The relationship between aircraft sound levels, noise annoyance and mental well-being: An analysis of moderated mediation

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ABSTRACT

The evidence of a relationship between environmental noise exposure and mental health-related quality of life (HQoL) is inconsistent. Several studies have shown an association between noise annoyance and mental HQoL. This has been interpreted in terms of a mediation effect of annoyance on mental health. The reversed hypothesis that individuals with poor mental health have low resources to cope with noise and thus are more annoyed is also discussed. For aircraft noise at Frankfurt Airport, both hypotheses that annoyance mediates the impact of noise exposure on mental HQoL and that mental HQoL contributes to the prediction of annoyance were analysed using longitudinal data of the NORAH study (Noise-related annoyance, cognition, and health). Results of SEM and OLS regressions indicate that annoyance mediates the effect of aircraft sound exposure on mental HQoL. During two years of measurement after the opening of a new runway this mediation effect is stronger for higher aircraft sound levels. The analyses also revealed a reciprocal association between noise annoyance and mental HQoL. In addition to annoyance, the change in noise exposure since 2011 affects mental HQoL.

INTRODUCTION

It is common sense in noise effect research that transportation noise annoys exposed people and contributes to health impairment. Following the concept of noise as a stress-inducing environmental burden it is plausible to assume that long-term exposure to aircraft noise leads to chronic annoyance and perceived stress followed on the long run by impairment of health-related quality of life including both physical and mental well-being. Health-related quality of life (HQoL) is here understood in accordance with the definition of the WHO [1] as an "individual's perception of his/her position in life in the context of the culture and value systems in which he/she lives, and in relation to his/her goals, expectations, standards and concerns. It is a broad-ranging concept, incorporating in a complex way the person's physical health, psychological state, level of independence, social relationships, and their relationship to salient features of their environment." [1, p. 1405]. Studies have shown that the evidence of a (direct) impact of environmental sound levels on mental HQoL is inconsistent [2]. With regard to aircraft noise, a lower degree of mental HQoL in highly exposed areas compared to areas with low exposure were found by [3]. [4] reported an association between aircraft sound levels and mental HQoL only in residents with two or more chronic diseases. No statistically significant change in mental health with variation of aircraft sound exposure was found in the Amsterdam Schiphol monitoring study [7]. Studies on the impact of noise on HQoL suggest that HQoL is more associated with noise annoyance than with objectively assessed sound levels [2, 8]. For aircraft noise, covariations between noise annoyance and mental health were observed e.g. in [4-8]. The associations between noise annoyance and mental health have been interpreted in terms of a mediation effect of annoyance on mental well-being [8-9]. This can be explained by stress-theoretical models indicating that long-term exposure to noise leads to long-term noise annoyance and, together with a lack of capacity to cope with the noise and to recover, to further impairment of mental (and physical) well-being [4].

However, the reversed causal direction of the annoyance - health association is also discussed and can be inferred from a noise-related stress concept. That is, it can be argued that individuals with (pre-existing) poor mental health have lower resources to cope with noise and thus are more annoyed [10]. The issue of the causal direction of noise annoyance and mental health might be in particular important when noise exposure changes. Several studies have shown that stepwise changes in noise exposure lead to the so-called 'change effect' in noise responses, i.e. "…an excess response to the new noise exposure over that predicted from steady-state exposure-response curves" – [6, p. 1]. [5] explain the change effect – in short – with maladaptive coping going along with (de-)sensitization to the perceived aversive component of the 'new' noise. It might either be that, in particular, those residents reporting lower mental HQoL perceive less capacity to cope with noise in a situation of an expected change to the worse and, thus, react with stronger noise annoyance than residents with higher mental HQoL. Or, residents might get sensitized to changes in noise exposure, are then concerned with re-adjusting their behaviour to cope with noise, which leads to a new degree of annoyance. Further on, the annoyance would then have an impact on mental HQoL, in particular when less capacity to cope with the new noise situation is perceived.

Within the research initiative NORAH (Noise-Related Annoyance, Cognition, and Health) the impact of transportation noise on noise annoyance and HQoL (WP1) has been studied. NORAH-WP1 includes a panel study at Frankfurt Airport on the impact of aircraft noise on annoyance, reported sleep disturbances and HQoL before (2011) and repeatedly after (2012, 2013) the opening of a new (fourth) runway (runway Northwest) in October 2011. The assumption was that long-term exposure to aircraft noise has an impact on HQoL - either directly or mediated by noise reactions such as disturbances and annoyance. The analysis included multiple regression models for mental and physical HQoL as assessed with a short form of the SF-36, the SF-8 [12] with aircraft sound levels and/or aircraft noise annoyance and further co-determinants/confounders as predictors. Results of brief simple tests of moderation and mediation (OLS regressions [13]) prior to the main regression analyses supported the assumption of a mediation effect of noise annoyance on HQoL. However, these pre-analyses were not controlled for longitudinal effects, in particular mutual effects of previous year values of annoyance and HQoL on annoyance and HQoL, respectively, of the considered year. Also, changes in aircraft sound exposure due to the airport expansion were not fully considered in the pre-analyses. Thus, the aim of this study is to analyse the association between aircraft noise annoyance and HQoL in more detail by means of the longitudinal data of the NORAH study. The study concentrates on mental HQoL as in NORAH WP1 the association between noise annoyance and physical HQoL was found to be similar but with lower effect size.

METHODS

Study design and sampling

WP1 of the NORAH research initiative entails a panel study at Frankfurt Airport before and after the opening of the new runway Northwest and the implementation of a night-flight ban from 11pm to 5 am (both in October 2011). Three main measurements were carried out: The first measurement in 2011 before the runway opening and repeated measurements in the first (2012) and the second year (2013) after the opening of the new runway and the implementation of the night-flight ban.

The study area around Frankfurt Airport was curtailed by the "envelope" of the 40 dB contours of the continuous aircraft sound levels for daytime ($L_{p\text{Aeq},06\text{-}22h}$) and night-time ($L_{p\text{Aeq},22\text{-}06h}$). Within this area adult residents were randomly sampled from population registries in 2011 with (1) aircraft sound levels (2.5 dB classes of the maximum of $L_{p\text{Aeq},06\text{-}22h}$ and $L_{p\text{Aeq},22\text{-}06h}$ calculated for 2007) and (2) the change in aircraft sound exposure, i.e. the difference between address-related estimated $L_{p\text{Aeq},24hrs}$ as predicted for 2020 and $L_{p\text{Aeq},24hrs}$ of 2007, categorized in three groups (increase in $L_{p\text{Aeq},24hrs}$ > 2 dB, decrease in $L_{p\text{Aeq},24hrs}$ > 2 dB, change within the range of ± 2 dB) as strata. Telephone numbers available from telephone registration were assigned to the sampled residents to enable telephone interviews as the main mode of survey. The continuous sound levels used for stratum and to define the perimeter of the study region were calculated for the residential address of each participant and refer to the air traffic of the six busiest months of the year 2007. Similarly, the sound levels predicted for 2020 refer to the six busiest months in 2020. See [14] for more information about the acoustical estimations.

Procedure

The participants of the panel study at Frankfurt Airport were sampled in spring 2011. All sampled residents received a cover letter to inform about the study and invite to participate in telephone interviews or optional online surveys with the same questionnaire. The first measurement was done in summer and autumn of 2011 and finished before the opening of the runway Northwest on 21 October 2011. Repeated measurements were carried out in summer/autumn of 2012 and again in 2013. The sampling and data management was supervised and certified by the responsible agency for data protection.

Noise exposure

The exposure to sound levels (continuous and mean maximum sound levels of aircraft, railway and road traffic) for each participant's residential address was calculated for a 12 months period from October to September for each survey wave for daytime, evening, night-time and for 24 hours. For the assessment of aircraft sound levels the German calculation method AzB 2008 was used. The average sound levels of railway and road traffic were determined based on the methods for calculation used for EU noise mapping [14]. For the analyses in this study the $L_{p\text{Aeq},24hrs}$ as indicator of aircraft sound exposure was used. In addition, in some of the analyses the source-specific $L_{p\text{Aeq},24hrs}$ of road traffic and railway sound were used for model adjustment.

Questionnaire

In all three survey waves 2011, 2012 and 2013 the questionnaire included the assessment of disturbances and annoyance to aircraft noise and other transportation noise (railway, road traffic), mental and physical quality of life, potential co-determinants of annoyance and HQoL (e.g. noise sensitivity, attitudes towards the source), questions concerning residential conditions (e.g. sound insulation, window type and position) and demographics. In the analyses described in this contribution the following main variables were assessed:

- *Aircraft noise annoyance* as assessed with the ICBEN 5-point scale according to the ICBEN recommendation [15].
- *Mental HQoL* together with physical HQoL was ascertained in all survey waves by means of the SF-8, a short form of the standardised SF-36 [12]. With eight items the eight dimensions of HQoL, general health (GH), physical functioning (PF), physical role (RP), bodily pain (BP), vitality (VT), social functioning (SF), emotional role (RE) and mental health (MH) were assessed for the period of 4 weeks prior to the interview. The item scores were transformed to T values with M = 50 and SD = 10 and summed up to two sum scores of HQoL, the mental component score *MCS* and the physical component score PCS, according to the QualityMetric's scoring algorithms [12]. The following analyses concentrate on the MCS.

Statistical analysis

The data was analysed descriptively in terms of the calculation of frequency, means, and standard deviations. The exposure-response relationship for the mental health score was analysed for each year of measurement by means of multiple logistic regressions based on the Generalized Linear Model (GzLM) with $L_{p\text{Aeq,24hrs}}$ as the acoustical parameter of aircraft noise exposure and/or aircraft noise annoyance. The basic models were adjusted for mode of survey (phone vs. online). The extended models were adjusted for mode of survey, gender, age, socio-economic status (SES), migration background, noise sensitivity (single item), occupancy, ownership of residence, hours during the day not at home, body mass index (BMI), physical activities, and $L_{p\text{Aeq,24hrs}}$ for road traffic and railway sound exposure, respectively. For the regression models the robust covariance matrix estimator (Huber-White-Sandwich estimator) was used in order to provide consistent estimates of covariance, even in case of heteroscedasticity. The causal direction of the relationship between aircraft noise annoyance and MCS was analysed by means of structural equation modeling (SEM) [16] with AMOS V.24. To allow for analysis and interpretation of results of SEM with non-normal data the asymptotically distribution-free estimation (ADF) was used for all SEM. Longitudinal data of the NORAH panel study were used in the SEM to address the issue of temporal order of annoyance and MCS as either dependent or independent variables. The logic for SEM with longitudinal data in research on noise annoyance is, for example, described in [17] (see also [18] for similar analyses with regard to the relationship between aircraft noise annoyance and trust in authorities). That is, the direct and indirect effects of aircraft sound exposure and aircraft noise annoyance as measured in one survey wave (t1) on MCS measured in the following survey wave (t2) was tested whilst controlling for the impact of the previous value of MCS (measured at t1). The same was done for the estimation of the effect of MCS measured at t1 on aircraft noise annoyance measured at t2. In addition, as aircraft sound exposure changed after the first measurement in 2011 due to the opening of runway Northwest and the implementation of the night-flight ban, a variable of change in exposure was included in the model. For this, the standardised residuum of the regression of the aircraft sound exposure ($L_{p\text{Aeq,24hrs}}$) calculated for t2 on the $L_{p\text{Aeq,24hrs}}$ calculated for t1 was estimated and used as a 'exposure change variable' in the SEM. The advantage of the residuum is that it expresses the residual change in exposure which cannot be explained by the aircraft sound level at t1. First, separate models for annoyance and MCS in t2 as outcome were estimated. Then, an integrated model formed by both models was calculated. It was found that coefficients in the separate models and in the integrated model are similar. Thus, results of the integrated model (Figure 1) are presented.

The integrated model was calculated for three combinations of two measurement years defined as t1 and t2 (Model A, B, and C, see Table 1).

Table 1: Overview of times (years) of measurements t1 and t2 in the SEMs of longitudinal NORAH data

Model (SEM)	Measurement t1	Measurement t2
A	2011	2012
B	2011	2013
C	2012	2013

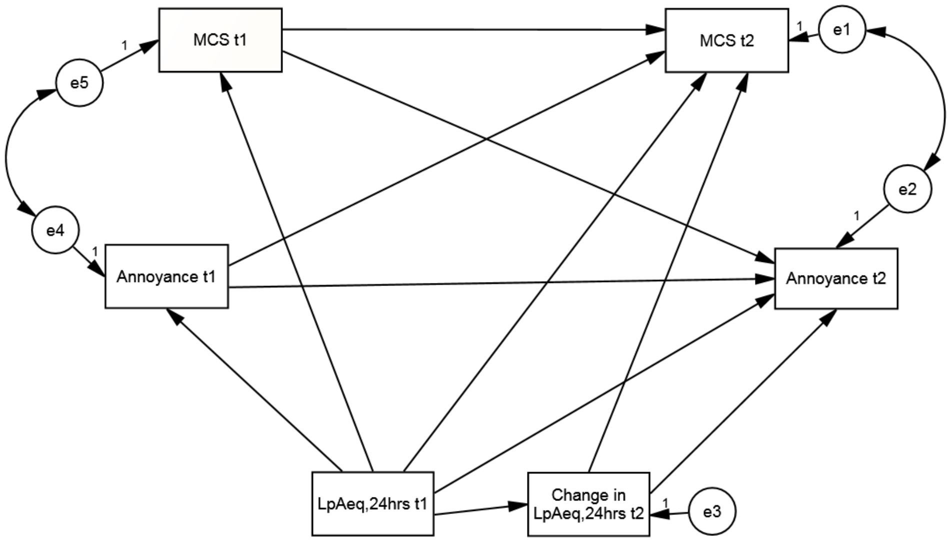


Figure 1: Specification of the structural equation models (SEM) for the relationship between aircraft noise annoyance and mental HQoL (MCS)

Models A and B include changes in aircraft sound exposure due to the airport expansion between t1 and t2. The times of measurement t1 and t2 in model C refer both to the period after the opening of the runway and the implementation of the night-flight ban and include minor changes in exposure, if at all. In addition to the SEM, moderated mediation effects were analysed by means of the OLS regression approach as implemented in the SPSS macro PROCESS [13]. All modelling included bootstrapping [19] with 5000 'bootstrap'-samples in order to assess the robustness of the models.

RESULTS

Descriptive statistics

In the NORAH panel study 9244 residents were interviewed in the first wave (2011) before the opening of the runway Northwest. 4867 of them took part in the second measurement (2012) after the opening of the new runway and the implementation of the night-flight ban, 3508 respondents took part in the third measurement in 2013. The following analyses were done with data of the respondents that took part in all measurements, i.e. the analyses are based on a sample of 3508 respondents (53.5% female, age range in 2011: 18 to 96 yrs, *M* = 53 yrs, *SD* = 14.5 yrs). In 2011, 88.5% of the participants (2012: 88.4%, 2013: 88.3%) were interviewed by phone, 11.5% (2012: 11.6%, 2013: 11.7%) responded to the same questions using the online mode. In 2011, the average aircraft sound levels for 24 hours $L_{p\mathrm{Aeq,24hrs}}$ ranged from 36 to 61 dB (*M* = 48.2, *SD* = 6.2). The range of $L_{p\mathrm{Aeq,24hrs}}$ was from 35 to 71 dB (*M* = 47.9, *SD* = 6.4 dB) in 2012 and from less than 35 dB to 70 dB (*M* = 47.2, *SD* = 6.3) in 2013. After the opening of the new runway, 517 persons (15%) experienced a decrease in aircraft sound exposure of more than 2 dB $L_{p\mathrm{Aeq,24hrs}}$ in 2012 compared to 2011, 399 respondents (11%)

experienced an increase of more than 2 dB and for 2592 participants (74%) there was no change in $L_{pAeq,24hrs}$ above 2 dB. The number of persons exposed to changes in aircraft noise is quite similar when sound levels of aircraft noise are considered separately for daytime (6am to 10pm) and night-time (10pm to 6am).

Table 2 presents the descriptive statistics for aircraft noise annoyance and the mental health score MCS by aircraft sound exposure, i.e. 2.5 dB-classes of $L_{pAeq,24hrs}$. In all years of measurement, means of aircraft noise annoyance increases with increasing aircraft sound levels. In all sound classes, the annoyance is higher in 2012 than in 2011 and 2013. The correlations are quite similar in all years of measurement (.47 ≤ r ≤ .48). With regard to the mental well-being it can be observed that the values of MCS slightly but statistically significant decrease with increasing sound levels, although the correlation with the $L_{pAeq,24hrs}$ is much weaker (-.13 ≤ r ≤ -.09) compared to the correlation between annoyance and sound level. Table 3 shows the descriptive statistics for MCS by aircraft noise annoyance. In all years of measurement means of MCS are lower in participants reporting a high degree of annoyance. The correlations between MCS and annoyance (not presented in Table 3) are in the range of -.24 ≤ r ≤ .18.

Table 2: Aircraft noise annoyance and mental HQoL by aircraft sound exposure ($L_{pAeq,24hrs}$ – classes)

$L_{pAeq,24hrs}$ in dB	Aircraft noise annoyance (ICBEN 5-pt scale)									SF-8 Mental Composite Score MCS								
	2011 (t1)			2012 (t2)			2013 (t3)			2011 (t1)			2012 (t2)			2013 (t3)		
	N	M	SD	N	M	SD	N	M	SD	N	M	SD	N	M	SD	N	M	SD
<= 37.5	55	1.9	1.0	180	2.3	1.1	243	2,2	1,1	55	52,4	8,1	55	52,4	8,1	243	52,1	8,7
37.6 - 40.0	283	2.3	1.2	342	2.4	1.2	330	2,3	1,1	283	51,4	9,3	283	51,4	9,3	330	51,5	9,2
40.1 - 42.5	490	2.6	1.2	376	2.8	1.2	451	2,6	1,1	490	51,0	9,2	490	51,0	9,2	451	52,1	8,7
42.6 - 45.0	448	2.8	1.2	379	3.0	1.2	328	2,9	1,2	448	51,5	8,7	448	51,5	8,7	328	51,1	9,3
45.1 - 47.5	395	3.1	1.2	341	3.3	1.2	397	3,3	1,2	395	50,4	10,1	395	50,4	10,1	397	51,1	9,4
47.6 - 50.0	394	3.3	1.2	403	3.6	1.2	462	3,5	1,2	394	50,5	9,5	394	50,5	9,5	462	50,0	9,6
50.1 - 52.5	442	3.7	1.1	381	3.8	1.2	458	3,8	1,1	442	49,3	10,2	442	49,3	10,2	458	50,3	9,3
52.6 - 55.0	411	3.9	1.1	549	3.9	1.1	414	3,9	1,2	411	49,2	9,7	411	49,2	9,7	414	50,1	9,3
55.1 - 57.5	341	4.2	1.0	414	4.1	1.0	262	4,0	1,1	341	50,2	9,3	341	50,2	9,3	262	48,6	11,0
> 57.5	249	4.2	1.0	143	4.3	0.9	163	4,1	1,0	249	48,6	10,5	249	48,6	10,5	163	48,8	11,0
Total	3508	3.3	1.3	3508	3.4	1.3	3508	3,2	1,3	3508	50,3	9,6	3508	50,3	9,6	3508	50,7	9,5

Table 3: SF-8 score for mental HQoL (MCS) in 2011 to 2013 by aircraft noise annoyance

Aircraft noise annoyance	SF-8 MSC								
	2011 (t1)			2012 (t2)			2013 (t3)		
	N	M	SD	N	M	SD	N	M	SD
1: not at all	422	51.8	9.4	343	54,1	7,8	425	53,5	8,4
2: slightly	638	52.6	8.5	619	53,4	8,1	694	52,9	8,6
3: moderately	741	51.4	9.1	741	51,7	9,0	756	51,6	8,7
4: very	899	50.0	9.3	922	50,2	8,9	880	50,2	8,8
5: extremely	808	47.1	10.5	883	46,6	11,2	753	46,7	11,0
Total	3508	50.3	9.6	3508	50,6	9,7	3508	50,7	9,5

Exposure response models for mental HQoL (MCS)

Results of the cross-sectional multiple logistic regression models (Table 4) reveal weak but statistically significant impact of $L_{pAeq,24hrs}$ for aircraft sound on MCS (basic models). After adjustment and inclusion of aircraft noise annoyance in the model, which clearly improves the models' fit (Akaike information criterion, AIC), there is no statistically significant effect of aircraft sound level on MCS anymore (extended model I). After exclusion of $L_{pAeq,24hrs}$ as predictor the model fit (AIC) as well as the size of the effect (*B*) of aircraft noise annoyance on MCS remains almost the same. This indicates a mediation effect of annoyance on MCS.

Table 4: Results of cross-sectional aircraft noise exposure-response models (multiple logistic regressions) for mental HQoL (SF-8 score MCS) with aircraft sound exposure ($L_{pAeq,24hrs}$) and aircraft noise annoyance (ICBEN 5-point scale) as main predictors and further co-determinants for adjustment

Predictor	Criterion: SF-8 score MCS								
	2011			2012			2013		
	B	***BCI -***	***BCI -***	***B***	***BCI -***	***BCI -***	***B***	***BCI -***	***BCI -***
Basic model	AIC = 25746.21			AIC = 25786.99			AIC = 25640.23		
Constant term	57.35	54.92	59.79	60.56	58.23	62.89	58.41	56.08	60.75
$L_{pAeq,24h}$ – aircraft	-0.15	-0.20	-0.10	-0.21	-0.26	-0.16	-0.16	-0.21	-0.11
Extended model I	AIC = 20374.81			AIC = 21012.83			AIC = 20984.89		
Constant term	49.93	46.72	53.00	50.78	47.68	53.76	48.79	45.86	51.58
$L_{pAeq,24h}$ - aircraft	0.01	-0.06	0.07	-0.01	-0.07	0.06	0.04	-0.02	0.10
Aircraft noise annoyance	-1.43	-1.84	-1.02	-2.14	-2.54	-1.76	-1.97	-2.35	-1.58
Extended model II	AIC = 20373.05			AIC = 21010.87			AIC = 20984.86		
Constant term	50.28	49.94	50.60	50.50	50.17	50.82	50.83	50.49	51.16
Aircraft noise annoyance	-1.41	-1.77	-1.05	-2.15	-2.50	-1.81	-1.84	-2.18	-1.48

BCI-/+: lower (-) and upper (+) 95% bootstrap confidence interval. Unlike signs of BCI- and BCI+ indicate a non-statistically significant regression coefficient B. The basic models are adjusted for mode of survey (phone vs. online). In addition, the extended models I and II are adjusted for gender, age, occupancy, hours out of home, ownership residence, socio-economic status, migration background, noise sensitivity, body mass index, physical activity, $L_{pAeq,24hrs}$ - road, $L_{pAeq,24hrs}$ - railway

However, the premise of the cross-sectional extended logistic regression models described above is that the causal path of the association between aircraft noise annoyance and MCS follows from annoyance to MCS. This assumption was tested by means of the SEMs A to C.

Structural equation model for aircraft noise annoyance and mental HQoL

Table 5 shows values of modal fit for the models A, B and C. Except for model C the test statistics show that the covariance matrix of the models do not differ in a statistically significant manner from the sample covariance matrix. All in all, the values of the fit indices shown in Table 5 indicate a sufficient fit for all models as most of the values are inside the range of conventionally defined cut-off values for a good model fit (χ^2/df ratio < 2, CFI ≥ 0.95, RMSEA ≤ 0.05 together with p_{close} > 0.50, SRMR ≤ 0.08 [16]).

Table 5: Model fit values of SEM A, B and C

SEM	t1	t2	Model test statistics				Fit indices				
			χ^2	df	p	χ^2/df	CFI	RMSEA	p_{CLOSE}	SRMR	AIC
A	2011	2012	2.34	2.00	0.31	1.17	1.00	0.01	1.00	0.01	40.34
B	2011	2013	1.55	2.00	0.46	0.77	1.00	0.00	1.00	0.01	39.55

C	2012	2013	8.60	2.00	0.01	4.30	1.00	0.03	0.92	0.01	46.60

χ^2 = Chi square, df = degree of freedom, CFI: comparative fit index, RMSEA: root mean square error of approximation, SRMR: standardized root mean residual, AIC = Akaike information criterion

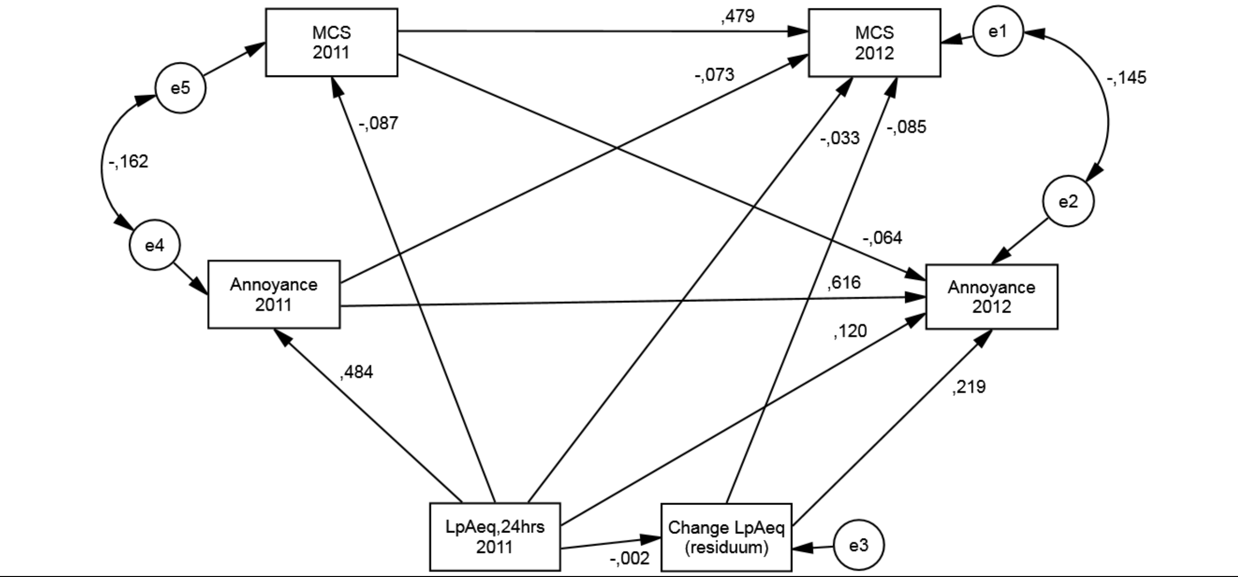
Table 6 depicts the estimated path coefficients of variables in SEM A, B and C. The paths from aircraft noise annoyance t1 to MCS t2 and from MCS t1 to annoyance t2 are of particular interest. In all models, both the path from annoyance to MCS and the path from MCS to annoyance are statistically significant. In model A and C the effect of annoyance t1 on MCS t2 is slightly higher than the effect of MCS t1 on annoyance t2. In model B the difference between the effect sizes is conversed. The mediation effect of annoyance t1 on MCS t2, i.e. the indirect effect of $L_{pAeq,24hrs}$ t1 on MCS t2 mediated by annoyance t1 is considerably higher than the mediation effect of MCS t1 on annoyance t2. Furthermore, Table 6 shows relatively strong direct and indirect effects (e.g. via annoyance t1) of aircraft sound level t1 on annoyance t2 and an even stronger direct effect of the residual change in sound level compared to the $L_{pAeq,24hrs}$ in 2011 (before the runway opening) on annoyance in 2012 and 2013. The effect of the residual change in sound exposure in the 'after-situation' between 2012 and 2013 on aircraft noise annoyance in 2013 is considerably lower. The different effects of the residual change in aircraft sound levels in Model A, B and C is similar for MCS, although in all models the size of these effects are lower for MCS than for aircraft noise annoyance. The direct effect of $L_{pAeq,24hrs}$ t1 on MCS t2 is weak in all models but somewhat higher in model A predicting aircraft noise annoyance and MCS in the first year after the changes at the airport (2012) than in the models B and C which predict annoyance and MCS in the second year after the airport expansion (2013).

Table 6: Standardised estimates of structural equation models A, B and C

Y1 = MCS t2 (sub-model 1) Y2 = Annoyance t2 (sub-model 2)			**Model A**	**Model B**	**Model C**
			t1=2011 t2=2012	**t1=2011 t2=2013**	**t1=2012 t2=2013**
Change in $L_{pAeq,24hrs}$	<---	$L_{pAeq,24hrs}$ t1	-.002 [a]	-.001 [a]	.001 [a]
Annoyance t2	<---	$L_{pAeq,24hrs}$ t1	.120	.117	.108
MCS t2	<---	$L_{pAeq,24hrs}$ t1	-.033 [b]	-.004 [a]	.008 [a]
Annoyance t2	<---	Change in $L_{pAeq,24hrs}$	.219	.200	.062
MCS t2	<---	Change in $L_{pAeq,24hrs}$	-.085	-.086	-.029 [b]
Annoyance t1	<---	$L_{pAeq,24hrs}$ t1	.484	.484	.474
MCS t1	<---	$L_{pAeq,24hrs}$ t1	-.087	-.087	-.134
Annoyance t2	<---	MCS t1	-.064	-.063	-.055
MCS t2	<---	Annoyance t1	-.073	-.055	-.083
MCS t2	<---	MCS t1	.479	.457	.503
Annoyance t2	<---	Annoyance t1	.616	.615	.729
e4 (annoyance t1)	<-->	e5 (MCS t1)	-.162	-.162	-.226
e2 (annoyance t2)	<-->	e1 (MCS t2)	-.145	-.149	-.081
Mediation effect of M_{t1} (indirect effect of X_{t1} = $L_{pAeq,24hrs}$ t1 via M_{t1} on Y_{t2})					
Y_{t2}		M_{t1}			
Annoyance t2	<---	MCS t1	.006	.005	.007
MCS t2	<---	Annoyance t1	-.035	-.027	-.039

[a] $p > 0.10$, [b] $0.01 < p < 0.05$. p for all coefficients ≤ .001 except for [a] and [b].
Paths between annoyance and MCS are highlighted

The specified model A with t1 = 2011 and t2 = 2012 as an example of a model of the longitudinal association between aircraft sound exposure, aircraft noise annoyance and mental health in a change situation (before/after changes of noise exposure in the context of the airport extension) and model C with t1 = 2012 and t2 = 2013 representing the longitudinal association after major changes at the airport are presented in Figure 2.



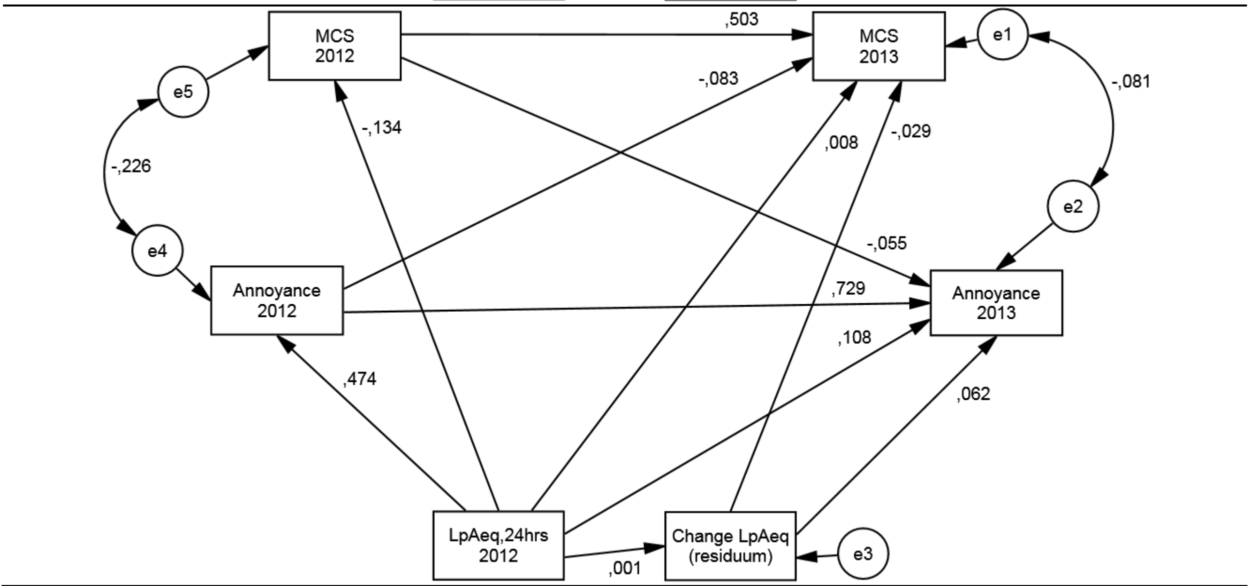


Figure 2: Structural equation models (standardised estimates) for the longitudinal relationship between aircraft sound exposure, aircraft noise annoyance and mental HQoL (MCS): Upper model A for t1 = 2011 and t2 = 2012 and lower model C for t1 = 2012 and t2 = 2013

Moderated mediation of aircraft noise exposure

As aircraft noise annoyance was found to mediate the effect of aircraft sound level on mental health an analysis of moderated mediation was done by means of the OLS regression approach [13]. That is, it was tested to what extent does the $L_{p\mathrm{Aeq,24hrs}}$ moderate its own indirect effect via the mediator aircraft noise annoyance on MCS. This moderated mediation effects requires an interaction between $L_{p\mathrm{Aeq,24hrs}}$ t1 and aircraft noise annoyance t1. Table 7 shows the results for variables of the 'before/after situation' 2011 and 2012 (OLS model 2011/12) and for variables assessed in the 'after situation' 2012 and 2013 (OLS model 2012/13). The OLS regression model 2011/13 reveal similar effects as the OLS model 2011/12.

As the results in Table 7 indicate, only in the OLS model 2012/13 the interaction between annoyance and $L_{p\mathrm{Aeq,24hrs}}$ is statistically significant. Thus, a moderated mediation effect occurs only for the 'after situation' 2012/13. The conditional indirect effects of $L_{p\text{Aeq,24hrs}}$ at different percentile indicate that the mediation effect of aircraft noise annoyance increases with increasing sound levels. In the OLS model 2011/12 the mediation effect of annoyance is not moderated by levels of $L_{p\text{Aeq,24hrs}}$. Instead, it is the residual change in $L_{p\text{Aeq,24hrs}}$ after the opening of the new runway, which has an impact on MCS in addition to the mediation effect of annoyance.

Table 7: Results of OLS regressions for the analysis of moderated mediation effects on MCS

Parameters		**OLS model 2011/12 t1 = 2011 --> t2 = 2012**				**OLS model 2012/13 t1 = 2012 --> t2 = 2013**			
		Beta	**SE**	**t**	**p**	**Beta**	**SE**	**t**	**p**
Outcome: Annoyance t1 (M)									
	constant	0.75	0.08	9.30	0.000	1.04	0.08	13.67	0.000
X	$L_{p\text{Aeq,24hrs}}$ t1	0.47	0.01	33.29	0.000	0.44	0.01	30.96	0.000
C1	MCS t1	-0.02	0.00	-9.45	0.000	-0.02	0.00	-13.71	0.000
C2	Residual change in $L_{p\text{Aeq,24hrs}}$	0.00	0.02	0.29	0.770	0.04	0.01	2.93	0.000
Outcome: MCS t2 (Y)									
	constant	-2.48	0.10	-24.76	0.000	-2.58	0.11	-24.04	0.000
M	Annoyance t1	-0.08	0.02	-4.74	0.000	-0.09	0.02	-4.99	0.000
X	$L_{p\text{Aeq,24hrs}}$ t1	-0.03	0.02	-1.92	0.055	0.01	0.02	0.31	0.754
XM	Annoyance * $L_{p\text{Aeq,24hrs}}$	-0.03	0.02	-1.65	0.100	-0.04	0.02	-2.70	0.007
C1	MCS t1	0.05	0.00	26.54	0.000	0.05	0.00	25.57	0.000
C2	Change in $L_{p\text{Aeq,24hrs}}$	-0.09	0.02	-5.78	0.000	-0.03	0.01	-2.00	0.046
Conditional indirect effect(s) of X ($L_{p\text{Aeq,24hrs}}$ t1) on Y (MCS t2) at values of the moderator(s) ($L_{p\text{Aeq,24hrs}}$ t1):									
	Percentile of $L_{p\text{Aeq,24hrs}}$	$L_{p\text{Aeq,24hrs}}$	Effect	BCI-	BCI+	$L_{p\text{Aeq,24hrs}}$	Effect	BCI-	BCI+
	10	40.1	-0.02	-0.04	0.00	38.8	-0.01	-0.04	0.01
	25	42.8	-0.03	-0.05	-0.01	42.5	-0.02	-0.04	-0.01
	50	48.1	-0.04	-0.05	-0.02	48.5	-0.04	-0.06	-0.03
	75	53.5	-0.05	-0.07	-0.03	53.4	-0.06	-0.08	-0.04
	90	56.3	-0.05	-0.08	-0.03	56.0	-0.06	-0.09	-0.04
*Index of moderated mediation (product of effect of X on M and of X*M on Y)*									
	Mediator (M)		Index	BCI-	BCI+		Index	BCI-	BCI+
	Annoyance t1		-0.01	-0.03	0.00		-0.02	-0.03	-0.01

BCI-/+: lower (-) and upper (+) 95% bootstrap confidence interval. Unlike signs of BCI- and BCI+ indicate a statistically non-significant indirect effect of X_{t1} ($L_{p\text{Aeq,24hrs}}$ t1).

DISCUSSION & CONCLUSIONS

In this study the longitudinal relationship between aircraft sound exposure, aircraft noise annoyance and mental HQoL before (2011) and after (2012, 2013) the expansion of Frankfurt Airport including the opening of the 4th runway Northwest and the implementation of a night-flight ban from 11pm to 5am in October 2011 was investigated by means of structural equation models (SEM). In the SEMs the direct and indirect effects of previous aircraft sound levels and annoyance (t1) on mental HQoL and annoyance, respectively, measured in following survey waves (t2) were analysed controlled by previous values of the outcome of interest (either mental HQoL or annoyance) and change in sound exposure. Although other variables known to be associated both with noise annoyance and mental health such as noise sensitivity [10] were not considered, the models analysed in this study are of sufficient goodness of fit. As both previous annoyance and mental HQoL (t1) have an impact of mental HQoL and annoyance measured at t2, respectively, it seems that annoyance and mental HQoL are reciprocally associated to each other. This is in line with [10], who discuss mental health not only as an outcome but also as a context factor which together with, e.g., noise sensitivity indicates vulnerability to environmental stressors. The mediation effect of aircraft noise annoyance, i.e. the indirect effect of aircraft sound exposure via annoyance is considerably higher than the mediation effect of mental HQoL indicating that the effect of mental HQoL on annoyance is independent from sound exposure. In two of three SEMs (B, C) the direct effect of aircraft sound exposure on mental HQoL is not significant, that is, annoyance fully mediates the relationship between aircraft noise exposure and mental HQoL.

In model A the aircraft sound level before the runway opening has, in addition to annoyance, a statistically significant effect on mental HQoL in the first year after the opening of the runway. It might be that the novelty of the changes at the airport in autumn 2011 has changed the salience of the air traffic and the aircraft noise exposure and its potential impact on residents' quality of life in the first year after the expansion. This is confirmed by the result that the residual changes in sound levels since 2011 have a statistically significant effect on mental HQoL, both in 2012 and 2013. In line with this, exposed residents might be concerned whether there is a need to re-adjust their behaviour to cope with aircraft noise, which, again, might have an impact on perceived mental HQoL, particularly depending on the perceived coping capacity. The correlations between coping capacity as assessed by judgments of six statements on a 5-point scale (Cronbach's alpha of mean score: .83 to .85 in the years 2011 to 2013) and mental HQoL, aircraft noise exposure and the residual changes in exposure confirms this interpretation (Table 8). Coping capacity is correlated with aircraft sound exposure ($L_{pAeq,24hrs}$), the residual change in $L_{pAeq,24hrs}$ since 2011 and mental HQoL.

Table 8: Correlation between MCS, coping capacity, $L_{pAeq,24hrs}$ for aircraft sound, change in $L_{pAeq,24hrs}$

Pearson's correlation r	**MCS 2013**	**Coping capacity 2012**	**Coping capacity 2013**	**$L_{pAeq,24hrs}$ 2012**	**$L_{pAeq,24hrs}$ 2013**	**Change in $L_{pAeq,24hrs}$ 2011 -> 12**	**Change in $L_{pAeq,24hrs}$ 2011 -> 13**
MCS 2012	.522	.306	.312	-.133	-.127	-.097	-.069
MCS 2013		.245	.301	-.098	-.102	-.103	-.096
Coping capacity 2012			.727	-.241	-.234	-.156	-.118
Coping capacity 2013				-.230	-.223	-.135	-.104
$L_{pAeq,24hrs}$ 2012					.965	.301	.226
$L_{pAeq,24hrs}$ 2013						.296	.396
Change in $L_{pAeq,24hrs}$ 2011 -> 2012							.749

$p < .001$ for all correlation coefficients

The relative strong effect of the residual change in sound levels since 2011 in particular on aircraft noise annoyance demonstrates the so-called 'change effect' in responses to changes in noise exposure [6]. In this study, the change effect could be observed not only for noise annoyance but also for mental HQoL.

All in all, this study has shown that the exposure to aircraft noise is relevant for mental HQoL, in particular when it comes to changes in noise exposure. The relationship of mental HQoL and noise exposure is complex, as annoyance as a mediator and other factors such as noise sensitivity (not discussed in this contribution) are involved and reciprocal associations between mental HQoL and noise responses (annoyance) could be identified. In this process the perceived coping capacity seems to play an important role. This has to be investigated in more detail in future research.

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