The relationship between aircraft noise and reading: Mediator and moderator effects

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ABSTRACT

There is considerable evidence that chronic exposure to aircraft noise is associated with lower reading performance in children. The discussion of underlying mechanisms focuses on noise-induced impairments of verbal precursors of reading, over-generalization of “tuning out”-strategies, and motivational deficiencies. There is, however, a lack of studies considering the impact of indirect or moderating factors on the association between noise and reading, such as quality of instruction, migration background, and urbanicity.

In the NORAH study [1], reading performance, noise exposure, and a range of potential moderating and mediating variables on the individual and class levels were assessed in second-graders living in the vicinity of Frankfurt/Main airport, Germany. Here, we present a theoretically motivated secondary analysis of the NORAH data set. We calculated multilevel analyses with integrated mediated and moderated models. We found empirical evidence for indirect and moderated effects in the relationship between noise and reading performance. Including these effects in the multilevel models resulted in a substantial increase of explained variance (R^2) in children´s reading.

1 Introduction

Negative effects of chronic aircraft noise exposure on children’s cognitive performance have been found in a number of studies. Especially, exposure to aircraft noise was found to be associated with lower reading performance in primary school children [2]. In terms of learning time, the effects correspond to a reading delay of 2 to 6 months in the most exposed compared to the least exposed children [e.g. 1, 3]. However, the results are not as consistent as predominantly claimed [e.g. 4, 5], and in one study, the negative effect of aircraft noise on reading performance was abolished after adjustment for socioeconomic status (SES) [6].

Research in this field has focused on direct relationships between noise and children's cognition. Hitherto, little is known on the mechanisms underlying and moderating these associations. Here, we present a theoretically motivated secondary analysis of the NORAH study [1] that considers indirect and moderated effects. We propose that noise-induced impairment of instruction is a mediator, and migration background and urbanization are moderators of the relationship between aircraft noise and reading.

Mediator effects

The discussion of potential mediators between aircraft noise and reading includes the over-generalization of "tuning-out"-strategies [7], impairments of verbal precursors for reading [8], learned helplessness [9], and teacher frustration [10]. However, current evidence for an alternative explanation comes from the RANCH and the NORAH project [1, 3]. In a post-hoc analysis of the RANCH teacher survey, Clark et al. [11] found that 20-25% of teachers exposed to aircraft noise reported impairments of classroom discourse and students´ attention and concentration. In the NORAH study [1], the teachers reported even stronger impairments of instructional quality due to aircraft noise. Especially, in NORAH, 52% of the teachers from the most exposed schools reported frequent interruptions of classroom discourse and observable distractions of the children due to aircraft noise. In view of the fact that in NORAH, aircraft noise levels at schools (LAeq) were below 60 dB(A) and thus considerably lower when compared to prior studies including RANCH, these results suggest that even comparably low levels of aircraft noise have harmful effects on classroom instruction in primary schools. In educational science, it is well understood that such impairments have negative effects on the efficiency of instruction, for example in terms of learning time and activation (e.g. 12, 13]. These findings indicate that the association between aircraft noise exposure and reading might be mediated by noise-induced distraction of the children during school lessons [14].

Moderator effects

Migration background: Migration background is strongly correlated with reading achievement [15, 16]. In Germany, families with migration background live predominantly in urban regions such as Rhine-Main, and migrant children are disproportionately affected by risk factors for academic attainment [17, 18]. Concerning reading achievement, these risk factors comprise economic disadvantages (lower socioeconomic status), less stimulating home literacy environment, and less contact with native speakers (models) in the residential environment [e.g.19-22].

There is evidence that aircraft noise exposure has differential effects on children with and without migration background. In NORAH, analyses in subgroups proved a significant association between aircraft noise and lower reading scores in children without a migration background, whereas in migrant children, the association was non-significant (see below). Furthermore, in a study performed in South Africa [23], a significant effect of aircraft noise on reading was found in children with English (i.e., the language of instruction) as first language, but not in children with English as second language.

Urbanization: Over the past few decades, urban areas have expanded rapidly, and nowadays more than 50% of the world population live in urban areas [24]. Urban areas differ from suburban and rural areas with respect to the amount of opportunities and risks for children´s health and cognitive development [25, 26]. A higher degree of urbanization leads to more

environmental stressors such as air pollution, noise, and crowding [cf.19, 27, 28]. In line with this, the degree of urbanization (measured in terms of outside density) proved a significant predictor for children's cognition [19, 26]. In addition, home density is associated with problematic social behavior in children and lower parental care (for review, see [27]).

In view of the accumulation of environmental stressors in urban areas, it might be argued that children and teachers from less urbanized areas are especially prone to harmful effects of specific stressors such as aircraft noise. In these areas, other environmental stressors (e.g., crowding, other noise sources, air pollution) might be less pronounced, resulting in a relatively more prominent impact of aircraft noise.

2 Methods

2.1 Recruitment of the school sample

Written information on the study and a questionnaire concerning socioeconomic factors and exposure to different noise sources were sent out to all 297 public primary schools in the Rhine-Main study region. Schools with the highest aircraft noise exposure levels (LAeq, 06-22, based on noise contours) were selected first. The remaining schools were matched according to the headmasters´ reports concerning children´s SES, migration background, and proficiency in the language of instruction (German). Post-hoc matching based on propensity scores confirms our successful matching without selection bias and confounding [14].

A total of 1,243 second-grade children participated in the study. Concerning migration background and reading performance, complete data were available for 1,090 children (age *M* = 8;4, *SD* = 5 month), and 60% of the children had a migration background. 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 at school (LAeq 08-14) and at home (LAeq 06-18) 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 [1, 29]. 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.

2.3 Assessment of urbanization

Urbanization was operationalized with the key factor density (people per km²). Data of density was available from the German Zensus 2011 (9 May 2011 [30]) for the postcodes areas of all schools.

2.4 Tasks and Materials

Migration background and distraction due to aircraft noise were assessed by means of questionnaires for parents and teachers, respectively. Reading was assessed through a standardized reading comprehension test for primary school children instructed in German [31]. More details concerning the test battery and the questionnaires are provided in [1].

2.5 Procedure

The reading test was conducted in the schools in groups of whole classes. Children took the parent questionnaire to their parents who filled it out at home. The teacher questionnaires were filled out by the class teacher during the testing session in her or his class.

2.6 Statistical Analyses

Firstly, we conducted extensive preliminary analysis with respect to psychometric quality, missing values and the appropriateness of imputation methods (for details, [14]). Secondly, we calculated the main 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 [32]. We used two-level random intercept models and we integrated the mediator “distraction due to aircraft noise” and the moderators “urbanization” and “migration background”. Given that the distribution of urbanization was not continuous and for a better understanding of the moderator effects, we run additional stratified analyses for each dichotomised characteristic of the two moderators. All models were adjusted for confounding factors of both hierarchical levels (Level 1: individual, Level 2: classes). Thirdly, we conducted analyses of robustness and used propensity score matching (PSM) to control for a potential selection bias.

3 Results

3.1 Reading direct effect (with vs. without migration background)

As illustrated in Figure 2, aircraft noise at school (LAeq, 8-14) ranged from 39 to 59 dB (*M* = 49.52; *SD* = 6.12) and maximum aircraft noise levels (LAmax, 8-14) ranged from 50 to 80 dB (*M* = 64.12; *SD* = 7.88).

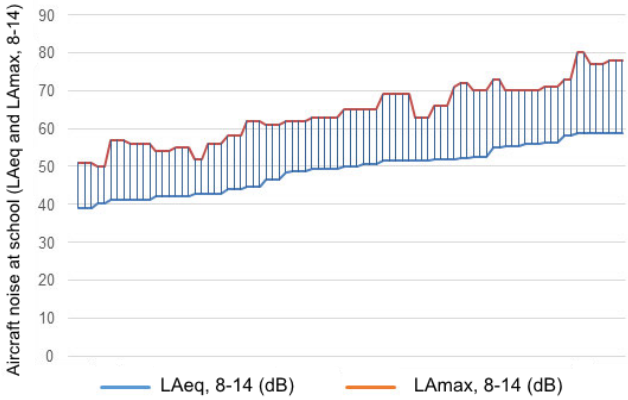

Figure 2: Association between average aircraft noise exposure (LAeq, 8-14) at school and maximum aircraft noise exposure (LAmax, 8-14).

For the whole sample (*N* = 1,090), aircraft noise exposure at school was significantly associated with a decrease in children's reading (*b* = -0.097, *SE* = 0.050, *p* = .027). This effect follows a linear trend (see Figure 3). In terms of learning time, a 10 dB (A) increase of aircraft noise at school corresponds to a reading delay of one month. Thus, in the current sample, there is a reading delay of two months between the most and least exposed children. We proposed migration background as a potential moderator of the effect. Therefore, we calculated stratified analyses for the two subsamples (children with vs. without migration background). Subsequently, we calculated exposure-effect curves (see for details [1]). For children with migration background (*N* = 651), we found a small and non-significant effect of aircraft noise on reading (*b* = -0.057, *SE* = 0.062, *p* = .179). In children without migration background (*N* = 439), the analysis revealed a significant association between aircraft noise exposure at school and lower reading scores (*b* = -0.142, *SE* = 0.075, *p* = .030). The variance (R^2) of reading explained was very similar in both models (with migration: R^2 = .261, without migration R^2 = .270). Multilevel model statistics and information about adjustment are provided in [1], and the results of post-hoc analyses of robustness are reported in [14].

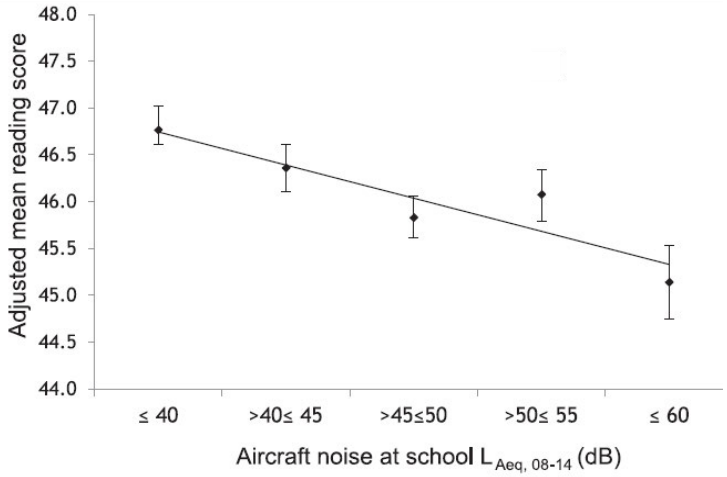

Figure 3: Exposure-effect relationship for global reading score and the whole sample (*N* = 1,090), taken from [1, p. 21].

3.2 Impairment by distraction as mediator (with vs. without migration background)

As mentioned before, we are interested in the mechanisms underlying the association between aircraft noise and reading, and we proposed that noise-induced distraction of children during the lessons is such a mechanism. Hence, we included the mediator "impairment by distraction" in the multilevel models (aircraft noise → impairment by distraction → reading). A significant indirect effect was found in the subsample of children without migration background (a*b = -0.145, 95% *CI*: -0.275, -0.015), but not for children with migration background (a*b = 0.031, 95% *CI*: -0.056, 0.118). In the children without migration background, a 10 dB increase in aircraft noise is associated with an increase in distraction of 1.47 scale points (see Figure 5). This effect is passed on to reading, i.e., higher distraction leads to lower reading performance. The inclusion of the mediator leads to a non-significant direct effect (*b* = -0.003, *SE* = 0.09, *p* = .975, 95% *CI*: -0.173, 0.168), indicating a complete mediation effect. The

importance of this mediation is mirrored in an increased R^2 for reading from .270 to .444 after integration of the mediator (ΔR^2 = .174). Subsequently, in order to control for a possible selection bias, we calculated analyses of robustness with migration background as matching variable. For the matched samples, mediator models were calculated, and we checked whether the results remain stable. The comparison of the mediator models shows no differences in the strength of relationships and intercepts. The mentioned mediation effect is shown only in children without migration background.

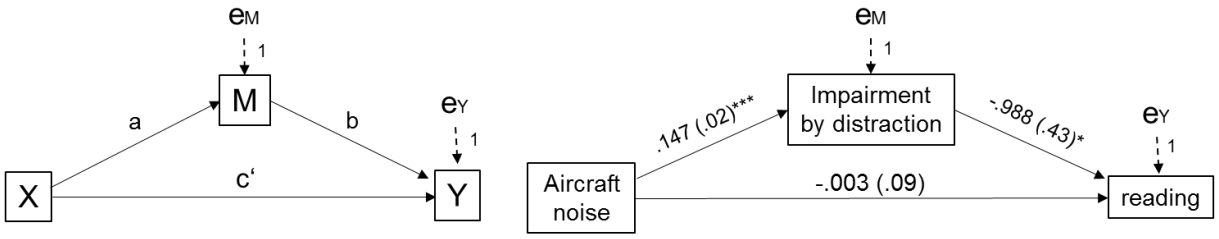

Figure 5: Mediation model. Complete mediation effect (children without migration background).

3.3 Urbanization

Finally, we calculated further analyses with urbanization as a moderator variable. Given that all schools are located in the metropolitan area Rhine-Main and all primary school children live in the immediate vicinity of the schools (school law, school district in Germany), in our sample no children live presumably in rural areas. Nevertheless, we found a broad variance of outside density (*M* = 1,552.08, *SD* = 831.90, Range = 446.00-2,890.00 people per km²).

We conducted a multilevel analysis with the whole sample and included the variable urbanization as a new predictor for reading into the existing direct effect model. Because it was necessary to correct the sample for statistical outliers (problems of distribution) in terms of the factor urbanization, sample size for the following analysis is *N* = 1048. We found that urbanization in the fully adjusted model is negatively associated with reading (β = -.392, *SE* 0.193, $p < .05$), and has a similar impact as the effect of aircraft noise in this analysis (β = -.338, *SE* 0.172, $p < .05$). Integration of urbanization increased explained variances from .208 to .371 (ΔR^2 = .163). However, we were interested in calculating moderator effects displayed by separate MLA for the levels of urbanization. Thus, for a better statistical validity (bi-modal distribution of the density data), we conducted a new grouping variable urbanization with two levels (medium urbanization: *N* = 734, high urbanization: *N* = 314). Schools with up to 1,495 people per square kilometer were assigned to medium urban areas and schools with more than 2,695 people per square kilometer were assigned to high urban areas. We found no statistical significant effects of aircraft noise on reading by children living in high urban areas (*b* = -0.055, *SE* = 0.051, *p* = .235), whereas we found a negative statistically significant aircraft exposure effect on reading by children in medium urban areas (*b* = -0.157, *SE* 0.064, *p* = .014).

4 Discussion and Conclusion

In the current study, we found harmful effects of aircraft noise exposure on children's reading performance. Importantly, the direct effect of noise exposure on reading was only found for children without migration background.

The main goal of this research was to consider possible explanations for the harmful aircraft noise effects. We found noise-induced distraction during school lessons to be such an explaining variable. The inclusion of impairment by distraction as a mediator substantially increased variance explained (R^2) (from .270 to .444, ΔR^2 = .174). We found our results to be robust also when controlled for a potential selection bias (PS matched samples). These indirect effects proved significant for children without migration background, but not for children with migration background.

Furthermore, we found level of urbanization to influence children´s reading performance irrespective of migration background. Including urbanization as a predictor into the multilevel models resulted in a substantial increase of explained variance in children´s reading performance (from .208 to .371, ΔR^2 = .163). Interestingly, level of urbanization also has a moderating role in the effect of aircraft noise on reading. We found the noise effect to be significant for children in medium urbanized areas but not for children in highly urbanized areas.

The findings are of relevance for policy of environmental noise and child development.

Acknowledgements

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REFERENCES

[1] 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

[2] Park, G., & Evans, G. W. (2016). Environmental stressors, urban design and planning: implications for human behaviour and health. *Journal of Urban Design, 21*(4), 453–470. doi:10.1080/13574809.2016.1194189

[3] Stansfeld, S. A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E., . . . Berry, B. F. (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. *The Lancet, 365*(9475), 1942–1949. doi:10.1016/S0140-6736(05)66660-3

[4] Clark, C., & Sörqvist, P. (2012). A 3 year update on the influence of noise on performance and behavior. *Noise & health, 14*(61), 292–296. doi:10.4103/1463-1741.104896

[5] Evans, G. W., & Hygge, S. (2007). Noise and cognitive performance in children and adults. In L. M. Luxon & D. Prasher (Eds.), *Noise and its effects* (pp. 549–566). Chichester, England, Hoboken, NJ: Wiley.

[6] Haines, M. M., Stansfeld, S. A., Head, J., & Job, R. (2002). Multilevel modelling of aircraft noise on performance tests in schools around Heathrow Airport London. *Journal of Epidemiology & Community Health*, *56*, 139-144. doi:10.1136/jech.56.2.139

[7] Evans, G. W., Hygge, S., & Bullinger, M. (1995). Chronic Noise and Psychological Stress. *Psychological Science, 6*(6), 333–338. doi:10.1111/j.1467-9280.1995.tb00522.x

[8] Evans, G. W., & Maxwell, L. (1997). Chronic Noise Exposure and Reading Deficits. *Environment and Behavior, 29*(5), 638–656. doi:10.1177/0013916597295003

[9] Evans, G. W., & Stecker, R. (2004). Motivational consequences of environmental stress. *Journal of Environmental Psychology, 24*(2), 143–165. doi:10.1016/S0272-4944(03)00076-8

[10] Evans, G., & Lepore, S. (1993). Non-auditory effects of noise on children: a critical review. *Children's Environments, 10* 42-72.

[11] 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.

[12] Schrader, F.-W., Helmke, A., & Hosenfeld, I. (2008). Stichwort: Kompetenzentwicklung im Grundschulalter. *Zeitschrift für Erziehungswissenschaft, 11*(1), 7–29. doi:10.1007/s11618-008-0001-y

[13] Schacter, J., & Thum, Y. M. (2004). Paying for high- and low-quality teaching. *Economics of Education Review, 23*(4), 411–430. doi:10.1016/j.econedurev.2003.08.002

[14] Spilski, J., Bergström, K., Möhler, U., Mayerl, J., Lachmann, T. & Klatte, M. (2016). Effects of aircraft noise on children´s reading and quality of instruction in German primary schools: Results from the NORAH study. In: *Proceedings of the 22nd International Congress on Acoustics (ICA, 2016)*, Buenos Aires, Argentina.

[15] Entorf, H., & Minoiu, N. (2005). What a Difference Immigration Policy Makes: A Comparison of PISA Scores in Europe and Traditional Countries of Immigration. *German Economic Review, 6*(3), 355–376. doi:10.1111/j.1468-0475.2005.00137.x

[16] Lüdemann, Elke; Schwerdt, Guido (2010): Migration background and educational tracking: Is there a double disadvantage for second-generation immigrants?,CESifo working paper: Economics of Education, No. 3256. Retriefed from: https://www.econstor.eu/handle/10419/46329

[17] Autorengruppe Bildungsberichterstattung. (2014). *Bildung in Deutschland 2014* [Education in Germany, 2014]. Bielefeld, Germany: Bertelsmann.

[18] Schnepf, S. V. (2007). Immigrants' educational disadvantage: an examination across ten countries and three surveys. *Journal of Population Economics, 20*(3), 527–545. doi:10.1007/s00148-006-0102-y

[19] Votruba-Drzal, E., Miller, P., & Coley, R. L. (2016). Poverty, Urbanicity, and Children's Development of Early Academic Skills. *Child Development Perspectives, 10*(1), 3–9. doi:10.1111/cdep.12152

[20] Burgess, S. R., Hecht, S. A., & Lonigan, C. J. (2002). Relations of the home literacy environment (HLE) to the development of reading-related abilities: A one-year longitudinal study. *Reading Research Quarterly, 37*(4), 408–426. doi:10.1598/RRQ.37.4.4

[21] Johnson, A. D., Martin, A., Brooks-Gunn, J., & Petrill, S. A. (2008). Order in the House! Associations among Household Chaos, the Home Literacy Environment, Maternal Reading Ability, and Children's Early Reading. *Merrill-Palmer quarterly (Wayne State University. Press), 54*(4), 445–472. doi:10.1353/mpq.0.0009.

[22] Sénéchal, M., & LeFevre, J.-A. (2014). Continuity and change in the home literacy environment as predictors of growth in vocabulary and reading. *Child development, 85*(4), 1552–1568. doi:10.1111/cdev.12222

[23] Seabi, J., Cockcroft, K., Goldschagg, P., & Greyling, M. (2012). The impact of aircraft noise exposure on South African children's reading comprehension: the moderating effect of home language. *Noise & health, 14*(60), 244–252. doi:10.4103/1463-1741.102963

[24] The United Nations (2014). "World's Population Increasingly Urban with More than Half Living in Urban Areas." Retriefed from: http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html

[25] Dahly, D. L., & Adair, L. S. (2007). Quantifying the urban environment: A scale measure of urbanicity outperforms the urban–rural dichotomy. *Social Science & Medicine, 64*(7), 1407–1419. doi:10.1016/j.socscimed.2006.11.019

[26] Gouin, M., Flamant, C., Gascoin, G., Rouger, V., Florin, A., Guimard, P., … Hanf, M. (2015). The Association of Urbanicity with Cognitive Development at Five Years of Age in Preterm Children. *PloS one, 10*(7), e0131749. doi:10.1371/journal.pone.0131749

[27] Evans, G. W. (2006). Child development and the physical environment. *Annual review of psychology, 57,* 423–451. doi:10.1146/annurev.psych.57.102904.190057

[28] Ferguson, K. T., Cassells, R. C., MacAllister, J. W., & Evans, G. W. (2013). The physical environment and child development: an international review. *International journal of psychology : Journal international de psychologie, 48*(4), 437–468. doi:10.1080/00207594.2013.804190

[29] 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/

[30] Zensus Statistisches Bundesamt. (2014). *Zensus 2011: Bevölkerung. Ergebnisse des Zensus 9. Mai 2011*. [Zensus 2011: Population, results of Zensus]. Wiesbaden. Retrieved from https://www.zensus2011.de/SharedDocs/Downloads/DE/Pressemitteilung/DemografischeGrunddaten/xlsx_Bevoelkerung.xlsx?__blob=publicationFile&v=4

[31] 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.

[32] Hox, J. J. (2010). *Quantitative Methodology Series: Multilevel analysis: Techniques and applications* (2nd ed.). New York, NY: Routledge