Aircraft noise exposure and children's cognition: evidence for a daytime NAT criterion

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ABSTRACT

There is growing evidence that chronic aircraft noise impairs children's cognition. In the literature, LAeq is the dominating noise exposure metric, although alternative metrics have been demanded (e.g., 1) in order to increase the explained variance in children's cognitive performance. In the German legal foundation, LAeq daytime, LAeq nighttime, LAmax, and number above threshold (NAT) nighttime criterion exist as noise parameters for effects on children (2). Concerning effects of aircraft noise on reading performance, these night-related measures are not suitable for explaining potential underlying mechanisms such as impairment of classroom instructions (3, 4). Here, we present a theoretically motivated secondary analysis of the NORAH data set (5), aiming to evaluate the adequacy of alternative noise metrics. We calculated multilevel analyses with robust estimation algorithms (MLR) and indirect effects, i.e., mediation models with distraction of children during the lessons as mediator between aircraft noise and reading, using different noise metrics (LAeq, LAmax, Emergence, NAT). Only the NAT60 criterion served as a significant predictor over and above daytime LAeq. The results indicate that, for protection of children´s learning at school, both LAeq and daytime NAT should be taken into consideration.

Keywords: Aircraft noise, NAT criterion, children's cognition

1. INTRODUCTION

Prior studies indicate negative effects of chronic aircraft noise exposure on children's quality of life and cognitive performance (e.g., 6, 7). Across studies, exposure to aircraft noise was consistently associated with lower reading performance (for a review, see 8).

This finding was recently confirmed by the NORAH study performed in second-graders (*N* = 1.090) in the Rhein-Main region around Frankfurt Airport, Germany (5). In this region, aircraft noise levels at school (LAeq 08-14) did not exceed 60 dB and were thus below the daytime criterion of the German legal foundation (5). Nevertheless, multilevel analyses confirmed a significant association between aircraft noise exposure and lower performance in a standardized reading test. Separate analyses in subsamples confirmed a significant detrimental effect of noise exposure on reading in children without a migration background (*n* = 439). For the migrant children (*n* = 651), the noise effect was in the same direction, but did not reach significance. The latter finding was attributed to a problem of statistical power: Due to an accumulation of risk factors for reading acquisition in the migrant children, the comparably small additional effect of aircraft noise on reading might be difficult to verify statistically.

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In a second step, the NORAH data was used to examine the mechanism underlying the association between aircraft noise and reading performance. Spilski et al. (4) have shown that, for children without a migration background, noise-induced distraction of children during the lessons (assessed via teacher questionnaires) is a significant mediator and leads to an increase in explained variance in reading. With inclusion of the mediator, the direct effect of aircraft noise on reading was non-significant, indicating a full mediation.

Here, we present a further analysis of the NORAH data set, aiming to evaluate the adequacy of different noise exposure metrics for analyzing the association between aircraft noise and reading. In the literature, LAeq is the dominating exposure metric, although alternative metrics have been demanded (e.g., 1) in order to achieve a substantial increase in explained variance of children's cognitive performance. In the German legal foundation, LAeq daytime, LAeq nighttime, LAmax, and number above threshold (NAT) nighttime criterion exist as noise parameters for effects on children (2). Unfortunately, LAmax and NAT lack empirical evidence and only refer to noise at night. However, concerning the protection of children's cognition, there is evidence that a focus on night-related noise metrics is not useful. Secondary analyses of the RANCH and Munich studies yielded no evidence for an effect of night-time noise exposure over and above the effects of daytime noise (9). Consequently, Stansfeld et al. (9, p.255) suggest that "the school should be the main focus of attention for protection of children against the effects of aircraft noise on school performance". Thus, for daytime exposure, consideration of alternative noise metrics is mandatory. The current analysis is related to the mediation effect of distraction due to aircraft noise (4), i.e., we analyse the effect of noise exposure (in terms of different exposure metrics) on reading through the mediator "noise-induced distraction during school lessons". As the mediation effect was non-significant in the migrant children (4), the current analysis is confined to the children without a migration background.

2 Methods

2.1 Participants

Participants were 439 German second-graders (mean age 8;3; *SD* 5 months; 230 girls) from 29 schools in the vicinity of Frankfurt Airport, Germany. Concerning distraction of children due to aircraft noise, data were available from 84 teachers (78 female).

2.2 Assessment of Noise Exposure

Average aircraft noise levels (LAeq, 08-14), maximum sound levels (LAmax, 08-14), difference between LAmax and LAeq (emergence) and number above thresholds (NAT, 08-14) for bands of five dB(A) were calculated for the time period of 12 months before data collection was conducted. Exposure levels were calculated on the basis of radar data from the Flight Track and Aircraft Noise Monitoring System (FANOMOS) provided by German Air Traffic Services (for details, see 5, 10). Road traffic and railway noise levels were estimated using a combination of information (e.g., traffic flow data, quantity of train runs) provided by local authorities. Classroom reverberation and insulation were assessed through screening procedures (10).

2.3 Tasks, Materials and procedure

Children´s distraction due to aircraft noise was assessed by means of a teacher questionnaire. The teachers had to rate the frequency of observable distractions of the children due to aircraft noise during the lessons on a 5-point rating scale ranging from "never" to "very often". Socioeconomic status and other potential confounding factors were assessed by means of parents questionnaires. Reading was assessed through a standardized reading comprehension test for primary school children instructed in German language (11). The test consists of three subtests measuring fluency and accuracy of reading comprehension on the level of words, sentences, and text paragraphs, respectively. A global reading score was calculated for each individual child by averaging the standard scores (T-Scores, $M = 50$; $SD = 10$) for each subtest. In addition to reading, the test battery included nonverbal abilities and verbal precursors of reading acquisition, i.e., story comprehension, phonological awareness, and rapid access to phonological representations. More details concerning the procedure, test battery, and the questionnaires are provided in Klatte et al. (5).

2.4 Statistical Analyses

Because children grouped within classes, multilevel analyses (MLA) were performed in order to deal with the hierarchical structure of the data and avoid misspecifications of parameters (e.g., underestimation of standard errors) (12). All models were adjusted for confounding factors on both hierarchical levels (level 1: individual, level 2: classes) and calculated using robust maximum likelihood estimation (MLR).

3 Results

3.1 Aircraft noise exposure

As illustrated in Figure 1, aircraft noise at school (LAeq, 08-14) ranged from 39 to 59 dB ($M = 49.52$; $SD = 6.12$), and the maximum aircraft noise levels (LAmax, 08-14) ranged from 50 to 80 dB ($M = 64.12$; $SD = 7.88$). The bars represent the average number of aircraft noise events for bands of five dB(A) for each classroom. For example, three classes had an exposure of 66 airplane events with LAmax (08-14) $\geq 55 < 60$ dB(A). Furthermore, three classes had an exposure of 58 events of airplanes with a LAmax (08-14) $\geq 60 <$ 65 dB(A). Descriptive statistics for the NAT metric and the emergence metric (aircraft noise: LAmax minus LAeq, 13) are shown in Table 1.

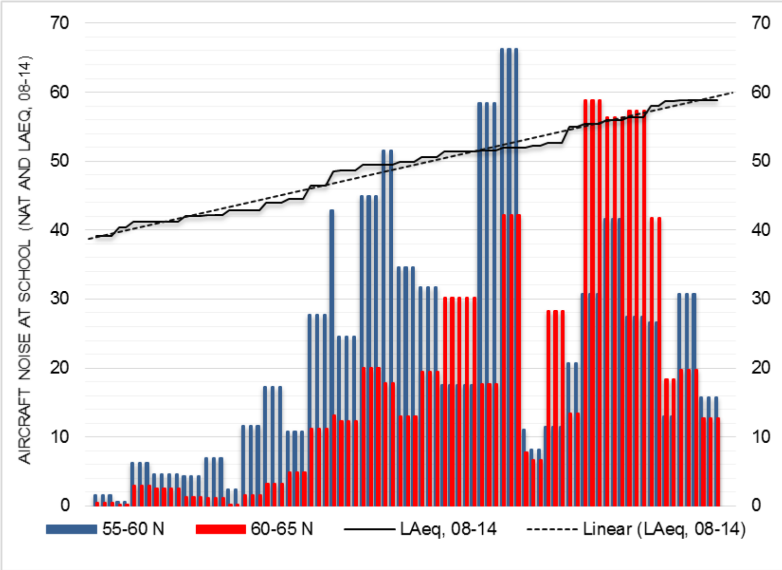

Figure 1 - Red and blue bars: number above thresholds at school (NAT, 08-14) for bands of five dB(A). Dark line: average aircraft noise exposure (LAeq, 08-14) at school.

Table 1 – NAT for bands of five dB(A) at school (08-14) and Emergence

		M	*SD*	*Range*
Emergence	dB(A)	14.924	2.66	9.20 – 21.30
NAT (bands)	20 < 50 dB(A)	367.37	63.79	192.76 – 448.26
	≥ 50 < 55 dB(A)	23.71	14.92	4.15 – 57.75
	≥ 55 < 60 dB(A)	22.60	17.15	0.67 – 66.33
	≥ 60 < 65 dB(A)	18.01	17.72	0.03 – 58.77
	≥ 65 < 70 dB(A)	9.95	14.27	0.00 – 63.61

Note. Emergence: LAmax (08-14) minus LAeq (08-14) at school

3.2 Effects of Aircraft Noise on Childen´s Reading

For LAeq, the inclusion of the mediator leads to a non-significant direct effect (path c´, see Table 2). A 1 dB increase in LAeq is associated with an increase in distraction of .147 scale points (path a). Higher distraction leads to lower reading performance (path b). These relationships indicate a significant indirect effect (a*b) (4). In order to evaluate the adequacy of alternative daytime noise metrics, we calculated multilevel mediator models for the LAmax, Emergence, and NAT exposure metric.

Fully-adjusted multilevel models showed that LAmax and Emergence (separately calculated models) are significant predictors of distraction of children due to aircraft noise (mediator); which in turn has a significant impact on reading performance (see Table 2). For the NAT criterion, this mediation effect was significant for number of aircraft events with levels between 60 and 65 dB(A) (a*b = -0.030; 95%CI: -0.057, -0.003), but not for lower levels (see Table 2). Further combined analyses with LAeq and the inclusion of the alternative metrics were conducted. However, inclusion of all three alternative metrics in one model was not possible because of problems with the convergence during the estimation of the model.

As shown in Table 2, distraction influences reading consistently. In the models aimed to combine the different acoustic metrics, we focused on the path *a* of the mediator model and used distraction as the dependent variable. The models depicted in Table 3 revealed that the NAT, but not the LAmax and Emergence metrics, served as a significant predictor of distraction of children due to aircraft noise over and above LAeq.

Table 2 – Fully-adjusted Multilevel Model for Effects of Aircraft Noise on Children's Reading Abilities

		b (SE)	*p*
LAeq, 08-14	a: Aircraft Noise → Distraction of children	0.147 (0.019)	< .001
	b: Distraction of children → Reading	-0.988 (0.432)	.022
	c: Aircraft Noise → Reading	-0.003 (0.087)	.975
	a*b (indirect effect) 95% CI	-0.145 (-0.275, -0.015)	
LAmax, 08-14	a: Aircraft Noise → Distraction of children	0.106 (0.014)	< .001
	b: Distraction of children → Reading	-0.969 (0.432)	.025
	c: Aircraft Noise → Reading	-0.006 (0.062)	.918
	a*b (indirect effect) 95% CI	-0.103 (-0.198, -0.007)	
Emergence	a: Aircraft Noise → Distraction of children	0.188 (0.043)	< .001
	b: Distraction of children → Reading	-0.965 (0.399)	.016
	c: Aircraft Noise → Reading	-0.029 (0.162)	.856
	a*b (indirect effect) 95% CI	-0.181 (-0.351, -0.011)	
NAT ≥ 50 < 55 dB(A)	a: Aircraft Noise → Distraction of children	0.000 (0.007)	.979
	b: Distraction of children → Reading	-0.992 (0.356)	.006
	c: Aircraft Noise → Reading	0.004 (0.028)	.894
	a*b (indirect effect) 95% CI	0.000 (-0.115, 0.014)	
NAT ≥ 55 < 60 dB(A)	a: Aircraft noise → Distraction of children	0.012 (0.009)	.160
	b: Distraction of children → Reading	-1.015 (0.350)	.004
	c: Aircraft noise → Reading	0.021 (0.025)	.402
	a*b (indirect effect) 95% CI	-0.012 (-0.030, 0.006)	
NAT ≥ 60 < 65 dB(A)	a: Aircraft noise → Distraction of children	0.032 (0.007)	< .001
	b: Distraction of children → Reading	-0.942 (0.376)	.012
	c: Aircraft noise → Reading	-0.009 (0.030)	.761
	a*b (indirect effect) 95% CI	-0.030 (-0.057, -0.003)	

Note. *SE* = Standard Error; *b* = unstandardized coefficient; CI = 95% confidence interval; *n* = 439. Adjusted for age, gender, SES, number of children's books, non-verbal abilities, story comprehension, phonological awareness, access to phonological representations, class SES, class size, percentage of children with a migration background, parental involvement in school affairs, classroom insulation, road-traffic and railway noise at school.

Table 3 – Fully-adjusted Multilevel Models with Inclusion of Several Alternative Metrics: Effect of Chronic Aircraft Noise Exposure on the Mediator (Distraction of Children due to Aircraft Noise)

	β (*SE*)	*p*	95% CI
Combined Model 1			
LAeq	0.167 (0.371)	.654	[-0.561, 0.894]
LAmax	0.295 (0.305)	.334	[-0.304, 0.894]
NAT	0.320 (0.160)	.046	[0.006, 0.633]
Combined Model 2			
LAeq	0.393 (0.182)	.030	[0.037, 0.749]
Emergence	0.099 (0.103)	.335	[-0.103, 0.302]
NAT	0.320 (0.160)	.046	[0.006, 0.633]

Note. *SE* = Standard Error; *β* = standardized coefficient, CI = 95% confidence interval. Emergence: LAmax (08-14) minus LAeq (08-14) at school; NAT: Number of Aircraft noise events above 60 dB(A). Adjusted for age, gender, SES, number of children's books, non-verbal abilities, story comprehension, phonological awareness, access to phonological representations, class SES, class size, percentage of children with a migration background, parental involvement in school affairs, classroom insulation, road-traffic and railway noise at school.

4 Discussion

In line with prior studies, the NORAH study (5) revealed a significant association between aircraft noise exposure at school and lower reading performance in primary school children. Further analyses of the NORAH data set (4) indicated a mediating role of children´s distraction due to aircraft noise during the lessons.

In NORAH and other studies in this field, LAeq was used as parameter of noise exposure. The current study aimed to evaluate the incremental value of other daytime exposure metrics for predicting negative effects of aircraft noise at school on children´s learning. Alternative daytime exposure metrics have hitherto not been considered in the German German Law for Protection against Aircraft Noise.

Our analyses confirmed that alternative noise metrics, i.e., LAmax, Emergence, and NAT, are significant single predictors of the harmful effects of aircraft noise exposure. For each of these metrics, exposure was significantly associated with noise-induced distraction of children during the lessons, which in turn was a significant predictor of children´s reading performance. However, further analyses revealed that only the NAT metric served as a second (unique) significant predictor over and above daytime LAeq. This supports the idea that, when assessing effects of aircraft noise on children´s learning at school, both the average of noise intensity (as mirrored by the LAeq), and the number of flight events above a certain noise threshold (NAT) should be taken into account. We found significant negative effects on reading performance even when the number of flight events in a band of 60 to 65 dB increased. Concerning noise abatement, consideration of the number of individual daytime flight events above the identified threshold is especially useful, since this parameter potentially can be controlled for more directly than the average of noise intensity. In sum, the NAT values for daytime noise exposure appear to be an adequate supplement to the existing LAeq criterion and should be considered in the German Law for Protection against Aircraft Noise.

Acknowledgements

This study is part of the NORAH research project. NORAH is commissioned by the Environment & Community Center/ Forum Airport & Region, Kelsterbach, Germany.

REFERENCES

1. Kamrath, M., & Vigeant, M. C. (2014). Gaps in the literature on the effects of aircraft noise on children's cognitive performance. *The Journal of the Acoustical Society of America, 136*(4), 2304. doi:10.1121/1.4900337
2. Gesetz zum Schutz gegen Fluglärm in der Fassung der Bekanntmachung vom 31. Oktober 2007 (BGBl. I S. 2550)" [German Law for Protection against Aircraft Noise], Bundesministeriums der Justiz und für Verbraucherschutz 30.03.1971.
3. Clark, C., Lopez Barrio, I., van Kamp, I., van Kempen, E., & Stansfeld, S. A. (2014, June). *Teachers' reactions to environmental noise at school in the RANCH project: A potential mechanism for noise effects on children's cognition?* Proceedings of 11th International Conference on Noise as a Public Health Problem, ICBEN, Nara, Japan.
4. Spilski, J., Bergström, K., Mayerl, J., Möhler, U., Lachmann, T., & Klatte, M. (2017, June). *The relationship between aircraft noise and reading: Mediator and moderator effects.* Proceedings of 12th International Conference on Noise as a Public Health Problem. ICBEN, Zürich, Switzerland.
5. Klatte, M., Spilski, J., Mayerl, J., Möhler, U., Lachmann, T., & Bergström, K. (2017). Effects of Aircraft Noise on Reading and Quality of Life in Primary School Children in Germany. *Environment and Behavior, 20,* 001391651664258. doi:10.1177/0013916516642580
6. Hygge, S., Evans, G. W., & Bullinger, M. (2002). A prospective study of some effectsof aircraft noise on cognitive performance in school children. *Psychological Science*, *13*, 469-474. doi:10.1111/1467-9280.00483
7. Clark, C., Martin, R., van Kempen, E., Alfred, T., Head, J., Davies, H. W., . . .Stansfeld, S. A. (2006). Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: The RANCH Project. *American Journal of Epidemiology*, *163*, 27-37. doi:10.1093/aje/kwj001
8. Clark, C., & Sorqvist, P. (2012). A 3 year update on the influence of noise on performance and behavior. *Noise & Health*, *14,* 292-296. doi:10.4103/1463-1741.104896
9. Stansfeld, S., Hygge, S., Clark, C., & Alfred, T. (2010). Nighttime aircraft noise exposure and children's cognitive performance. *Noise Health,* 12, 255-62.
10. Möhler, U., Liepert, M., Mühlbacher, M., Beronius, A., Nunberger, M., Braunstein, G., ... Bartel, R. (2014). *Verkehrslärmwirkungen im Flughafenumfeld: Erfassung der Verkehrsgeräuschexposition* [Effects of traffic noise in areas surrounding airports: Report of methods of noise exposure assessment]. Retrieved from http://www.laermstudie.de/ergebnisse/basismodul-akustik/
11. Lenhard, W., & Schneider, W. (2006). *Ein Leseverständnistest für Erst- bis Sechstklässler (ELFE 1-6)* [Reading comprehension test for grades 1 to 6].Gottingen, Germany: Hogrefe.
12. Hox, J. J. (2010). *Quantitative Methodology Series: Multilevel analysis: Techniques and applications* (2nd ed.). New York, NY: Routledge
13. Griefahn, B. (2003). Physiologische Lärmwirkungen [physiological effects of noise]. In R. Schuemer, D. Schreckenberg & U. Felscher-Suhr (Hrsg.), *Wirkungen von Schienen- und Straßenverkehrslärm* (S. 111-123). Bochum: ZEUS GmbH. Retrieved from http://www.verkehrslaermwirkung.de/03schstr.pdf.