Effects of aircraft noise on annoyance and sleep disturbances before and after expansion of Frankfurt Airport – results of the NORAH study, WP 1 'Annoyance and quality of life'

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ABSTRACT

In October / November 2011 a new runway was opened at Frankfurt Airport and a night curfew from 11pm to 5am has been implemented. Within the project NORAH (Noise Related Annoyance, Cognition and Health) a longitudinal study on the impact of aircraft noise on annoyance and reported sleep disturbances before and after these changes had been carried out. The study included a survey with a stratified random address sample of residents living near the airport who were interviewed before the runway opening (2011) and in follow-ups in 2012 and 2013. Among others, the source-specific aircraft noise exposure in terms of $L_{p\mathrm{Aeq}}$ for different times of day were calculated for a 12-months-period for each address and each survey wave. 3508 of 9244 residents interviewed in 2011 took part in all 3 survey waves. Results show that the exposure-response curve for aircraft noise annoyance against the $L_{p\mathrm{Aeq,24h}}$ shifts after opening of the new runway depending on local changes in sound levels. Reported sleep disturbances were reduced after the introduction of the night curfew except with respect to disturbances while falling asleep or in the early morning. Several non-acoustical factors partly explain the changes in aircraft noise reactions.

Keywords: Aircraft Noise, Annoyance, Sleep disturbances, Change Effect, NORAH
I-INCE Classification of Subjects Number(s): 63.2, 63.4, 66.1, 66.2

1. INTRODUCTION

With about 487'000 movements, 56.4 million passengers and 2.2 million freight ton (year 2011) Frankfurt Airport is the largest airport in Germany. In the year 1997 Frankfurt Airport and the home carrier Deutsche Lufthansa requested an airport expansion including a new terminal and the construction of a 4th runway in order to be able to increase the capacity up to 120 – 126 movements per hour (about 83 – 86 before expansion). During the following years regional planning and zoning procedures were running with the final zoning decision in December 2007, allowing the construction of the 4th runway ('Runway Northwest'). In the same period a stakeholder dialogue process took place, including a mediation process (2000 – 2002), and was followed by the installation of dialogue forums (2000 – 2007 Regionales Dialogforum Flughafen Frankfurt, RDF, since 2008 Forum Flughafen und Region, FFR) on the decision of the Landtag (state parliament) of Hesse.

The new runway has been opened in October 2011 and implies the rerouting of flights. Part of the

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rerouting (downwind approaches) already started in March 2011. In November 2011 a night curfew from 11pm to 5am has been implemented, following eventually an agreement of the mediation group (2000 – 2002). In 2005, a socio-acoustical survey on the impact of aircraft noise on residents' annoyance and health-related quality (RDF study, 1), has been carried out by commission of RDF. Results of the RDF study showed a considerable shift in the exposure-response-relationship towards a higher percentage of annoyed people per unit of sound level (L_{den}, L_{dn}) as compared to generalized exposure-response curves for aircraft noise annoyance, e.g. by Miedema & Oudshoorn (2). Results of the RDF study revealed that, among others, expectations and fears concerning the future residential life after the expansion of the airport contributed to the explanation of aircraft noise annoyance and perceived health-related quality of life.

The opening of the new runway as well as the implementation of the night curfew means a step change in aircraft noise exposure for residents living in the vicinity of the airport. It is well known that step changes in transportation noise exposure lead to the so-called change effect in human responses to noise exposure. This is defined as "… an excess response to the new noise exposure over that predicted from steady-state exposure-response curves (which predict the exposure effect)" (3, p. 1). With regard to the categorization of environmental noise interventions by Brown and van Kamp (4) the new runway belongs to Type C interventions (new/closed infrastructure), whereas the night curfew is an intervention of Type A (source intervention, time restrictions on source operations).

Janssen & Guski distinguish between low-rate change and high-rate change airports and define high-rate change airports as those with a significant and permanent disruption of the typical trend of aircraft movements. The authors even classify an airport as a high-rate change airport before the step change occurs, "if there has been public discussion about operational plans within 3 years before and after the study" (5, p. 8). According to this definition Frankfurt Airport belongs to the high-rate change airports at the time of the study presented here.

There is evidence that the changes in aircraft noise exposure due to an airport expansion result in a change effect which is not an issue of short duration and can last up to two years (6-7). Whether the change effect is of even longer duration is unknown with regard to aircraft noise as up to now the authors do not know of longitudinal studies covering a longer period of time after the step change in aircraft noise exposure. For changes in noise exposure due to mitigation interventions the evidence for a change effect is mixed. At least, positive changes in terms of a decrement in exposure or respite from noise for respondents lead to a smaller change effect than an increment in noise exposure (3). However, this might depend on the way mitigation measures are implemented.

The expansion of Frankfurt Airport is associated with complex multiple configurations. According to operations predicted for the time after the opening of the new runway areas around the airport would be more exposed by aircraft noise, others less exposed and in other areas there would be no significant change in exposure, i.e. the change is less than or equal to ± 2 dB in $L_{p\mathrm{Aeq,24h}}$. In addition, the night curfew and other operational measures of noise control since 2011 tested at Frankfurt Airport contribute to multiple and in part opposing changes of the aircraft noise exposure in communities around the airport. Therefore, it is almost impossible to hypothesize about the extent and direction of the change effect in responses to aircraft noise after the opening of the new runway and the implementation of the night curfew.

A longitudinal study has been carried out before and after the introduced changes at Frankfurt Airport (new runway, ban on night flights) in order to (i) update exposure-response curves for aircraft noise annoyance as well as for reported sleep disturbance and (ii) to study the impact of the step changes in aircraft noise exposure on these responses to aircraft noise. In this paper, results of the analysis with regard to the change effect are exemplarily shown for aircraft noise annoyance. The study is part of workpackage 1 'Annoyance and quality of life' of the NORAH research program (8).

2. METHODS

2.1 Study design and sampling

The study entails a longitudinal survey design with measurements in 2011 (prior to the opening of the new runway Northwest) and repeated measurements in 2012 and 2013 (after the runway opening and the implementation of the night flight ban). The study region around Frankfurt Airport includes residential areas within the "envelope" of the 40 dB contours of the continuous aircraft sound levels for daytime ($L_{p\mathrm{Aeq,06\text{-}22h}}$) and night-time ($L_{p\mathrm{Aeq,22\text{-}06h}}$). Within this region a panel of residents was randomly sampled from the population registries in 2011 and was stratified by continuous aircraft sound level classes (2.5 dB classes of the maximum of $L_{p\text{Aeq},06\text{-}22\text{h}}$ and $L_{p\text{Aeq},22\text{-}06\text{h}}$) and by predicted change in aircraft noise exposure for 2020 in relation to the aircraft noise exposure in 2007 (increase in $L_{p\text{Aeq},24\text{h}}$ > 2 dB, decrease in $L_{p\text{Aeq},24\text{h}}$ > 2 dB, no change, i.e. change within the range of ± 2 dB). The sample was then linked to the contact information from the telephone registration 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 by using the German calculation model for aircraft noise exposure, AzB 2008 (9), and refer to the air traffic of the six busiest months of the year 2007. The sound levels predicted for the six busiest months in 2020 used for sampling are based on data modeled by means of the AzB 2008 on the occasion of the zoning procedure.

2.2 Procedure

The sampling of the panel group at Frankfurt Airport was done in the spring of 2011. A cover letter was sent to the sampled residents to inform about the study and invite them to participate in telephone interviews or optional online surveys with the same questionnaire. The first wave of interviews was carried out in summer and autumn of 2011 and finished before the opening of the runway Northwest on 21 October 2011. Repeated interviews were carried out in summer/autumn of 2012 and again in 2013.

Comparative cross-sectional surveys (not further reported here) had been carried out at the airports Berlin-Schoenefeld, Cologne/Bonn and Stuttgart. The sampling and data management was supervised and certified by the responsible agency for data protection.

2.3 Noise exposure

For the residential address of every participant the exposure to source-specific equivalent sound levels, as well as mean maximum sound levels of aircraft, railway and road traffic were calculated for the past 12 months of each survey wave for different times of day (12). For the assessment of aircraft sound levels the calculation method AzB 2008 (9) was used. The average sound levels of railway and road traffic were determined based on the methods for calculation (VBUSCH, VBUS) used for EU noise mapping (10, 11).

2.4 Questionnaire

The questionnaires used in the three survey waves include the assessment of responses to transportation noise (aircraft, railway, road traffic), such as annoyance and disturbances, variables of quality of life, potential moderator variables and co-determinants, variables concerning residential conditions (e.g sound insulation, window type and position) and demographics. The following variables assessed in the questionnaire were used in the analysis in the study described in this paper:

- Aircraft noise annoyance assessed with the ICBEN 5-point scale according to ISO/TS 15666 (13).
- Sleep disturbances assessed with three items which refer to aircraft noise-related disturbances when falling asleep, when sleeping during the night and in the early morning. A 5-point response scale similar to the ICBEN scale was used. The responses to these three items were summarized to a mean score of reported sleep disturbances (Cronbach's alpha t1 (2011) = .91, t2 (2012) = .85, t3 (2013) = .84.
- Self-reported noise sensitivity (1 item) assessed on a 4-point scale ((0: strongly disagree, 1: slightly disagree, 2: slightly agree, 3: strongly agree).
- Coping capacity/perceived control assessed with judgments of six statements on a 5-point scale (agree (1) not to (5) strongly). A mean score of the responses to the six items were calculated (Cronbach's alpha: t1 = .83, t2 = .85, t3 = .84).
- Attitudes towards air traffic: Four items with regard to evaluation of air traffic as useful, comfortable, dangerous, and harmful to the environment (5-point scale: (1) not to (5) very).
- Positive expectations concerning the impact of air traffic at Frankfurt airport on the economic development of the region and the individual (residential) quality of life. Judgments of four items on a 5-point scale (agree (1) not to (5) strongly) were summarized to the mean score 'positive expectations' (Cronbach's alpha: t1 = .71, t2 = .74, t3 = .74).
- Demographics: Age, gender, migration background, period of residence, house ownership, socio-economic status.
- Mode of survey: telephone interview vs. online survey.

2.5 Statistical analysis

Exposure-response relationships for highly aircraft noise annoyed people (%HA) and highly sleep disturbed people (%HSD) were analyzed for each year of measurement by means of multiple logistic regressions with $L_{p\mathrm{Aeq,06\text{-}22h}}$ (for %HA) and $L_{p\mathrm{Aeq,22\text{-}06h}}$ (for %HSD), respectively, as acoustical parameters of aircraft noise exposure. The two upper categories of the annoyance scale (very, extremely), i.e. cut-off point = 60% of the response scale, was used to define %HA according to the ICBEN recommendations (14). For %HSD the same cut-off value was used for definition. Noise sensitivity, the judgments of air traffic as useful, comfortable, and environmentally harmful, the demographic variables, the mode of survey, the average road traffic and railway sound levels as well as the interaction between age and mode of survey (because younger participants more often used the online mode than older ones) were included for adjustment.

In order to assess the change effect at Frankfurt from 2011 (prior to the step changes in aircraft noise exposure) to 2013 (after the changes) and to identify factors explaining the effect, Latent Growth Curve Models (LGCM, 15) were used for analysis. The LGCM allows to model a multifactorial change process within a sample as well as individual changes over time. Two aspects are relevant in LGCM: (1) the latent intercept of the dependent variable, in this paper, the initial value in aircraft noise annoyance in 2011 and the factors contributing to it and (2) the latent slope, i.e. the change in the dependent variable, here, aircraft noise annoyance in 2012 and 2013, respectively, and the factors explaining the change. The following variables as ascertained in all survey waves, 2011 (t1), 2012 (t2), and 2013 (t3) were included as indicators: average aircraft sound levels ($L_{p\mathrm{Aeq,24h}}$), noise sensitivity, coping capacity, the items addressing the attitudes towards air traffic, positive expectations concerning the impact of the air traffic, demographics as described in section 2.4, the interaction of survey mode with age and with the evaluation of air traffic as dangerous and the average sound levels of road traffic and railway traffic.

For each group of participants experiencing either an increase, a decrease or no change above ± 2 dB in $L_{p\mathrm{Aeq,24h}}$, four LGCM were estimated: (1) a base model without growth, (2) a model with linear growth, (3) a model with curvilinear growth, and (4) a final adjusted model (either linear or curvilinear depending on the goodness of fit of model 2 or 3) including selected indicators of model 2 or 3 (indicators with $p < .20$) to avoid overfitting. For all LGCM for aircraft noise annoyance model 3 (curvilinear growth) provides a better fit to the data and was therefore selected for the adjusted final model.

All final models (exposure-response models, LGCM) included bootstrapping (16) with 5000 'bootstrap'-samples in order to assess the robustness of the models.

3. RESULTS

3.1 Sample and aircraft noise exposure

A sample of 9244 participants took part in the first survey wave in 2011. This is 17% of the total number of available telephone numbers and 7% of those persons invited by letter to participate. A non-responder-analysis, several sensitivity analyses and the bootstrapping applicated for the exposure-response models indicate the robustness of the results (see 8 for more details).

In 2012 4867 of the 9244 participants took part in the repeated measurement and in 2013 the number of remaining participants was 3508. Comparisons of exposure-response curves with the total sample sizes in 2011 and 2012 and with the 3508 participants taking part in all survey waves revealed no significant differences. Therefore, the analyses described in the following were done with the 3508 persons participating in all survey waves. 54% of them were female, age ranged from 18 to 96 years (mean: 53 years).

In 2011, the average aircraft sound levels for 24 hours $L_{p\mathrm{Aeq,24h}}$ ranged from 36 to 61 dB, mean (M) was 48 dB. In 2012, $L_{p\mathrm{Aeq,24h}}$ ranged from 35 to 60 dB (M = 48 dB), in 2013, from ≤ 35 to 60 dB (M = 47 dB). The sound levels for daytime $L_{p\mathrm{Aeq,06\text{-}22h}}$ ranged from 37 dB to 62 dB in 2011 (M = 50 dB), to 61 dB in 2012 (M = 49 dB), and from 36 dB to 62 dB in 2013 (M = 49 dB). With regard to aircraft noise at night-time, $L_{p\mathrm{Aeq,22\text{-}06h}}$ levels ranged from ≤ 35 to 57 dB in 2011 (M = 42 dB) and to 55 dB (M = 42 dB) in 2012 and 2013, respectively. In all cases the standard deviation (SD) of average sound levels was 6 dB.

517 persons (15%) experienced a decrease in aircraft sound levels of more than 2 dB $L_{p\mathrm{Aeq,24h}}$ in 2012 compared to 2011, 2592 participants (74%) had no change in sound levels above ± 2dB and 399 respondents (11%) experienced an increase of more than 2 dB.

With regard to the average sound levels for night-time ($L_{p\mathrm{Aeq,22\text{-}06h}}$) these were 633 persons (18%)

experiencing a decrease in aircraft sound levels of more than 2 dB, 2617 participants (75%) without a change in sound levels above ± 2dB and 258 persons (7%) with an increase of more than 2 dB.

3.2 Percentage of highly annoyed and sleep disturbed people

The average sound levels for daytime and night-time are consistently associated with aircraft noise annoyance and self-reported sleep disturbances, although, for sleep disturbances correlation coefficients are somewhat lower in 2012 and 2013 after implementation of the night flight ban from 11pm to 5am as compared to the coefficients in 2011. For the respondents taking part in all survey waves $L_{p\mathrm{Aeq},06\text{-}22\mathrm{h}}$ correlates with aircraft noise annoyance with r = .48 in 2011 and r = .47 in 2012 and 2013. $L_{p\mathrm{Aeq},22\text{-}06}$ correlates with self-reported sleep disturbances with r = .41 in 2011 and r = .36 in 2012 and 2013 (for all correlation coefficients p < .001).

Figure 1 shows the percentage of highly annoyed people (%HA) in 2011 prior to the opening of the runway Northwest and in the first (2012) and second year (2013) after. There is a shift in %HA in 2012 compared to 2011, in particular below 55 dB $L_{p\mathrm{Aeq},06\text{-}22\mathrm{h}}$. The %HA-curve in 2013 lies in between the curves from 2012 and 2011. However, the main difference can be seen in comparison of results of the RDF study at Frankfurt Airport in 2005 (1). For comparison, the $L_{p\mathrm{Aeq},06\text{-}22\mathrm{h}}$ values in the RDF study were re-calculated using the calculation method AzB 2008 and radar track information (STANLY) as input data. %HA was re-defined similar to the definition used in the NORAH study (cut-off = 60%).

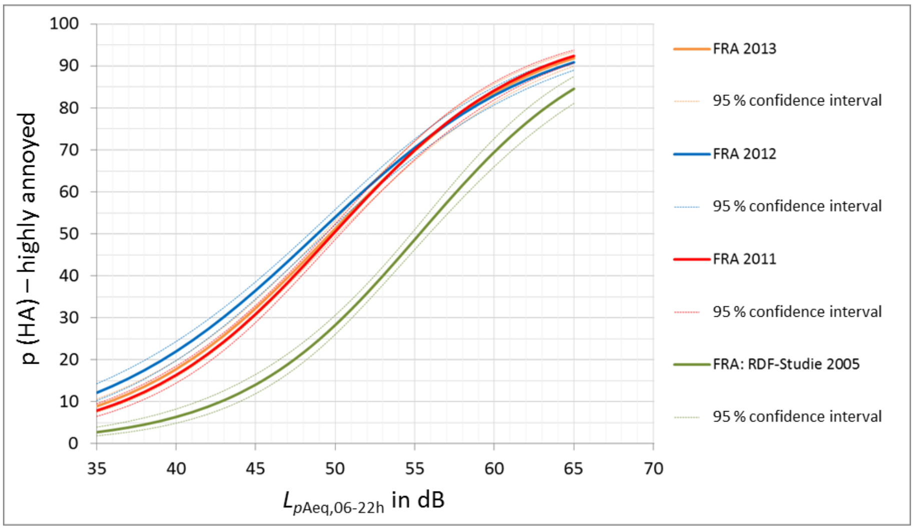

Figure 1 – Percentage of highly annoyed people (%HA) by $L_{p\mathrm{Aeq},06\text{-}22\mathrm{h}}$ in the NORAH study (2011 – 2013) compared to results of the RDF study 2005 (1).

As Figure 2 indicates the percentage of highly sleep disturbed people (%HSD) was considerably decreased after implementation of the night curfew from 11pm to 5am in 2012 and 2013 as compared to %HSD in 2011. Note, that the $L_{p\mathrm{Aeq},22\text{-}06\mathrm{h}}$ values in 2012 and 2013 mainly refer to aircraft sound events in the shoulder hours 10-11pm and 5-6am. However, the shift down of the exposure-response curve for %HSD is in particular true for sleep disturbances during the night. The exposure-response curves for the degree of sleep disturbances when falling asleep is quite similar before and after implementation of the night curfew, whereas for the same average sound level for night-time the sleep disturbances are lower in 2012 and 2013 as compared to sleep disturbances in 2011.

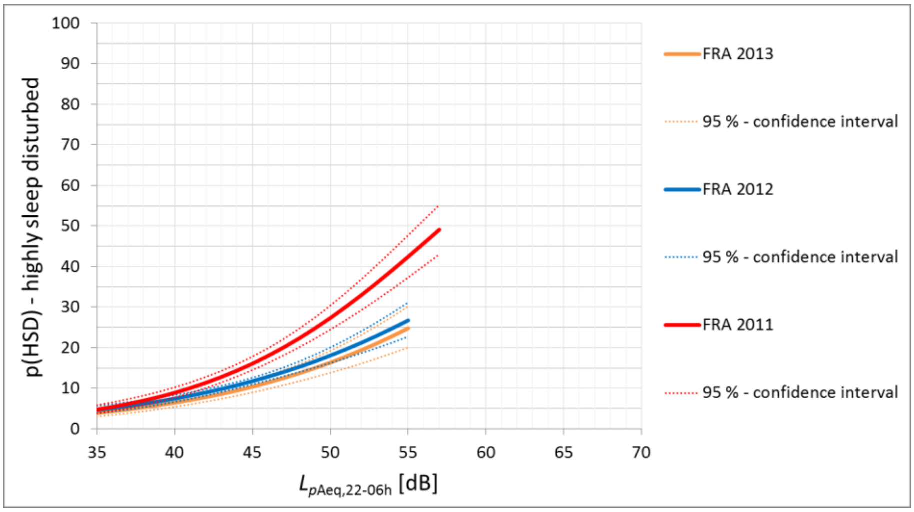

Figure 2 – Percentage of highly sleep disturbed people (%HSD) by $L_{pAeq,22\text{-}06h}$ in 2011, 2012, and 2013

3.3 Estimation of the change effect on aircraft noise annoyance

Table 1 shows the results of the LGCM analysis on the change in aircraft noise annoyance before (2011) and after (2012, 2013) the step changes at Frankfurt Airport. The exposure-response relations for aircraft noise annoyance in the three years 2011 to 2013 is presented in Figure 3. Beside the base exposure-response model for 2011 the figure shows the expected annoyance for 2012 and 2013 derived from cross-sectional regression analysis with regression coefficients of the base model 2011 and predictor values of 2012 and 2013, respectively. Furthermore, the 'occurred' annoyance in 2012 and 2013 was estimated using regression coefficients and predictor values of 2012 and 2013, respectively. The discrepancy between the exposure-response relationship for the expected and the 'occurred' aircraft noise annoyance in 2012 and 2013, respectively, can be interpreted as the change effect.

In the change group *'Reduction of aircraft noise exposure'* aircraft noise annoyance in 2011 is explained by the aircraft sound level. In addition, railway sound level, survey mode, coping capability, positive expectations and the judgment of air traffic as environmentally harmful are associated with aircraft noise annoyance in 2011. Participants interviewed by telephone reported higher noise annoyance than online participants. Railway sound level is somewhat negatively associated with aircraft noise annoyance. Higher coping capacity, positive expectations concerning air traffic and lower degree of evaluation of air traffic as harmful to the environment are positively associated with the annoyance in 2011. Changes in aircraft noise annoyance in 2012 and 2013 after opening of the new runway are predicted by aircraft sound levels, coping capability, air traffic-related expectations and the judgment of air traffic as dangerous. Figure 3 shows that in the group 'Reduction in aircraft noise exposure' aircraft noise annoyance has been decreased in 2012 and 2013 as compared to 2011.

In the change group *'Stable aircraft noise exposure'* the aircraft noise annoyance in 2011 is explained by the $L_{pAeq,24h}$ for aircraft, house ownership and noise sensitivity. That is, house owners reported higher noise annoyance than tenants, sound level and noise sensitivity are positively associated with annoyance. Depending on the initial annoyance value in 2011 on average the group shows a decrease in aircraft noise annoyance after the opening of the runway Northwest until 2013. In 2012 the annoyance moves up and in 2013, again, down. The change over time is higher for participants with lower initial aircraft noise annoyance in 2011 (see Figure 3). Beside the aircraft sound levels, particularly coping capacity and positive expectations concerning the air traffic contribute to the explanation of the change in annoyance.

In the change group *'Increase in aircraft noise exposure'* the factors $L_{pAeq,24h}$ for aircraft and for railway, house ownership, coping capability, positive expectations concerning air traffic, and the judgment of air traffic as environmentally harmful contribute significantly to the prediction of aircraft noise annoyance in 2011. The change in aircraft noise annoyance over time is not explained by changes in the average aircraft sound level $L_{pAeq,24h}$, in the group experiencing an increase in aircraft noise exposure in 2012 and 2013 after the opening of runway Northwest. Instead, annoyance changes are predicted by coping capacity, positive expectations concerning air traffic and judgments of airport as dangerous and environmentally harmful and the interaction between survey mode and the judgment of air traffic as dangerous in 2011. In 2012 the exposure-response relation for aircraft noise annoyance moves up and moves down again in 2013, but is still higher as compared to 2011. The discrepancy between expected and occurred annoyance in 2012 and 2013 is higher in the lower band of sound levels below 55 dB $L_{p\mathrm{Aeq,24h}}$ (up to 0.70 points of the response scale) than above (about 0.15 points of the response scale).

Table 1: Results of the LGCMs for changes in aircraft noise annoyance 2011, 2012, 2013

Variables	Groups of change in aircraft noise exposure ($L_{p\mathrm{Aeq,24h}}$)					
	Decrease > 2 dB		Stable ± 2 dB		Increase > 2 dB	
	B (SE)	p	B (SE)	p	B (SE)	p
Intercept						
2011 Air ($L_{p\mathrm{Aeq,24h}}$)	.068 (.007)	< .001	.077 (.003)	< .001	.068 (.013)	< .001
2011 Road ($L_{p\mathrm{Aeq,24h}}$)	.000 (.005)	.995	-.005 (.002)	.038	-.008 (.006)	.223
2011 Rail ($L_{p\mathrm{Aeq,24h}}$)	-.014 (.007)	.046	-.006 (.003)	.016	-.019 (.007)	.009
2011 Age			.052 (.016)	.001		
2011 Age²					-.028 (.033)	.391
2011 Socio-economic status	.055 (.036)	.127			-.015 (.040)	.700
2011 Migration	-.047 (.039)	.226	-.041 (.015)	.005		
2011 Period of residence	.043 (.034)	.210	.112 (.021)	< .001		
2011 House ownership					.101 (.037)	.007
2011 Survey mode	.085 (.033)	.010	.112 (.021)	< .001	.055 (.033)	.098
2011 Noise sensitivity			.084 (.022)	< .001		
2011 Coping capability	-.450 (.054)	< .001	-.337 (.025)	< .001	-.368 (.070)	< .001
2011 Positive expectations air traffic	-.354 (.061)	< .001	-.318 (.027)	< .001	-.381 (.073)	< .001
2011 Air traffic useful			-.012 (.018)	.526	.052 (.041)	.201
2011 Air traffic dangerous (rec.)			-.098 (.022)	< .001	-.109 (.063)	.085
2011 Air traffic comfortable			.016 (.016)	.323		
2011 Air traffic environm. harmful (rec.)	-.155 (.045)	.001	-.039 (.023)	.084	-.129 (.062)	.039
Slope *M_{Slope} / p*	*-0,317*	*<.001*	*-0,058*	*<.001*	*0,714*	*<.001*
2011 Air ($L_{p\mathrm{Aeq,24h}}$)	-.155 (.041)	< .001	-.076 (.009)	< .001	-.251 (.163)	.123
2012 Air ($L_{p\mathrm{Aeq,24h}}$)	.104 (.048)	.029	.029 (.009)	.002	.304 (.348)	.384
2013 Air ($L_{p\mathrm{Aeq,24h}}$)	.028 (.026)	.290	.038 (.005)	< .001	-.248 (.310)	.425
2011 Road ($L_{p\mathrm{Aeq,24h}}$)	-.007 (.005)	.160	.001 (.001)	.688	.068 (.058)	.239
2011 Rail ($L_{p\mathrm{Aeq,24h}}$)	.012 (.007)	.098	.000 (.001)	.899	.071 (.077)	.362
Gender	-.053 (.032)	.097			.093 (.048)	.055
2013 Socio-economic status	-.052 (.037)	.163	.008 (.008)	.322		
2011 Survey mode			-.029 (.011)	.009		
Migration	.055 (.043)	.198				
2012 House ownership	-.056 (.033)	.091				
2011 Noise sensitivity			-.037 (.012)	.003	-.043 (.034)	.198
2012 Noise sensitivity			.008 (.003)	.008		

Variables	Groups of change in aircraft noise exposure ($L_{pAeq,24h}$)					
	Decrease > 2 dB		Stable ± 2 dB		Increase > 2 dB	
	B (SE)	p	B (SE)	p	B (SE)	p
2013 Noise sensitivity					-.042 (.022)	.058
2011 Coping capability	.319 (.057)	< .001	.152 (.016)	< .001	.661 (.163)	< .001
2012 Coping capability	-.159 (.053)	.003	-.081 (.014)	< .001	-.416 (.118)	< .001
2013 Coping capability	-.114 (.046)	.014	-.134 (.015)	< .001	-.488 (.124)	< .001
2011 Positive expectations air traffic	.273 (.075)	< .001	.123 (.017)	< .001	.305 (.115)	.008
2012 Positive expectations air traffic	-.156 (.056)	.005	-.024 (.017)	.159	-.435 (.126)	< .001
2013 Positive expectations air traffic	-.188 (.053)	< .001	-.126 (.016)	< .001		
2011 Air traffic comfortable	.059 (.034)	.082				
2011 Air traffic dangerous (rec.)			.047 (.013)	< .001	.153 (.092)	.095
2012 Air traffic dangerous (rec.)			-.034 (.011)	.001	.141 (.072)	.052
2013 Air traffic dangerous (rec.)	-.081 (.040)	.043	-.053 (.011)	< .001	-.146 (.065)	.025
2011 Air traffic environm. harmful (rec.)	.081 (.047)	.088	.023 (.013)	.078	.146 (.073)	.046
2012 Air traffic environm. harmful (rec.)			-.026 (.011)	.015		
2012 Air traffic useful			.023 (.010)	.019	.116 (.052)	.027
Surv. mode * Air tr. dangerous (rec.) 2011					.140 (.064)	.028
Surv. mode * Air tr. dangerous (rec.) 2012					-.060 (.060)	.312
Surv. mode * Air tr. dangerous (rec.) 2013					.056 (.044)	.202

rec. = item recoded (inverted) in order to get a positive orientation of all response scores addressing the attitudes towards air traffic

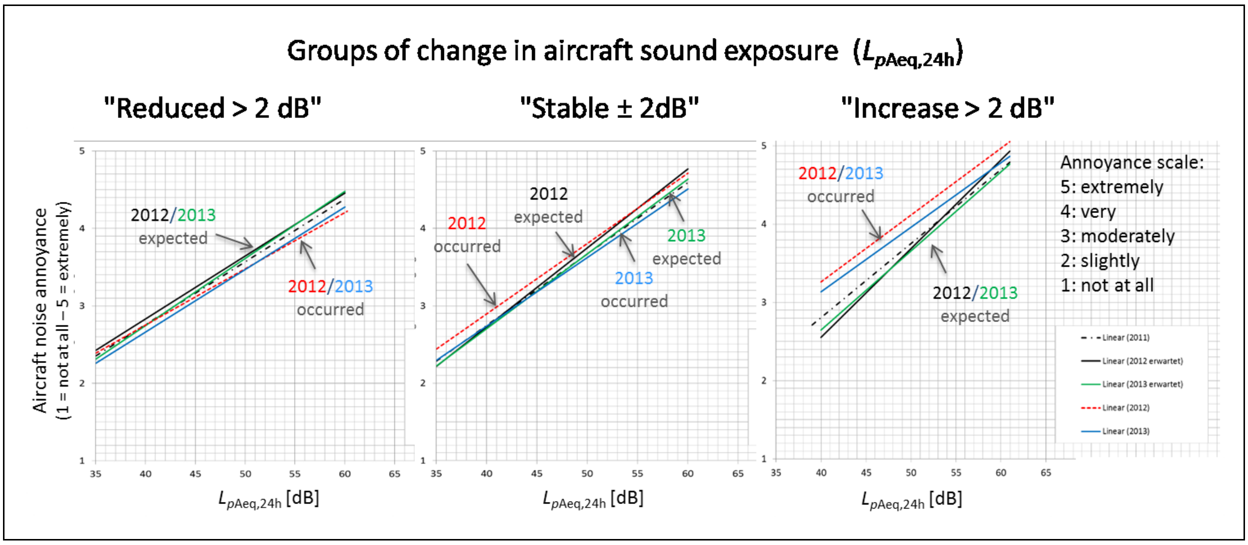

Figure 3 – Exposure-response estimations for aircraft noise annoyance at Frankfurt Airport before (2011) and after (2012/2013) the opening of runway Northwest in different groups of change in $L_{pAeq,24h}$.

3.4 Change effect for self-reported sleep disturbances

A change effect also occurred for self-reported sleep disturbances due to aircraft noise. It turns out that in 2012 and 2013, after implementation of the night flight ban (in November 2011), the sleep disturbances in participants experiencing a decrease or no change in aircraft sound levels at night-time above 2 dB was lower than expected. In particular, the $L_{p\mathrm{Aeq,22\text{-}06h}}$ for aircraft, age, noise sensitivity, coping capacity, positive expectations concerning the air traffic, and the evaluation of air traffic as dangerous contributed to the explanation of the change effect in sleep disturbances.

All in all, for participants experiencing an increase in aircraft noise exposure at night-time in 2012 as compared to 2011 no statistically significant change effect was found for participants' self-reported sleep disturbances (see 8 for more details).

4. CONCLUSIONS

A longitudinal study was carried out at Frankfurt Airport in order to assess the impact of aircraft noise on annoyance and sleep disturbances prior to the opening of the new runway Northwest in October 2011 and to the implementation of a night flight ban from 11pm to 5am in November 2011 and after that in 2012 and 2013. A total of 3508 residents took part in all repeated measurements in 2011, 2012, and 2013. Telephone interviews (optional online surveys) were carried out and for the address of each participant sound levels of aircraft, railway and road traffic were calculated for the past 12 months of each survey wave for different times of day.

The study revealed a change effect in aircraft noise annoyance and self-reported sleep disturbances due to aircraft noise, i.e. an excess response to the new aircraft sound levels in 2012 and 2013 over that predicted from the exposure-response curves obtained in 2011 and over the expected curves in 2012 and 2013 as estimated in cross-sectional regression analysis. The change effect followed the direction of the local change in aircraft sound levels. For aircraft noise annoyance the change effect was stronger (i) in lower bands of $L_{p\mathrm{Aeq,24h}}$, (ii) for participants experiencing an increase in aircraft noise exposure in 2012 as compared to 2011, and (iii) in 2012 than one year later in 2013. With regard to self-reported sleep disturbances before and after the implementation of the night curfew the change effect occurred in the groups of participants experiencing a reduction and no change above 2 dB $L_{p\mathrm{Aeq,22\text{-}06h}}$. In the group of respondents experiencing an increase in sound levels at night-time the change in sleep disturbances was statistically not significant.

Both, the change in aircraft sound levels as well as non-acoustical factors contributed to the change effect. In the group of participants experiencing an increase in $L_{p\mathrm{Aeq,24h}}$ after opening of the new runway only the non-acoustical factors contributed to the change effect in aircraft noise annoyance. In particular, those non-acoustical factors turned out to be relevant for the prediction of (the change in) annoyance and sleep disturbances that according to environmental stress-related models (e.g. 17, 18) are supposed to contribute to resources of human beings to cope with noise, i.e. perceived coping capacity/control, attitudes, expectations addressing the noise source, and noise sensitivity.

The study also showed that %HA in all measurements from 2011 to 2013 was considerably higher as compared to %HA in the RDF study carried out at Frankfurt Airport in 2005. This might indicate that the change effect in noise responses due to the expansion of Frankfurt Airport started earlier to 2011 after the announcement of the expansion in 1997 during the following years of debates and regional planning and zoning procedure. On the other hand, the exposure-response curves for %HA at the other airports included in the NORAH study (not presented in this paper) are also higher in comparison to the RDF curve and, thus, higher than the generalized curves of Miedema & Oudshoorn (2). This is in line with results of a recent review on environmental noise annoyance carried out for WHO (19). The review shows evidence that beside annoyance differences between studies at high-rate and low-rate change airports there seem to be a general shift in exposure-response curves for %HA related to average sound level over time even at low-rate change (steady-state) airports.

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