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# Effects of aircraft noise and living environment on children´s well-being and health

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## ABSTRACT

There are few and inconsistent results suggesting that chronic exposure to aircraft noise is associated with poorer quality of life or health in children. Therefore, a recent WHO review pointed out that the current evidence is insufficient. Previous publications mainly analyzed the isolated relationships between single stressors (e.g., aircraft noise, pollution) and health in children. A combined consideration of environmental stressors and residential environment factors, such as degree of urbanization, access to green/open space urbanity, and other urban planning data did not occur. In the NORAH study, health variables, noise exposure measures, and a variety of potential moderating variables (residential environments factors) were assessed from second-graders who live in the vicinity of the Frankfurt/Main airport, Germany. We present a theoretically motivated secondary analysis (stress-diathesis hypothesis) of the NORAH data set. Post hoc, we linked this data with spatial and urban planning data, to model the impact of aircraft noise and children´s real life circumstances. We calculated moderated and mediated regression models and found empirical evidence for mediation effects in the relationship between aircraft noise exposure, stress response (annoyance) and well-being, moderation effects for health as well as direct effects of the living environment.

Keywords: Aircraft Noise, Living Environment, Well-Being, Health

## 1. INTRODUCTION

Both acute noise events and chronic noise exposures can lead to stress reactions (1-3). Chronic noise exposure leads to a prolonged biological stress response compared to acute noise. This means that the release of stress hormones (e.g., catecholamine, adrenaline and cortisol) is more prolonged compared to a single acute noise event. In addition to a biological response, environmental noise can also lead to a psychological stress response in the form of annoyance. Besides sleep disturbances, annoyance is one major burden of disease effects of environmental noise, according to WHO (4). If the burdens of stressors and adverse predispositions to diseases are too high and exceed a critical threshold, symptoms develop or diseases breaks out. The stress-diathesis hypothesis attempts to explain a disorder or its development as the result of an interaction between a disposition and a stress-induced burden by life experiences (5). Therefore, in accordance with Clark & Paunovic (6), we follow the stress-diathesis hypothesis which suggests that with increasing exposure to environmental stressors (e.g., aircraft noise) stress responses increase, and increased stress responses negatively affect well-being and health, because they reinforce adverse disposition. This indicates that exposure to aircraft noise has an indirect negative effect on children's well-being and health, mediated through the mediator aircraft noise annoyance. Based on the NORAH study, we hypothesize:

H1: Increasing aircraft noise exposure increases the aircraft noise annoyance of children which, in turn, leads to poorer well-being and health in children.

However, aircraft noise exposure is only one environmental stressor which can have an impact on children's well-being and health. Thus, both the psychological stress responses (e.g., annoyance) and the relevant diseases can be triggered or promoted not only by noise exposure, but also by other conditions and stress factors. Urban areas differ from suburban and rural areas with respect to the amount of opportunities and risks for children´s health (7). Other environmental stressors such as toxins, pollutants, other noise sources and crowding increase with increasing degrees of urbanization (8, 9). In line with this, the degree of urbanization (measured in terms of outside density for the postcode area) proved a significant predictor for stress responses and children's development and health (10-12). However, in less urbanized areas, aircraft noise has a relatively stronger impact on children's well-being and health because other environmental stressors are less pronounced and therefore aircraft noise is more prominent. In view of the accumulation of environmental stressors in urban areas, we hypothesize:

H2: The indirect effect described in H1 is moderated by the degree of urbanization. In less urbanized areas, aircraft noise has a relatively stronger impact compared to more urbanized areas.

After we have presented a relatively broad construct with the degree of urbanization and possible effects on children's well-being and health, the proportion of imperviousness space is a more specific predictor. Imperviousness space very precisely considers a quality aspect of residential environments that is important for children. Inhabited areas differ not only in population density but can also vary greatly in terms of imperviousness space and percentage of accessibility of green spaces (for recreation) and other factors (e.g., bioclimate, air hygiene, building condition, sunlight exposure, ventilation), although urbanization, for example, has not changed. In this paper we focus on the percentage of imperviousness space and use it as a countervalue to possible undeveloped, ergo natural areas. The literature discusses life environments that protect against stress or at least stimulate regeneration and moderates stress. Current systematic reviews report that access to green spaces (conversely, the non-existence of sealed area) has positive effects on children's well-being and health (13, 14). To show that the proportion of imperviousness space is not synonymous with the degree of urbanization (measured in terms of outside density for the postcode area) and the specific population density in the corresponding 100 x 100 m area (1 ha), we calculated the correlations. We found no significant correlations between the population density in Eurostat 100 x 100 m areas (INSPIRE-Raster, 1 ha, European Commission - EUROSTAT, Luxembourg 2019) and the corresponding percent of imperviousness ($r$ = - .008, $p$ = .764; 95% *C.I.*: -.064/ .048). However, a significant correlation was found for the degree of urbanization (the population density in the postcode area) ($r$ = -.220, $p$ < .001; 95 % *C.I.*: -.0272/-.166), and also for the population density in Eurostat 100 x 100 m areas ($r$ = .315, $p$ < .001; 95 % *C.I.*: .0.264/0.364). That shows that the factors share variance, but have a substantial part of unique variance that cannot be mutually explained. Therefore, modelling the specific predictor imperviousness space as a moderator seems to be useful. The existence of natural areas should reduce stress in children (14). However, we argue that in areas with less imperviousness (many natural areas) the exposure to aircraft noise appears as a dominant stress factor whereas in areas with high imperviousness the variety of other environmental stressors (e.g., toxins, pollutants) decreases the impact of aircraft noise as a single stress factor. For this reason, we hypothesize:

H3: The indirect effect described in H1 is moderated by the degree of imperviousness. In less impervious areas, aircraft noise has a relatively stronger impact compared to more impervious areas.

# 2. METHOD

## 2.1 Participants

A total of 1,243 second-graders from 29 primary schools participated in the NORAH study. For information on sampling, see Klatte et al. (15). Mean age for children was 8 years and 4 months (*SD* 5 months). Concerning children's health and well-being as well as living environment at home, complete data were available for 1,118 children and their parents.

## 2.2 Assessment of Noise Exposure

Aircraft noise levels (LAeq 06-22) at children's home address for the past 12 months before data acquisition were calculated based on radar data from the Flight Track and Aircraft Noise Monitoring

System (FANOMOS), provided by German Air Traffic Services. For more details see (16). Road traffic and railway noise were calculated using a combination of information (e.g., traffic flow data, street types, proportion of heavy traffic; quantity of train runs, speed and length of the trains) provided by local authorities.

## 2.3 Assessment of Living Environment

The moderator urbanization (H2) was operationalized with the key factor density (measured in terms of outside density for the postcode area; people per km²). Data of density was available from the German Zensus 2011 (9 May 2011 (17)) for the postcode areas of all home addresses.

For the investigation of more specific moderating spatial variables, the area in which the children´s places of residence were located was divided into regular raster cells (standard-hectare grid of European statistics, INSPIRE grid) with an edge length of 100 m. The raster cells were used for the analysis of the spatial variable imperviousness (H3) in the closest living environment. The imperviousness space data for the INSPIRE grid were obtained from the European Environment Agency's Copernicus Land Monitoring Service. Figure 1 shows the geographical distribution of residential addresses and the NORAH study area.

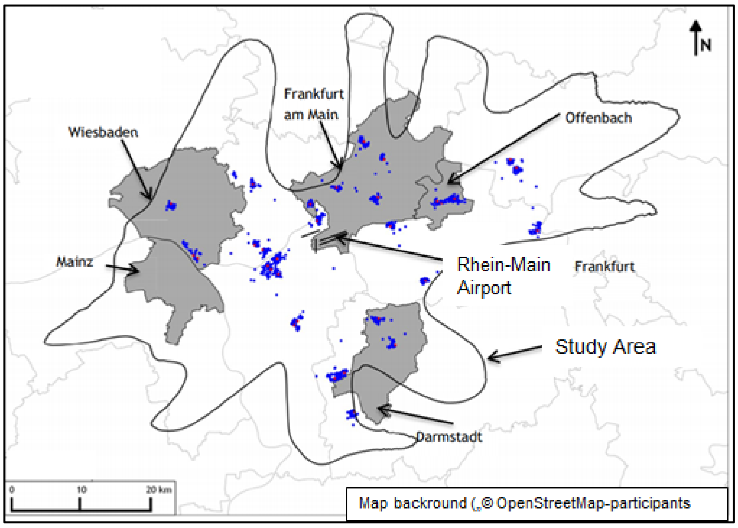


Figure 1 – Distribution of respondent addresses (blue) in the study area (schematic) taken from Möhler et al. p. 144 (16); map background "© OpenStreetMap-participants

## 2.4 Materials and Procedure

The following description of the procedure has been published elsewhere (e.g. 15, 18). The questioning of the children was performed in groups of whole classes. Each statement was carefully explained to the children and practiced with examples. All statements were read aloud by the experimenter and a combination of a picture and a number represented the statement. The children took the parent questionnaire to their parents who filled it out at home. The parental questionnaire contained questions concerning children’s well-being, health-related outcomes (physical diseases and developmental abnormalities, see Table 1) and potential confounding factors (e.g., SES).

The scales used in the children questionnaire comprised health-related quality of life [KINDL-R (19)], home environment, annoyance, and noise at home (20). Table 1 shows the items concerning health-related quality of life and annoyance due to aircraft noise exposure. Principal axis analyses and confirmatory factor analyses were carried out on the items from the children questionnaire. For the well-being variables from the children questionnaire, aggregation of items was not justified by the data, although the scales of the KINDL-R were used. Therefore, well-being analyses were based on single items. However, the parental assessment of the child's well-being could be aggregated to index values (physical and psychological well-being; see Table 1). More details concerning the procedure, the questionnaires, and statistical examination of psychometrics are provided by Klatte et al. (14, 21).

Table 1 – Selected NORAH outcome variables concerning children's annoyance due to aircraft noise exposure at home, health-related quality of life, physical diseases and developmental abnormalities.

| | Outcome variable | Psychometrics/ Questions | Response scale |
|---|---|---|---|
| **child judgments** | Index "Annoyance due aircraft noise at home" (6 Items) | *CR* = .83, α = .80; *AVE* = .71 | 4-point scale (*strongly disagree, disagree, agree, strongly agree*) |
| | Physical well-being (single variables) | PWB 1: Last week I had a headache and stomach ache.<br>PWB 2: Last week I felt sluggish and tired. | 3-point scale (*never, sometimes, often*) |
| | Psychological (mental) well-being (single variables) | MWB 1: Last week I laughed a lot and had a lot of fun.<br>MWB 2: Last week I was bored. | 3-point scale (*never, sometimes, often*) |
| **parental judgments** | Physical diseases and developmental disorders | e.g., middle ear inflammation, asthma, neurodermatitis, migraine, attention disorders, speech and language disorders | 3-point scale (*no, never; yes, once; yes, several times*) |
| | | intake of medically prescribed drugs, ADS | 2-point scale (*no, yes*) |

*Notes. CR* = composite reliabilities, α = Cronbach's α, *AVE* = average variance extracted

### 2.5 Statistical Analysis

To model the impact of aircraft noise and children´s real life circumstances, we linked the NORAH data with spatial and urban planning data. For the main analyses (test of our hypotheses), we used IBM SPSS 25 and the PROCESS 3.3 macro by Hayes (22). The procedure of analysis was as follows. First, we tested the mediation model for the outcome variables listed in Table 1 (H1: PROCESS Model 4). Second, we extended the mediation model by the moderators to a moderated mediation model (H2: PROCESS Model 8, H3: PROCESS Models 8 & 10) and tested the model for the outcome variables listed in Table 1. All models were adjusted for confounding factors.

## 3. RESULTS

### 3.1 Aircraft Noise and Living (Residential) Environment

**Aircraft Noise.** In the NORAH study, aircraft noise levels at home (LAeq 06-22) did not exceed 60 dB for the majority of children (99.19%) and were thus below the daytime criterion of the German legal foundation (23). Aircraft noise at home (LAeq, 06-22) ranged from 36.40 to 60.80 dB (*M* = 49.15; *SD* = 6.16) for a period from 6 a.m. to 10 p.m. for the residential address (06-22).

**Urbanization.** Given that all children´s home addresses were located in the metropolitan area Rhine-Main, our sample did not contain children who live in rural areas (see Table 2, last column). Nevertheless, we found a broad variance of outside density for postcode areas (*M* = 1,552.08, *SD* = 831.90, *Range* = 446.00-2,890.00 people per km²). Thus, for a better statistical validity (bi-modal distribution of the density data), we generated a new grouping variable "urbanization" with two levels (medium urban areas and high urban areas). Residential postcode areas with up to 1,495 people per square kilometer were assigned to medium urban areas and residential postcode areas with more than 2,695 people per square kilometer were assigned to high urban areas. This classification corresponds exactly to Eurostat's proposal (DEGUBRA, 2011).

**Imperviousness:** Percentages of sealed areas around the home addresses (INSPIRE grid) ranged from 0 to 100 percent (*M* = 58.15; *SD* = 11.59). Figure 2 visualizes the results of the sealed areas as a heat map. Green, yellow and red marked areas correspond to completely unsealed areas (0 %), 50 % sealed areas and completely sealed areas (100 %), respectively. Black dots represent the distribution of respondent addresses.

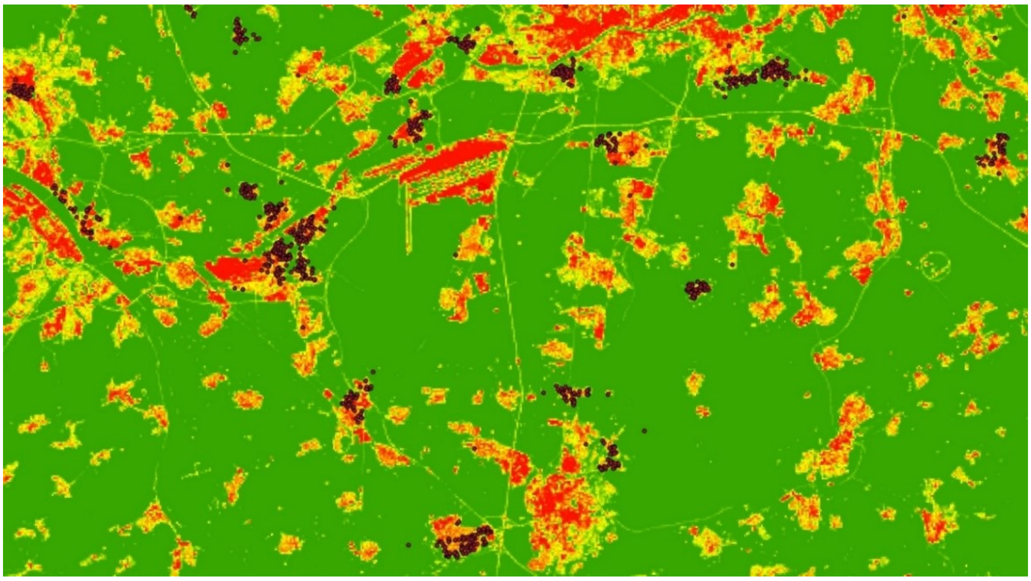

Figure 2 - Heatmap imperviousness, own diagram based on German Federal Office of Statistics (Statistisches Bundesamt), hectares grid, and European Environment Agency (24)

### 3.2 Relationship Noise, Environment Well-being and Health

**Results for H1.** We have hypothesized that exposure to aircraft noise has an indirect negative effect on children's well-being and health, mediated through aircraft noise annoyance. Hence, we included the mediator annoyance into a regression model: aircraft noise → annoyance → well-being/ health (see Figure 3).

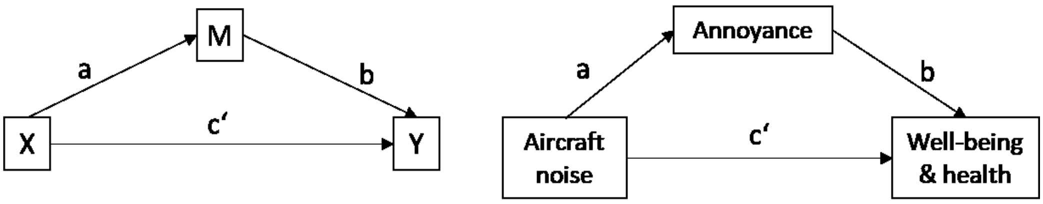


Figure 3 - Hypothesis 1 (Mediation-Model)

First, we tested the mediation model with regard to **children's well-being** (H1: PROCESS Model 4). Significant indirect effects were found for physical well-being (PWB 1: a*b = 0.003, 95% *C.I.*: 0.001/0.006; PWB 2: a*b = 0.006, 95% *C.I.*: 0.003/0.010) (see table 3). Accordingly, a 10 dB increase in aircraft noise is associated with an increase in annoyance of 0.81 scale points. This effect is passed on to physical well-being, i.e., higher annoyance leads to higher problems with physical well-being (e.g., more headache and stomach ache). The inclusion of the mediator led to a non-significant direct effect ($b$ = - 0.003, $SE$ = 0.004, $p$ > .05, 95% *C.I.*: - 0.011, 0.006), indicating a complete mediation effect. While the meditation effect was statistically robust with respect to physical well-being, the results for psychological well-being were not consistent. Here, we found an indirect effect for the variable "Last week I was bored" (MWB2), but a non-significant indirect effect for the variable "Last week I laughed a lot and had a lot of fun" (MWB1) (see Table 3).

After we had examined the mediation effects with regard to well-being, the model was also calculated with regard to health variables. We tested H1 for 15 **health-related outcomes** and **developmental disorder** variables (measured by a parental questionnaire), as already listed in Table 3. Contrary to children´s well-being, we did not find any effect of aircraft noise exposure on children's health (neither a direct effect nor an indirect effect, all $p$'s > .05, all 95% *C.I.* included 0). Therefore, there was no evidence that H1 could be maintained for children with regard to the incidence of disease (parental evaluation).

Table 3 – Fully Adjusted Mediation Model for Effects of Aircraft Noise Exposure on Children's Well-being (Hypothesis 1).

| | *ß* | *b (SE)* | *p* | *95% C.I.* |
|---|---|---|---|---|
| **Physical Well-being** | | | | |
| a: Aircraft Noise → Annoyance | .434 | .081 (.005) | < .001 | .071/.091 |
| b: Annoyance → well-being (PWB 1) | .077 | .040 (.017) | < .05 | .006/.074 |
| c': Aircraft Noise → well-being (PWB 1) | .017 | .002 (.003) | > .05 | -.005/.008 |
| a*b (indirect effect) | .033 | .003 (.001) | | .001/.006 |
| a: Aircraft Noise → Annoyance | .434 | .081 (.005) | < .001 | .071/.091 |
| b: Annoyance → well-being (PWB 2) | .118 | .076 (.021) | < .001 | .035/.118 |
| c': Aircraft Noise → well-being (PWB 2) | -.021 | -.003 (.004) | > .05 | -.011/.006 |
| a*b (indirect effect) | .051 | .006 (.002) | | .003/.010 |
| **Psychological Well-being** | | | | |
| a: Aircraft Noise → Annoyance | .437 | .081 (.005) | < .001 | .070/.091 |
| b: Annoyance → well-being (MWB 1) | .078 | .042 (.018) | < .05 | .007/.076 |
| c': Aircraft Noise → well-being (MWB 1) | -.097 | -.010 (.003) | < .01 | -.016/-.003 |
| a*b (indirect effect) | .056 | .007 (.002) | | -.003/.010 |
| a: Aircraft Noise → Annoyance | .430 | .081(.005) | < .001 | .070/.091 |
| b: Annoyance → well-being (MWB 2) | .129 | .081 (.021) | < .01 | .041/.121 |
| c': Aircraft Noise → well-being (MWB 2) | .075 | .009 (.004) | < .05 | .001/.017 |
| a*b (indirect effect) | .055 | .007 (.002) | | .003/.010 |

Notes. *SE* = standard error; *b* = unstandardized coefficient; *ß* = standardized coefficient; 95% *C.I.*: = 95% bootstrapping confidence interval. Adjusted for age, gender, socioeconomic status (SES), road-traffic and railway noise at home.

**Results for H2.** As mentioned before, we extended the mediation model to a moderated mediation model by including the moderator "degree of urbanization" (H2: PROCESS Model 8). All models were adjusted for potential confounding factors as already indicated in the notes of Table 3. For a better understanding, the extension of the model is shown in Figure 4.

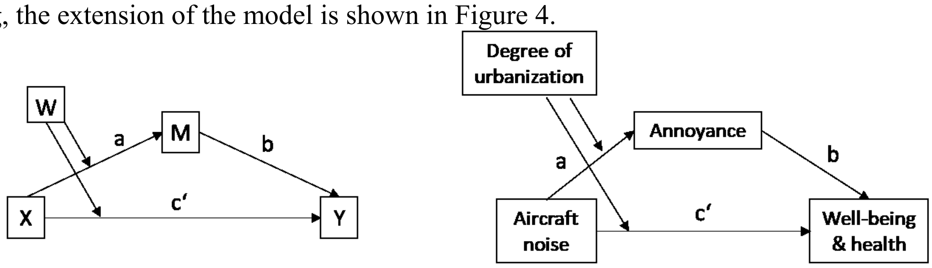


Figure 4 - Hypothesis 2 – (moderated mediation model)

The analysis showed no significant moderator effects on the indirect relationship (i.e., interaction terms were non-significant, all $p > .05$, all 95% *C.I.* included 0). However, the indirect effects (mediation effects) already shown remained statistically significant for children's physical and also psychological well-being. The indirect effect became significant for the psychological well-being variable "Last week I laughed a lot and had a lot of fun" (MWB 1 medium urban areas: a*b = 0.003, 95% *C.I.*: 0.001/0.006; high urban areas: a*b = 0.003, 95% *C.I.*: 0.001/0.007). Apparently, the inclusion of the moderator reduced error variance, so that this mediation effect could be statistically supported.

Although we had assumed moderated mediations, we could not statistically confirm them for the well-being measures. However, for the health-related outcomes we found a significant moderation by the degree of urbanization. For example, there was a significant interaction effect on the variable "intake of medically prescribed drugs" (W*X: $b$ = - .122, $SE$ = .051, $p$ = .018; 95% *C.I.*: - .223/-.021). The probability of taking medically prescribed drugs increased with increasing aircraft noise in areas with a medium degree of urbanization, but not in high urban areas.

**Results for H3.** As mentioned before, we extended the moderated mediation model by including the degree of imperviousness as a second moderator (H3: PROCESS Model 10) as shown in Figure 5. Contrary to the hypothesis, there were no moderating effects by the degree of imperviousness on the mediation relationship. However, the analyses showed that the degree of imperviousness is a significant predictor of annoyance (*b* = .003, *SE* = .001, *p* < .05; 95% *C.I.*: -.223/-.021). In addition to the degree of urbanization, degree of imperviousness is another significant moderator on the direct relationship of aircraft noise exposure on children's health (Z*X: *b* = -.003, *SE* = .001, *p* < .01; 95% *C.I.:* -.004/-.001). The probability of taking medically prescribed drugs increased with increasing aircraft noise in areas with a low degree of imperviousness (-1*SD*), but not in medium (0*SD*) or high degree of imperviousness (+1*SD*).

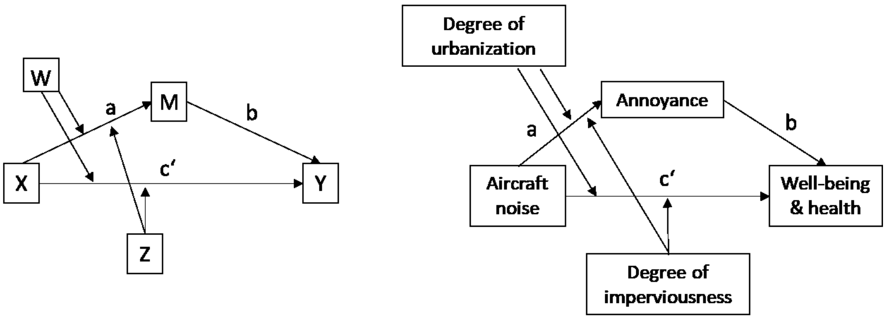


Figure 5 - Hypothesis 3 (Moderated-Mediation-Model)

## 4. DISCUSSION AND CONCLUSION

In accordance with the stress-diathesis hypothesis (5), the current study found harmful effects of aircraft noise exposure on children's well-being and health as well as on annoyance due to aircraft noise exposure. We found evidence that annoyance mediated the relationship between aircraft noise and children's well-being, so that we could maintain H1 with respect to well-being. However, we found no mediation relationships with respect to the health-related outcomes recorded by parental judgements.

Contrary to the hypotheses H2 and H3, there were no moderating effects by degree of urbanization and degree of imperviousness on the mediation relationship between aircraft noise exposure, annoyance due to aircraft noise exposure and children's well-being. This result was also evident for the health-related outcomes. As a result, we have to reject H2 and H3.

Interestingly, however, the assumed stronger effect of aircraft noise on health was found for medium urbanised areas, but not for high urban areas. However, this effect was only observed for the direct effect of aircraft noise on health and not, as assumed, for the indirect effect. This suggests that aircraft noise has a stronger effect for health related outcomes on a lower degree of urbanization, as other stressors are less pronounced and therefore aircraft noise is more prominent. The same result was also shown for the degree of imperviousness, according to which the influence of aircraft noise is significant at a lower degree of imperviousness, but not in higher degrees. The degree of imperviousness seems to be a relevant context factor for children, which at least has an influence on the perceived annoyance of a child. This may be an indication that further space variables should be included in models for predicting aircraft noise effects in order to adequately map the living environment. The findings are of relevance for policy of environmental noise and children's wellbeing and health.

## ACKNOWLEDGEMENTS

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