Effects of aircraft noise on reading and oral language abilities in German children near Frankfurt/Main airport: Results of the NORAH (noise-related annoyance, cognition, and health)-study

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Summary

Prior research indicates that chronic exposure to aircraft noise may impair children's cognitive development, especially reading acquisition. The hitherto most comprehensive study in this field RANCH yielded a linear exposure–effect relationship between aircraft noise levels and decreasing reading performance. In the framework of the NORAH-study, the effects of aircraft noise on cognitive performance were investigated 1090 German second-graders from 29 schools in the vicinity of Frankfurt/Main Airport. In addition to reading and episodic long-term memory (story recall), phonological precursors of reading were assessed in order to investigate the mechanisms underlying the relationship between aircraft noise and reading ability. Potential confounding factors such as socioeconomic status, migration background, non-verbal abilities, classroom insulation and exposure to road traffic and railway were also assessed. Although aircraft noise levels at schools did not exceed 60 dB (LAeq 8-14) and were thus considerably lower than in RANCH and other studies, multilevel analyses revealed significant effects of aircraft noise on children´s reading comprehension after adjustment for individual (e.g. socioeconomic status) and class-related (e.g., road traffic noise at school, classroom insulation) factors. A 10 dB increase in aircraft noise was associated with a decrement of one-tenth of an SD on the reading test, corresponding to a one month reading delay in this test. Concerning phonological processing abilities and episodic memory, no significant effects of aircraft noise were found. The magnitude and relevance of the noise effects, and potential mechanisms underlying the association between aircraft noise and reading are discussed.

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1. Introduction

Pior studies proved negative effects of aircraft noise exposure on children’s quality of life, noise annoyance, and cognition [1]. Across studies, exposure to aircraft noise was consistently associated with lower reading performance [2,3,4]. The hitherto most comprehensive study in this field, the cross-sectional RANCH (road-traffic and aircraft noise exposure and children´s cognition and health) study [4] included children (N = 2844) living in the vicinity of huge international airports in the UK (Heathrow), the Netherlands (Schiphol), and Spain (Barajas). Whereas prior studies confined to comparisons of highly exposed and non-exposed children, noise exposure in the RANCH study was included as continuous variable, aiming to reveal the noise levels at which the harmful effects on children’s cognition begin. With socioeconomic status (SES) being controlled, the authors found no effect of aircraft noise exposure on sustained attention, working memory, and delayed recall of orally presented stories, but a linear exposure–effect relationship between aircraft noise and decreasing reading comprehension.

Some researchers proposed that enduring exposure to noise in early childhood affects the development of basic language functions which are of special importance in reading acquisition [5,6]. This is a reasonable argument in view of, on the one hand, the vulnerability of children´s phonological abilities (e.g., speech perception, short-term memory, phonological awareness) for disruption due to acute noise [7], and on the other hand, the important role of these functions in reading acquisition [8]. However, the mechanisms underlying the adverse effects of aircraft noise on children´s reading are still unclear.

2. The present study

In the framework of the NORAH-study (noise-related annoyance, cognition and health), the effects of aircraft noise on children’s annoyance, quality of life, reading and reading-related phonological abilities were investigated in second-graders living in the vicinity of Frankfurt/Main Airport, Germany. This paper focuses on the effects of aircraft noise on children’s reading and phonological abilities. The effects of aircraft noise on children´s well-being at school and health-related quality of life are presented in a separate EURONOISE 2015 paper [9].

3. Methods

3.1. Participants

Participants were 85 teachers (78 female) and 1243 second-grade children from 29 primary schools near Frankfurt/Main Airport. From a total of 297 schools, 29 schools were selected by extent of aircraft noise exposure. Those schools exposed to the highest amounts of aircraft noise were selected first. The remaining schools were selected using a combination of criteria. The schools were matched by indicators of the pupils´ SES, migration background, and German language proficiency, according to the headmasters´ reports. Schools whose headmasters reported high noise levels from road traffic, railroad traffic, industry or other noise sources were excluded.

We obtained approval for the study from the Hessian Ministry of Education, and written parental consent. In this paper, the data of 1090 children aged 7 to 10 years (mean age 8 years 4 months; 557 girls, 533 boys; 60% with a migration background) are reported, as full data from the parent questionnaires and the test battery were required for inclusion in the statistical analyses.

3.2 Noise exposure assessment

The children´s aircraft noise exposure at school and at home was assessed by means of radar data provided by “Deutsche Flugsicherung GmbH” (DFS, German Air Traffic Services). Road traffic and railway noise were calculated using a combination of information (e.g., traffic flow data, street types, proportion of heavy traffic and traffic census data; quantity of train runs, speed and length of the trains).

Noise exposure during the time period of 12 months before data collection was assessed for each individual child by linking the school and home addresses to the modeled aircraft, road traffic and railway noise levels computed for different times of day (school: 08-14h, home: 06-18h, 20 – 06h). Classroom insulation was assessed using a combination of variables (e.g., glazing, wall thickness). Aircraft noise levels were treated in the statistical analyses as continuous variables in dB(A): $L_{pAS,eq,08\text{-}14}$ at school and $L_{pAS,eq,06\text{-}18}$ and $L_{pAS,eq,20\text{-}06}$ at home. Road traffic and railway noise levels were entered as classed variables into the final model.

3.3 Tasks and Materials

Reading
Children´s reading abilities were assessed by means of a standardized reading test for primary school children instructed in German language [10]. The test consists of three subtests measuring reading speed and accuracy on the level of single words, sentences, and short paragraphs. For each subtest, the children´s raw scores were transformed into standard scores (T-scores, mean 50, SD 10). In addition, a global reading score was computed for each child by averaging the T-scores across subtests.

Nonverbal abilities
In order to control for general intellectual abilities, a short form of the Coloured Progressive Matrices was used [11]. Incomplete visual patterns are presented to the children. The children have to select the missing item from 6 alternatives. The test consists of 16 items increasing in difficulty.

Episodic memory (story memory)
The subtest "auditory memory" from the German version of the "Intelligence and Development Scales" [12] was modified for the current study and adapted for testing in groups of children. A short story about a boy and a dog is read to the children. After a delay filled with other tasks, the children are asked questions relating to central and marginal aspects of the story content. For each question, the children have to select the correct answer out of three alternatives which are read out loud by the experimenter. The response alternatives are illustrated by pictures shown on a screen in front of the classroom. The test consists of 22 questions.

Rapid retrieval of words from long-term memory
Answer sheets printed with an array of 96 pictures of common objects (e.g., bed, dog, tree, knife) are given to the children. The task is to cross out pictures representing words which start with the phoneme /b/, and to mark all pictures representing other words with a circle. Performance is assessed via the number of items correctly marked in two minutes.

Speech perception
Speech perception was assessed by means of a word-to-picture matching task requiring identification of noise-masked words [6]. Lists of three similar-sounding common and concrete German nouns were created (e.g. *Fee* [fe:], *Reh* [re:], *See* [se:]). Each item is represented by a picture. In each trial, three pictures representing the similar-sounding words are presented to the children. Two seconds after onset of this slide, a spoken word corresponding to one of the three pictures is presented in a multitalker speech noise with an S/N of about -4 dB. The children have to mark the appropriate picture on prepared answer sheets. Prior to the task, the pictures are presented one-by-one and named by the experimenter.

Verbal short-term memory
Verbal short-term memory was assessed via storage of pseudowords [6]. In each trial, a pair of pseudowords is presented to the children. In 9 of the 24 pairs, the pseudowords are equal, in 15 trials, the second pseudoword differs from the first with respect to one or two phonemes. For instruction, the task is embedded in a story about a fairy who is teaching magic spells to her assistant. The children have to decide whether or not the assistant was successful in repeating what the fairy said. Responses are marked on prepared response sheets on which each trial is represented by a smiling face ("same") and a sad face ("different").

Phonological awareness
In this task, the children have to decide which of three CVC-pseudowords differs from the others with respect to the initial sound [13]. This is a standard task in the assessment of phonological processing in children called 'odd one out'. The position of the 'odd' syllable in the sequence has to be marked on prepared response sheets. Prior studies have shown that performance in this task is closely related to reading and spelling, and that the task is highly sensitive to negative effects of acute noise[6].

Questionnaires
Socioeconomic status (SES), migration background, main language spoken at home, and parental support in school learning were assessed via parent questionnaires. SES scores were calculated from parents´ education and income. For children with a migration background, individual ratings of proficiency in German language were obtained from the class teachers.

3.4 Procedure

Data collection took place from April to June 2012. The tests were performed in the morning in groups of whole classes. The pictures were presented via a notebook and a low-noise beamer on a screen in front of the classroom. The speech materials were presented via wireless headphones, at a comfortable signal level adjusted in pilot studies. The headphones were used in order to ensure perfect signal quality at each working place in the classroom, and thus eliminate acute effects of classroom reverberation and noise from outside. The presentation of the pictures and sounds was controlled by means of standard presentation software. Each task was carefully explained to the children and practiced with examples. The experimenter and two assistants ensured that all children followed the instructions. All in all, the testing session in the classroom took about 2 hours, including breaks.

3.5 Statistical analyses

In order to account for the hierarchical structure of the data (Level 1: children; Level 2: classes), the associations between aircraft noise exposure and children´s abilities were assessed through multi-level analyses (MLAs). The unadjusted model included only aircraft noise. The final (fully adjusted) model was adjusted for the L2-variables sound insulation, road traffic noise, and railway noise, and for the Level 1 (L1)-variables age, gender, nonverbal abilities, SES, migration background, number of books at home, and German language proficiency. When reading scores were considered as outcome variables, story memory, attention, and phonological awareness were also included as L1 predictors.

4. Results

4.1 Aircraft noise exposure

Aircraft noise levels are given in Table I. Strong correlations were found between aircraft noise at school and at home (r = .96, p < .001), and between daytime and nighttime aircraft noise exposure at home (r = .95, p < .001).

Table I. Aircraft noise exposure at school and at home

Daytime exposure at school ($L_{pAS,eq,A,08\text{-}14}$)	
Mean(SD)	49.52 (6.12)
Median (Range)	50.60 (39.10-58.90)
Daytime exposure at home ($L_{pAS,eq,A,06\text{-}18}$)	
Mean (SD)	49.39 (6.17)
Median (Range)	50.00 (40.00-60.90)
Nighttime exposure at home ($L_{pAS,eq,A,20\text{-}06}$)	
Mean (SD)	44.79 (5.99)
Median (Range)	45.58 (34.1-56.60)

Due to the strength of the correlations, it was not possible in the current study to disentangle effects of aircraft noise at school from effects of aircraft noise at home, or effects of daytime noise at home from effects of noise during the night.
Table I shows that aircraft noise levels at school did not exceed 60 dB. It has to be kept in mind that, in the current study, children´s aircraft noise exposure was considerably lower when compared to prior studies. For example, in the RANCH-study [4], aircraft noise levels at school reached 77 dB (LAeq 06-23). In the Munich longitudinal study [3], schools with aircraft noise levels of 59 dB (LAeq, 24h) were included as “unexposed” controls.

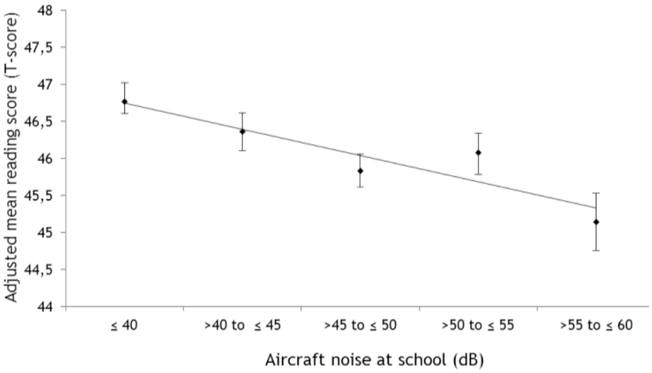
4.2 Effects of aircraft noise at school on children’s reading abilities

Aircraft noise exposure at school was significantly associated with a decrease in children’s reading after full adjustment. The coefficients (b), standard errors and p-values are reported in Table II. Concerning the association between aircraft noise level and impairment in reading, there was no departure from linearity. A 10 dB increase of aircraft noise at school was associated with a decrease in children’s global reading scores by one tenth of an SD, i.e. one point on the T-score scale. The linear exposure-response-relationship is depicted in Figure 1.
Concerning the reading subtests, detrimental effects of aircraft noise were found for word and text reading. For sentence reading, the effect of aircraft noise did not reach significance.
As a further step, separate analyses were performed in children with and without a migration background. In the former, the effect of aircraft noise failed to reach significance. In the latter, a 10 dB increase in aircraft noise at school was significantly associated with a 1.4 point decrease in global reading scores.

4.3 Effects of aircraft noise at school on children’s phonological abilities

Concerning the verbal tasks (episodic memory, short-term memory, rapid naming, phonological awareness, speech perception), no effect of aircraft noise was found. This holds for overall analyses as well as for analyses in the subgroups of children with and without a migration background.

Figure 1: Exposure-response-relationship for children´s reading. Adjusted mean T-score (95 % CI)



for 5 dB bands of aircraft noise at school.

5 Discussion

In the framework of the NORAH-study, the effects of aircraft noise on reading and phonological abilities were assessed in German second-graders living in the vicinity Frankfurt/Main Airport. Although aircraft noise levels at schools did not exceed 60 dB, and were thus considerably lower than in prior studies [e.g., 3, 4], multilevel analyses revealed significant detrimental effects of aircraft noise on children's reading abilities. A 10 dB increase in aircraft noise was associated with a decrement of one-tenth of an SD on the reading test, i.e., one point on the T-score scale. This corresponds to a one month reading delay in this test. Further analyses not reported here revealed comparable effects for aircraft noise at home. However, due to the strong correlation, no conclusion can be drawn concerning differential effects of aircraft noise at home and at school.
The finding of a linear exposure-effect relation after taking into consideration potential confounders, is evidence for the detrimental effect of aircraft noise on children's reading acquisition.

Concerning the verbal tasks (episodic memory, short-term memory, rapid naming, phonological awareness, speech perception), no effect of aircraft noise was found. Thus, the current study does not support the assumption that the adverse effect of aircraft noise on reading acquisition is mediated by effects on phonological abilities. However, such mediating effects cannot be ruled. The paper-and-pencil test used in the current study might not be sensitive enough to uncover small effects of aircraft noise on phonological abilities.

In the current study, the detrimental effect of aircraft noise on reading comprehension was more evident in the group of children without migration background compared to children with migration background. However, this should not be interpreted in terms of a lower vulnerability of migrant children for the detrimental effects of aircraft noise. Rather, the non-significant effect may result from a lack of statistical power: Migration background is associated with a number of factors that are disadvantageous for reading achievement (e.g., lower socioeconomic status and language proficiency), which may lower the chance for uncovering the comparatively small effect of aircraft noise. Concerning children without migration background, a 10 dB increase in aircraft noise was associated with a decrement of 1.4 points on the T-score scale, corresponding to about one and a half- month reading delay. As the aircraft noise levels at school covered a 20 dB – range, a 3 month difference in reading is to be expected between the least and most exposed children.
With confounding variables controlled, the current study proved adverse effects of aircraft noise below 60 dB on children´s reading acquisition. The findings are of relevance for policy of environmental noise and child health.
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Table II. Multilevel model parameter estimates for aircraft noise on children´s reading abilities (global score), for unadjusted and fully adjusted models.

	Unadjusted Model		Fully adjusted Model	
	b (SE)	*p*	*b (SE)*	*p*
Whole sample	-0.103 (0.049)	0.018	-0.097 (0.05)	0.027
Children with a migration background	-0.061 (0. 059)	0.152	-0.057 (0.062)	0.179
Children without a migration background	-0,153 (0.071)	0.015	-0.142 (0.075)	0.030

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