which of the remaining two annoyed them more. Results are shown in Figure 2.

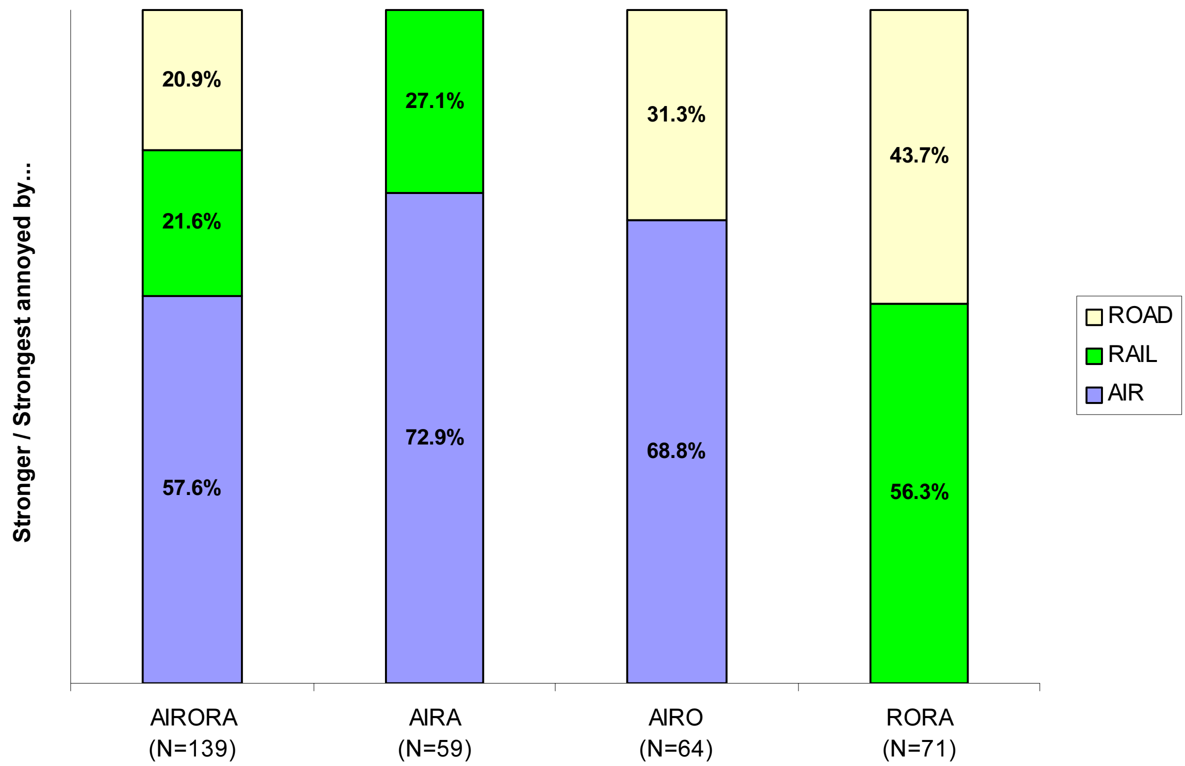

Figure 2: Noise annoyance comparison between the three modes air (AI), road (RO) and rail (RA) traffic. Number of nights given in parentheses.

If subjects had exactly perceived what had been played back, N=72 would be expected in each category. N=139 in the AIRORA category indicates that in many nights with two or even one traffic mode all three categories have been perceived. Here, subjects felt most strongly annoyed by aircraft noise (57.6%), followed by equal percentages of road (20.9%) and rail (21.6%) traffic noise. If two traffic modes were perceived including aircraft noise, subjects felt stronger annoyed by aircraft noise then by road or rail traffic noise in 68.8% and 72.9%, respectively. At the same time, annoyance ratings between road and rail traffic noise did not differ if both traffic modes were perceived. In conclusion, subjects felt most strongly annoyed by aircraft noise, followed by equal annoyance ratings of road and rail traffic noise.

3.3 Fatigue

A fatigue score was generated from questionnaire data according to Samn and Pirelli [3] (translated to German), a score of 20 representing maximum fatigue and a score of 0 representing maximum wakefulness. Figure 3 shows differences in fatigue scores of exposure nights compared to noise-free nights.

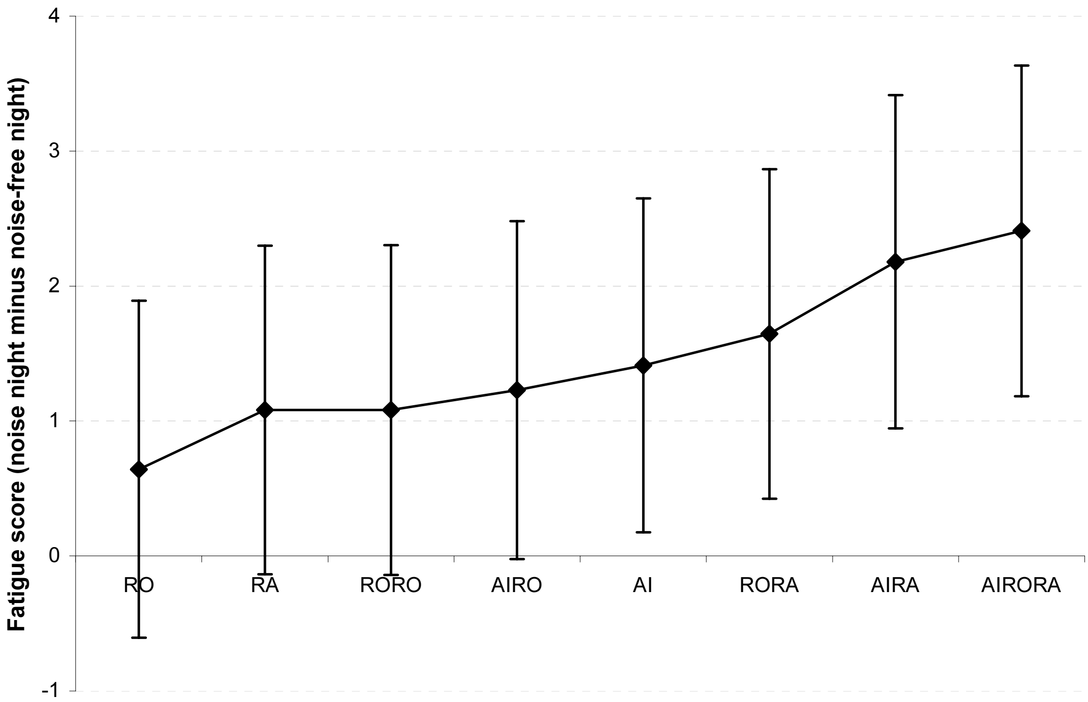

Figure 3: Fatigue score depending on exposure pattern. Difference "noise night" minus "noise-free night" and 95% confidence limits (SAS Version 9.1, Proc Mixed) are shown.

Fatigue was elevated in all noise-nights compared to the noise-free night. It was statistically significantly higher in nights with AI, RORA, AIRA and AIRORA exposure patterns. Fatigue was lowest in the single exposure night with road traffic and highest in the triple exposure night.

3.4 Polysomnographic awakenings

Event correlated analysis of changes to sleep stage S1 or Wake under the influence of traffic noise was performed as described in [2]. Here, analysis were based on exposure nights with one traffic mode only. A multivariable random effects logistic regression model (EGRET, Version 2.0.31) on parts of the whole data set with maximum sound pressure level and two indicator variables for rail and road traffic noise as the only explanatory variables showed decreasing reaction probabilities in the order road → rail → aircraft noise.

4 SUMMARY AND CONCLUSIONS

Differences in the effects of air, road and rail traffic noise on sleep were investigated in a polysomnographic study with a carefully balanced cross-over design. Additionally, the effect of combined exposures to two or three traffic modes was examined.

Sleep quality (questionnaire data) decreased in the order road, air and rail traffic noise, with lower sleep quality in double and the lowest sleep quality in triple exposure nights.

In a comparative analysis, subjects felt most annoyed by air traffic noise, and equally annoyed by road and rail traffic noise.

Fatigue (questionnaire data) was increased in all exposure nights compared to noise-free nights, least for single exposure nights with road and most in the triple exposure night with all traffic noises.

Preliminary analyses indicate decreasing awakening probabilities in the order road, rail and air traffic noise. This is a somewhat surprising result, and therefore the analyses of the complete data set will be essential to confirm this result. Detailed analyses will give insight into the mechanisms leading to the changes in awakening probability.

Obviously, exposure to more than one traffic mode lead to more severe changes in objective and subjective sleep structure variables than exposure to a single traffic mode. Therefore, all traffic modes should be simultaneously taken into account by legislative and political bodies.

5 REFERENCES

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