PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Examination of the causal relationship between aircraft noise exposure, noise annoyance and diagnoses of depression using structural equation modelling

Sarah BENZ[1,2]; Dirk SCHRECKENBERG[1]

[1] ZEUS GmbH, Germany

[2] Heinrich-Heine University Dusseldorf, Germany

ABSTRACT

Environmental noise is ubiquitous in daily life and a major environmental burden, though the effects of transportation noise on mental health are sparsely investigated to date. The recently published WHO review on the impact of transportation noise on quality of life and mental health shows inconsistent findings. Noise annoyance, as an approved psychological stress response to noise, is identified as one of the health impacts of environmental noise. There is some evidence that the impact of noise on health is at least partly mediated by noise annoyance. A re-analysis of data is conducted using data from the socio-acoustical longitudinal survey NORAH (Noise-Related Annoyance, Cognition, and Health), which has been performed mainly at Frankfurt Airport, Germany, from 2011 to 2013. Residents older than 18 and living in the 40 dB-noise contour around Frankfurt Airport were randomly selected to participate in the study. A telephone and online survey assessing, among others, diagnosed depressions and aircraft noise annoyance were conducted once a year/annually. Aircraft sound levels were calculated for the exact address of every participant. The present work is an approach to examine the causal relationship between noise exposure, noise annoyance and diagnoses of depression using structural equation modelling.

Keywords: aircraft noise annoyance, aircraft noise exposure, depression

1. INTRODUCTION

Environmental noise has been shown to negatively affect various aspects of human health. Besides negative effects of aircraft noise exposure on sleep or cardiovascular diseases (1, 2), there are inconsistent findings on the effect of aircraft noise exposure on mental health and well-being (3, 4). However, there is evidence for a negative association of noise annoyance due to aircraft traffic and health-related mental quality of life (5-6) as well as noise annoyance and depression (7-8). Noise annoyance is considered as a three dimensional psychological concept covering cognitive, affective and behavioural reactions on noise (9). Further, noise annoyance as a stress reaction is discussed to (partly) mediate the influence of aircraft noise on mental health (6). Most of these findings are based on cross-sectional studies, not allowing for a causal interpretation.

The objective of this study is to investigate the causal relationship between aircraft noise, diagnosed depression and aircraft noise annoyance. Three research questions have been addressed:

1) Is there a direct impact of aircraft noise exposure on the prevalence of diagnosed depression?
2) Is there a mediation effect of aircraft noise annoyance on future diagnosed depression?
3) In case, aircraft noise exposure affects the prevalence of diagnosed depression, can the presence of a depression mediate the impact of aircraft noise exposure on the magnitude of future aircraft noise annoyance?

2. PROCEDURE, METHODS

2.1 Study design, sampling

Data from the socio-acoustical longitudinal survey NORAH (Noise-Related Annoyance, Cognition,

[1] benz@zeusgmbh.de; schreckenberg@zeusgmbh.de

and Health), which was conducted in the vicinity of Frankfurt Airport, was re-analyzed. The study sample was randomly selected from the full-aged population living in the Rhine Main area, particularly from people living within the envelope of the 40-dB L_{pAeq} contours for day and night-time around Frankfurt Airport, following a stratification plan with two strata. The first stratum was the current aircraft noise exposure. The second stratum was the predicted change of aircraft noise exposure after the opening of the new runway and the implementation of the night flight ban for 2020 in relation to the aircraft noise exposure in 2007 (increase in $L_{pAeq,24h} > 2$ dB, decrease in $L_{pAeq,24h} > 2$ dB, change within the range of ± 2 dB). From 2011 to 2013 annually measurements were carried out: one before and two after the opening of a new runway and the implementation of a night flight ban. Telephone interviews were performed (with the alternative option to participate via an online survey) to assess, among others, diagnosed depression and aircraft noise annoyance (for further details see (10)). As a new runway was opened and a night-flight ban was implemented at Frankfurt Airport in October 2011, the subsequent two years are investigated (2012 and 2013) to study the impact of the change in noise exposure.

2.2 Assessment of aircraft noise exposure

The aircraft noise exposure was calculated for each participant's exact address at the most exposed façade of the residential building/residency. In this study, aircraft noise was operationalised with the L_{den}, the weighted and averaged day–evening–night noise level for 24 hours. It is composed of the day level, which in the present case refers to the time between 6am to 6pm, the evening level which refers to 6pm to 10pm and the night level from 10pm to 6am. For the evening and night levels a penalty is applied; with 5 dB for the evening and 10 dB for the night level. For this study, the aircraft noise exposure was modelled for 12 months from October 2011 to September 2012 for t1 (2012) and from October 2012 to September 2013 for the survey wave in 2013 (t2), respectively.

2.3 Assessment of noise annoyance and diagnosis of depression

Noise annoyance was measured using the standardised noise annoyance question as recommended by the International Commission on the Biological Effects of Noise (11), "Thinking about the last 12 months, when you are here at home, how much does noise from aircraft bother, disturb, or annoy you?" with a 5-point semantic answer scale ranging from (1) 'not at all' to (5) 'extremely'.
Two items were used to assess life time prevalence and 12-months prevalence of diagnosed depression. The first item assessed whether a physician or therapist ever diagnosed a depressive disorder (dichotomous item with "yes" and "no"). If yes, it was asked if a depressive disorder was diagnosed in the last 12-months.

2.4 Statistical analysis

The descriptive analysis of the data includes the calculation of frequency, means, standard deviations, and correlations. The percentage of annoyed people (%A) as well as the prevalence of diagnosed depressions have been calculated for 2.5-dB classes of L_{den}. Further, for each level of noise annoyance the share of people diagnosed with depression has been examined. Differences between groups (people with a diagnosis of depression vs. no depression) were tested using inference statistical tests (Mann-Whitney-U and Chi-Square test).

Logistic regression models were used to evaluate the effects of aircraft noise exposure and noise annoyance on the prevalence of depression for last 12 months. In augmented models the potential influence of additional determinants of depression was analysed, including age, sex, migration background, period of residence, hours spent out of home, home ownership, socio-economic status, noise sensitivity, body mass index (BMI), sports, railway noise exposure (L_{den}), road noise exposure (L_{den}), alcohol consumption and tobacco consumption.

Structural equation modelling was carried out to assess the causal relationship between aircraft noise exposure, noise annoyance and diagnoses of depression with the statistics software MPLUS V.6.11.

3. RESULTS

3.1 Descriptive statistics

A total of 3,508 subjects participated in all three waves of the longitudinal survey from 2011 to 2013. Cases with missing depression data were excluded from the analysis, thus, the investigated sample included 3,319 residents. The mean age was 53.7 years (SD±14.6; range 19-97 years) with 53% being female and 47% male. The average period of residence at the registered address was 26.5 years (SD± 18.2).

Table 1 shows the degree of noise annoyance for each 2.5 dB class of L_{den} of aircraft noise exposure in t1 (2012) and t2 (2013). At both measurement time points, there is an increase in aircraft noise annoyance with increasing aircraft noise exposure, while mean noise annoyance in t1 (2012, M = 3.38, SD = ±1.30) is higher than in t2 (2013, M = 3.22, SD = ±1.32).

Table 1 - Aircraft noise annoyance for 2.5 dB classes of L_{den}

2,5 dB classes of L_{den}	aircraft noise annoyance					
	t1 (2012)			t2 (2013)		
	n	*M*	*SD*	*n*	*M*	*SD*
≤ 40 dB	100	2,13	1,05	126	2,13	0,95
40,1 - 42,5 dB	255	2,36	1,12	309	2,23	1,06
42,6 - 45,0 dB	407	2,64	1,22	425	2,51	1,18
45,1 - 47,5 dB	357	2,88	1,17	338	2,84	1,17
47,6 - 50,0 dB	309	3,30	1,23	338	3,21	1,28
50,1 - 52,5 dB	369	3,49	1,19	439	3,41	1,24
52,6 - 55,0 dB	404	3,75	1,17	377	3,63	1,19
55,1 - 57,5 dB	461	3,86	1,16	442	3,75	1,22
57,6 - 60,0 dB	416	4,02	1,09	296	3,97	1,13
> 60 dB	241	4,22	0,93	229	4,05	1,05
Total	3319	3,38	1,30	3319	3,22	1,32

Note. *n* = number of participants; *M*= mean; *SD*= standard deviation.

Table 2 shows the life time prevalence of diagnosed depression in t1 (2012) and t2 (2013) for each 2.5 dB class of aircraft noise exposure. Naturally, absolute numbers of prevalence rise from t1 (2012) to t2 (2013). Within each study year, there is no continuous rise of prevalence with increasing levels of aircraft noise exposure.

Table 2 - Prevalence of depression for aircraft noise exposure in 2.5 dB classes of L_{den}

2,5 dB classes of LDEN	life time prevalence of depression			
	t1 (2012)		t2 (2013)	
	%	*n*	%	*n*
≤ 40 dB	1,5	7	2,2	11
40,1 - 42,5 dB	8,4	38	10,5	52
42,6 - 45,0 dB	12,8	58	12,9	64
45,1 - 47,5 dB	11,9	54	11,3	56
47,6 - 50,0 dB	9,5	43	8,7	43
50,1 - 52,5 dB	10,6	48	13,7	68
52,6 - 55,0 dB	10,8	49	11,3	56

55,1 - 57,5 dB	14,6	66	14,1	70
57,6 - 60,0 dB	12,1	55	8,7	43
> 60 dB	7,7	35	6,8	34
Total	100	453	100	497

Note. *n* = sample size; dB = decibel.

Life time prevalence for depressive disorders diagnosed by a physician or therapist was 13.6% in t1 (2012), 12 months prevalence was 7.8%. This is comparable to the prevalence rates in the German population with 11.6% of life time prevalence and 8.1% for the 12 months prevalence of diagnosed depressive disorders (12).

There was no significant difference in noise exposure from aircraft, road and railway noise between the two groups of people with and without diagnosed depression (p > .100). Further, there was no significant difference between the two groups for the change of noise exposure from t1 to t2 after the opening of the new runway and the implementation of the night flight ban (p > .100). However, the two groups differed in the degree of aircraft noise annoyance (p < 0.01), with higher means of aircraft noise annoyance for the three survey years in the depression group.

Table 3 shows the share of people for levels of aircraft noise annoyance. The share of people rise with the intensity/degree of noise annoyance, from (1) not at all to (5) extremely in both study groups (people with depression vs. without depression).

Table 3 - Distribution of people with and without life-time depression for levels of aircraft noise annoyance

	t1 (2012)				t2 (2013)			
	depression		healthy		depression		healthy	
levels of noise annoyance	n	%	n	%	n	%	n	%
not at all (1)	42	9,3	293	10,3	54	10,9	359	12,8
slightly (2)	60	13,2	520	18,3	83	16,7	574	20,5
moderately (3)	92	20,3	609	21,5	99	19,9	610	21,8
very (4)	114	25,2	751	26,5	129	26,0	694	24,8
extremely (5)	145	32,0	662	23,4	132	26,6	557	19,9
Total	453	100	2.835	100	497	100	2.794	100

Note. n =sample size.

3.2 Logistic regression models for the prediction of diagnoses of depression

Logistic regression models were used to evaluate the effects of aircraft noise exposure and noise annoyance in t1 (2012) on prevalence of depression for the last 12 months in t2 (2013). In augmented models we tested the potential improvement of models and the prediction of depression by adding possible predictors. Results of logistic regression models are shown in excerpts in table 4.

In a basic model (model 1), aircraft noise exposure in t1 (2012) was shown to have a significant effect on the prevalence of diagnosed depression in t2 (2013; B = -0.02, SE = 0.01, p < .05). In an augmented model, potential determinants of depression were included, resulting in a smaller and non-significant effect of aircraft noise exposure (B = 0.01, SE = 0.01, p = .26). In model 2, noise annoyance was included and a significant predictor of depression (B = -0.20; SE = 0.08, p <.01), whereas the noise level remained a non-significant predictor. . Hence, we tested two additional models: model 3 as the basic model with noise annoyance as a further predictor and model 4 including aircraft noise annoyance and excluding aircraft noise levels. Model 3turned out to better fit than the other models (AIC = 1131.7), but not better than the basic model. The best model fit is found in model 4 with noise annoyance instead of aircraft noise levels (AIC =59.0), with the same effect size of aircraft noise annoyance. This indicates that aircraft noise annoyance is a better predictor for a diagnosis of depression than the acoustic variable aircraft noise level.

Table 4 - Results of logistic regression models for the evaluation of effects of aircraft noise exposure and noise annoyance in t1 on the period prevalence of depression in t2 (excerpt)

	model 1					model 2					model 3					model 4				
parameter	B	SE	p	CI-	CI+	B	SE	p	CI-	CI+	B	SE	p	CI-	CI+	B	SE	p	CI-	CI+
(constant term)	3.68	0.56	***	2.59	4.77	3.42	0.71	***	2.02	4.82	3.44	0.57	***	2.33	4.55	3.37	0.22	***	2.93	3.81
aircraft noise level L_{DEN}	-0.02	0.01	*	-0.04	-0.00	0.00	0.02	0.76	-0.03	0.03	-0.00	0.01	0.89	-0.02	0.02					
mode	-0.15	0.06	*	-0.27	-0.03	-0.21	0.08	*	-0.37	-0.05	-0.16	0.06	**	-0.27	-0.04	-0.16	0.06	**	-0.27	-0.04
aircraft noise annoyance						-0.20	0.08	**	-0.34	-0.05	-0.21	0.06	***	-0.38	-0.09	-0.21	0.06	***	-0.33	-0.10
AIC value	718.3					1252.7					1131.7					59.0				

Note. B = regression coefficient; SE = standard error; p = probability value; CI -/+ = lower/upper bound of 95 % wald-confidence interval, AIC = Akaike information criterion; * p < 0,05; ** p < 0,01; *** p < 0,001, mode = survey mode (telephone vs. online); additional predictors included in the augmented model (model 2): age, sex, migration background, period of residence, hours spent out of home, home ownership, socio-economic status, noise sensitivity, body mass index (BMI), sports, railway noise exposure (LDEN), road noise exposure (LDEN), alcohol consumption and tobacco consumption.

3.3 Structural equation modelling to test the causal relationship of aircraft noise exposure, aircraft noise annoyance and diagnosis of depression

To test the causal association between aircraft noise exposure, aircraft noise annoyance and the prevalence of depression for 12 months, structural equation modelling was conducted. Co-determinants are not included in the model due to a better fit of the basic models without determinants.

Figure 1a) specifies the model to test whether the impact of aircraft noise exposure in t1 (2012) on diagnoses of depression in t2 (2013) is mediated by aircraft noise annoyance in t1 (2012). Figure 1b) shows the model that examines a potential mediation effect of diagnosed depression in t1 (2012) on the effect of aircraft noise exposure in t1 (2012) on the magnitude/intensity of aircraft noise annoyance in t2 (2013). To control for the influence of depression and noise annoyance in the previous year, their effect on the following year was tested.

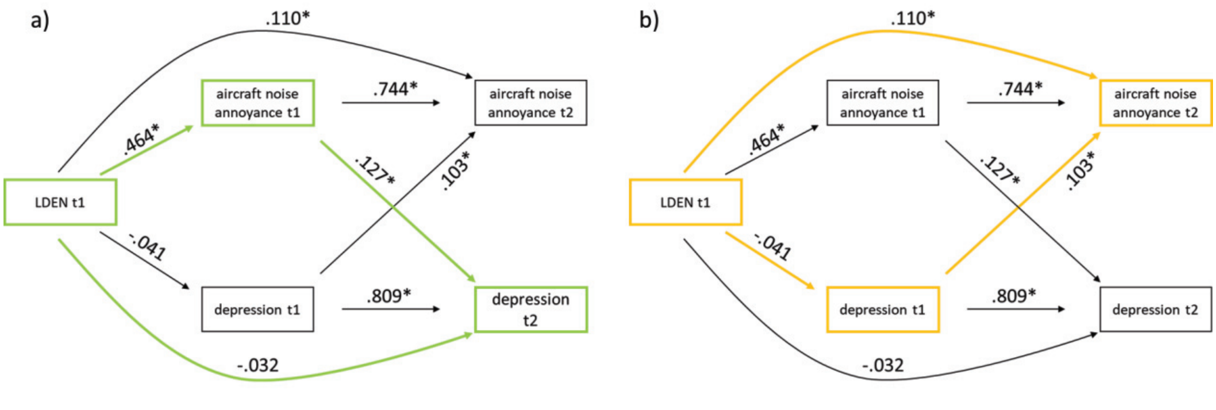

Figure 1 – the effect of aircraft noise exposure in t1 (2012) on a) prevalence of depression in t2, potentially mediated by aircraft noise annoyance in t1, b) on aircraft noise annoyance in t2, potentially mediated by depression in t1.

Results show no significant direct effect of aircraft noise exposure in t1 (2012) on prevalence of depression in t2(2013) (β* = -0.032, p =.372), whereas there are significant effects via the indirect path from aircraft noise exposure on aircraft noise annoyance (β* = 0.464, p <.001) and aircraft noise annoyance in t1 on the prevalence of depression in t2 (2013) ($\beta^* = 0.127$, $p < .01$). In the present study the effect of aircraft noise exposure in t1 on depression in t2 is largely mediated by aircraft noise annoyance in t1, the mediation effect of annoyance (t1) is of moderate size ($\beta^* = 0.059$, $p < .01$).

Results do not confirm the reversed hypothesis that prevalence of depression in t1 mediates the effect of aircraft noise exposure on the intensity of aircraft noise annoyance in t2. There is a direct effect of aircraft noise exposure in t1 on aircraft noise annoyance in t2 ($\beta^* = 0.110$, $p < .001$), but no significant effect of aircraft noise exposure on depression ($\beta^* = 0.041$, $p = .205$). However, prevalence of depression in t1 appears to affect aircraft noise annoyance in t2 ($\beta^* = 0.103$, $p < .001$).

4. DISCUSSION AND CONCLUSIONS

Findings indicate no direct effect of noise exposure on the 12 months prevalence of depression, confirming results of previous studies with no effect of aircraft noise exposure on depression or mental health (12-14). Thus, aircraft noise annoyance in t1 has been found to significantly mediate the effect of aircraft noise exposure in t1 on the diagnosed 12 months prevalence of depression in the following year (t2). Further, a significant reciprocal effect of noise annoyance and depression was observed, showing that depression also accounts for the degree of noise annoyance in the following year. These results support evidence for aircraft noise annoyance as a mediator of the relationship between aircraft noise exposure and mental health outcomes (6), indicating further that effects cannot only be found for quality of life but also for manifest mental disorders, emphasizing the adverse effects of annoyance from aircraft noise.

Noise annoyance as a cognitive, emotional and behavioural stress response to noise (9, 16) combined with physiological stress reactions (17, 18) might enhance the impact of noise and take its full effect in contributing to the development of depression.

Depression cannot be confirmed as a mediator of the relationship between aircraft noise exposure and aircraft noise annoyance in the following year. However, depression can be confirmed as a potential predictor (either moderator or co-determinant) of aircraft noise annoyance, which is in line with evidence for an association of noise annoyance and mental health quality of life (6, 19).

Depression could result in lower perceived coping capacity and the feeling of lack of control of the noise situation that might lead to more annoyance. This is in line with Stallen, emphasizing the role of coping capacity and perceived control on noise annoyance (16). Underlying processes for the mediation effect of noise annoyance on depression should be addressed in future research. Overall, these results support the relevance of aircraft noise annoyance as an indicator of the health impacts of noise.

ACKNOWLEDGEMENTS

This study is part of a master’s thesis within the frame of the conceptual and methodological work of the WPs 2 and 3 of the EU project ANIMA (Aviation Noise Impact Management through Novel Approaches). ANIMA has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 769627. For this study, data of the research project NORAH (Noise-Related Annoyance, Cognition, and Health) was used. NORAH was commissioned by the Environment & Community Center / Forum Airport & Region, Kelsterbach, Germany.

REFERENCES

1. Van Kempen E, Casas M, Pershagen G, Foraster M. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary. Int J Environ Res Public Health 2018; 15.
2. Basner M, McGuire S. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep. Int J Environ Res Public Health 2018; 15.
3. Clark C, Paunovic K. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Quality of Life, Wellbeing and Mental Health. Int J Environ Res Public Health Health 2018; 15: 2400.
4. Seidler, A., Hegewald, J., Seidler, A. L., Schubert, M., Wagner, M., Dröge, P. et al. (2017). Association between aircraft, road and railway traffic noise and depression in a large casecontrol study based on secondary data. Environmental research, 152, 263–271. https://doi.org/10.1016/j.envres.2016.10.017
5. Black DA, Black JA, Issarayangyun T, Samuels SE (2007). Aircraft noise exposure and resident's stress and hypertension: A public health perspective for airport environmental management. J Air Transp

Manag 2007; 13: 264–276.
6. Schreckenberg D, Benz S, Belke C, Möhler U, Guski R. The relationship between aircraft sound levels, noise annoyance and mental well-being: An analysis of moderated mediation. Proc ICBEN 2017, June 18-22, 2017: Zurich, Switzerland 2017.
7. Beutel ME, Jünger C, Klein EM, Wild P, Lackner K, Blettner M et al. Noise Annoyance Is Associated with Depression and Anxiety in the General Population- The Contribution of Aircraft Noise. PloS one 2016; 11: e0155357.
8. Niemann H, Maschke C, Hecht K. Lärmbedingte Belästigung und Erkrankungsrisiko. Ergebnisse des paneuropaeischen Lares-Survey. Bundesgesundheitsblatt 2005; 48: 315–328.
9. Guski R, Felscher-Suhr U, Schuemer R. The concept of noise annoyance: How international experts see it. J Sound Vibration 1999; 223(4):513–27.
10. Schreckenberg D, Faulbaum F, Guski R, Ninke L, Peschel C, Spilski J & Wothge J. Wirkungen von Verkehrslärm auf die Belästigung und Lebensqualität. In Gemeinnützige Umwelthaus gGmbH (eds.), NORAH (Noise related annoyance cognition and health): Verkehrslärmwirkungen im Flughafenumfeld (Bd. 3). 2015 Kelsterbach: Umwelthaus gGmbH.
11. Fields JM, Jong RG de, Gjestland T, Flindell IH, Job RFS, Kurra S et al. Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation. J Sound Vibration 2001; 242(4):641–79.
12. Busch MA, Maske UE, Ryl L, Schlack R, Hapke U. Prävalenz von depressiver Symptomatik und diagnostizierter Depression bei Erwachsenen in Deutschland: Ergebnisse der Studie zur Gesundheit Erwachsener in Deutschland (DEGS1). Bundesgesundheitsblatt 2013; 56: 733–739.
13. Baudin C, Lefèvre M, Champelovier P, Lambert J, Laumon B, Evrard A-S.. Aircraft Noise and Psychological Ill-Health: The Results of a Cross-Sectional Study in France. Int J Environ Res Public Health 2018; 15.
14. Floud S, Vigna-Taglianti F, Hansell A, Blangiardo M, Houthuijs D, Breugelmans O et al.. Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. Occup Environ Med 2011; 68: 518–524.
15. Hardoy MC, Carta MG, Marci AR, Carbone F, Cadeddu M, Kovess V et al.. Exposure to aircraft noise and risk of psychiatric disorders: the Elmas survey-aircraft noise and psychiatric disorders. Soc Psych Psych Epid 2005; 40: 24–26.
16. Stallen PJM. A theoretical framework for environmental noise annoyance. Noise Health 1999; 1(3):69.
17. Lefèvre M, Carlier MC, Champelovier P, Lambert J, Laumon B, Evrard AS. Effects of aircraft noise exposure on saliva cortisol near airports in France. Occup Environ Med 2017; 74: 612–618.
18. Selander J, Bluhm G, Theorell T, Pershagen G, Babisch W, Seiffert I et al.. Saliva cortisol and exposure to aircraft noise in six European countries. Environ Health Perspect 2009; 117: 1713–1717.
19. Van Kamp I, van Kempen E, Baliatsas C, Houthuijs D. Mental health as context rather than health outcome of noise: competing hyptheses regarding the role of sensitivity, perceived soundscapes and restoration. Proc INTERNOISE 2013; Innsbruch, Austria 2013.