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# Effects of Aircraft Noise on Noise Annoyance and Quality of Life around Frankfurt Airport

*Final abbridged report*

**Effects of Aircraft Noise on Noise Annoyance and Quality of Life around Frankfurt Airport**

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# 1. Introduction

The Evaluation of Aircraft Noise Annoyance in the Frankfurt Airport Region as contracted by the Regional Dialogue Forum (RDF) includes:

1. Registering annoyance caused by air traffic in the Rhine-Main region while additionally collecting information on life satisfaction and health-related quality of life.
2. Measuring the extensity of aircraft noise annoyance at various times of day and night depending on the objective air traffic noise exposure.

The first task in this evaluation was realized by conducting a large survey with 2312 participants from Rhine-Main residential areas within the vicinity of the Frankfurt Airport. Using a multi-level and layered random sampling method, selected residents were surveyed in a 45-minute face-to-face interview on issues such as quality of life, residential quality, impairments due to various noise sources as well as expectations regarding Frankfurt Airport’s extension.

In statistical analyses, the survey data was compared with aircraft noise exposure levels referring to individual addresses. Further, acoustic parameters for street and railway traffic noise were determined for each address and used to investigate noise effects in a more controlled manner. Data collection was conducted from April until December 2005.

The second task, determining noise annoyance at various times of day, was initially realized in the interview survey by registering annoyance due to aircraft noise during specified hours of the day. Within a secondary study, 200 participants from the survey panel recorded their current annoyance every hour from 7:00 – 23:00 on four successive days by means of a handheld computer (‘experience sampling study’).

In addition, these participants filled out subsidiary questionnaires every morning and evening, answering items on sleep and course of daily events. Annoyance data gathered in the initial interview survey and in the secondary study was compared with air traffic noise parameters from the respective interview time frame. The secondary study was conducted on eight different four-day blocks between August and November 2005.

# 2. Results

## 2.1 Annoyance and Disturbance due to Aircraft Noise

Compared with populations from Hesse and the entire Republic of Germany, people residing in the Rhine-Main area express higher noise annoyance. The latter is significantly determined by aircraft noise. Among acoustic measures describing air traffic noise ($L_{max}$, $NAT_{70}$, $L_{eq3}$), the $L_{eq3}$ shows the closest connection to annoyance and disturbance judgements. In the data collected in this evaluation, however, there is only a marginal difference between estimation measures of long term aircraft noise exposure (Real Noise Distribution, 100/100 Rule) when investigating the relationship between noise level and annoyance.

For the 100/100 Rule, an envelope is calculated from noise data derived from east and west operation during the six months with the highest flying frequency. In Frankfurt, this time frame usually constitutes the months of May until October. Therefore, the mean worst case from the east and the west noise situation is represented independent of the frequency of occurrence. In the Real Noise Distribution, the mean frequency distribution, determined with the six most congested months of the year on a long-term basis (in 2005 67% West and 33% East in a 24h day), is used in noise parameter calculation. This procedure is in accordance with the *AzB* ("Instructions for Measuring Aircraft Noise") and international regulations. Aircraft noise levels measured with this procedure describe the mean noise exposure while including the flight distribution in the time of reference.

Dose-response relationships for total as well as day and night annoyance due to aircraft noise are presented in Figure 1. Noise annoyance by air traffic noise (altogether) is measured using the verbal 5-point scale and the numerical 11-point scale suggested by the International Commission on Biological Effects of Noise (ICBEN; s. Fields et al., 2001). Further noise annoyance judgements (due to air traffic noise day, night, per hour; other noise sources) are measured with the verbal 5-point scale. The total mean annoyance by aircraft noise is somewhat higher than nighttime annoyance, which in turn lies above 16h daytime annoyance.

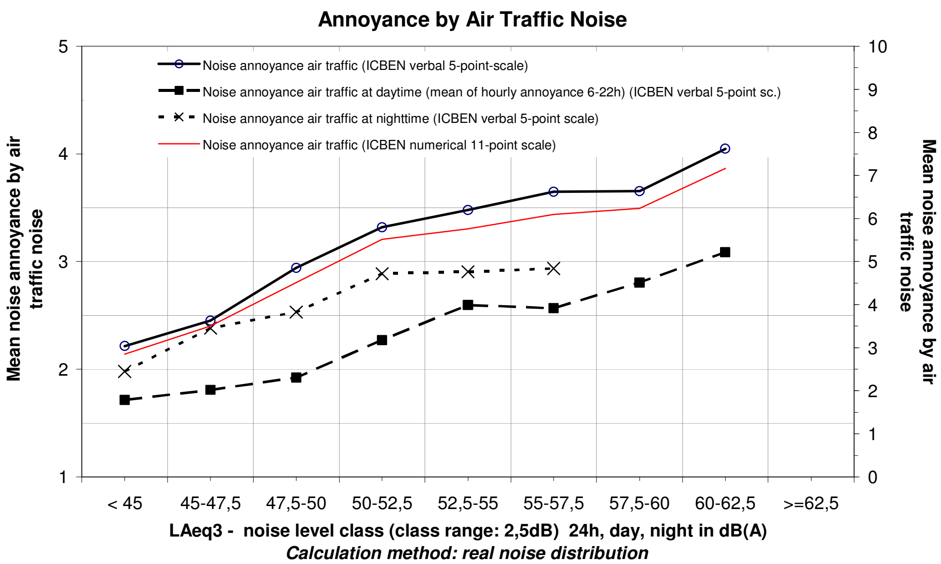


*Figure 1: Noise annoyance by air traffic noise altogether (5-point, 11-point scale), day and night (both 5-point scale) for different noise level classes (n= 2309)*

The current dose-response relationships for noise annoyance by aircraft noise determined in this study harmonize with results from similar European studies, as revealed in Figure 2. In order to obtain annoyance measures for different studies that are comparable, the response categories of the judgements on total annoyance by aircraft noise (numerical 11-point scale) were translated into a scale of 0 to 100. This translation is based on the assumption that a set of annoyance categories divides the range of 0 to 100 in equally spaced intervals. The general rule that gives the position of an inner category boundary on the scale from 0 to 100 is: scoreboundary i = 100i/m. Here it is the rank number of the category boundary, starting from 1 for the upper boundary of the lowest annoyance category, and m is the number of categories. The distribution of the annoyance scores in a population exposed to a given noise level is summarised by choosing a cut-off point on the scale of 0 to 100, and determining the percentage of the responses exceeding the cut-off. If the cut-off is 72 (as used in this study) on a scale of 0 to 100, then the result is called the percentage 'highly annoyed' persons (s. also Miedema & Vos, 1998).

Figure 2 shows data of the percentage of high noise annoyance by aircraft noise (%HA) obtained in this study in comparison to results from 11 similar studies. The figure with exposure-response data of the 11 studies is part of a review of 28 studies on aircraft noise annoyance conducted by van Kempen and van Kamp (2005, p. 25, Fig. 3b). All studies compared in this figure use a cut-off point of 70-75 on a transformed scale 0-100 as a definition of %HA.

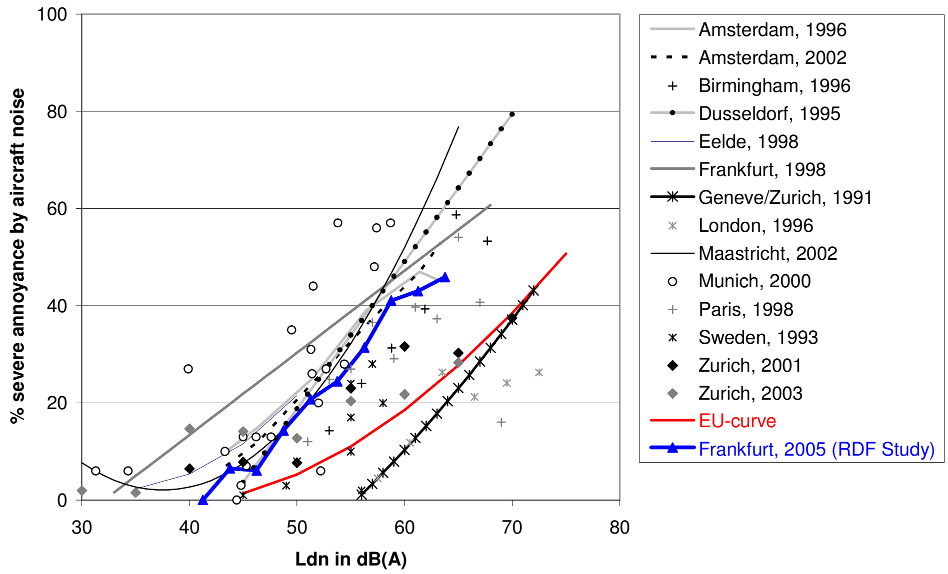


*Figure 2: Severe annoyance by aircraft noise. Results from different international studies*

Source: van Kempen, und van Kamp (2005, p. 25, Fig. 3b), modified by supplementing data of the Swiss Noise Study 2000 (Brink et al. 2005) and the current RDF Study (blue line).

The %HA estimate for the RDF study is well above the curve presented in the EU Position Paper on noise annoyance ("EU-curve"; EC/WG2, 2002). Nevertheless the RDF data do not indicate any extreme conditions in the Rhine-Main areas in terms of noise annoyance. Besides annoyance data collected in Swiss (Geneva/Zurich, 1991) and British (London-Heathrow, 1996) studies, all other data gathered lies above the EU-curve. Furthermore, new data from the Swiss Noise Study 2000 (Brink et al. 2005, Wirth, 2004) on the percentage of highly annoyance due to aircraft noise confirm the results on the extensity of aircraft noise annoyance found in this study. The EU-curve, however, refers to data collected from 1965 – 1992; the mean age in the generalized curve is 14 years (in 2006). The fact that air traffic has changed considerably since then may be one of the main reasons for a shift in the percentage of annoyed persons in reference to the generalized curve.

Often, in noise effect expertise the noise level associated with 25% to 30% highly annoyance in the population is seen as a limit value for acceptable noise exposure. In this study at least 25% of the residents are altogether highly annoyed by aircraft noise if aircraft noise level $L_{Aeq3,24h}$ exceeds 50 dB(A)[1] and $L_{dn}/L_{den}$ exceeds 54 dB(A), respectively. At least 25% of the residents are highly annoyed at daytime if $L_{Aeq3,\ 6\text{-}22h}$ exceeds 57,5 – 60dB(A) and highly annoyed at nighttime if $L_{Aeq3,\ 22\text{-}6h}$ lies above the aircraft noise level class 55-57,5 dB(A).

As expected, aircraft noise at daytime disturbs activities outside the home the most, i.e. outdoor communication and recreation. There are no differences between the disturbance of communication and recreation by aircraft noise indoor and also outside the house. As can be seen in Figure 3, the degree of noise annoyance is almost equivalent to the degree of disturbances by aircraft noise outside the house.

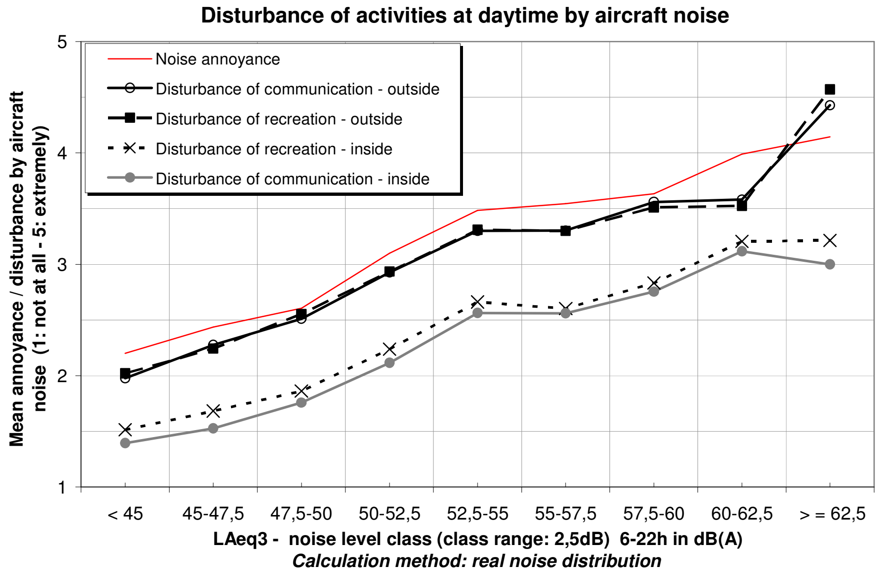


*Figure 3: Disturbance of activities by aircraft noise in dependence of daytime noise level classes ($L_{Aeq3,\ 6\text{-}22h}$)*

Besides noise level, non-acoustical factors are associated with current aircraft noise annoyance: e.g. individual noise sensitivity (Pearson correlation r= .324), trust in authorities responsible for noise level reduction (r= -.307), expected changes in residential situation due to airport extension[2]

[1] Estimation measure: real noise distribution

[2] Planned construction of a fourth runway in the north-west area of Frankfurt Airport

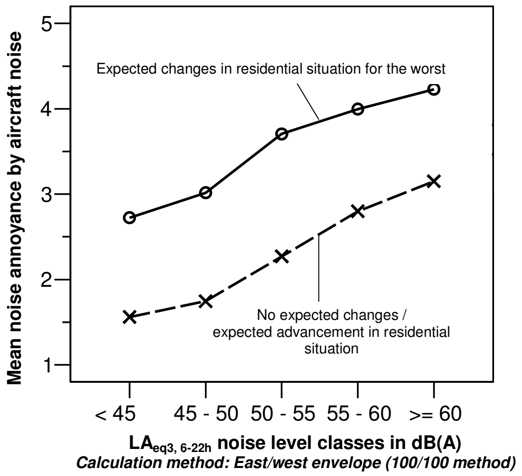


*Figure 4: Actual noise annoyance by noise level ($L_{Aeq, 6\text{-}22h}$) and expected changes in residential situation after the airport extension (2-factorial ANOVA: $F_{expection}$= 571.1; p< .000, $\eta_p^2$= .232)*

In addition, situative aspects such as airing behaviour are associated with annoyance by aircraft noise. People with normally closed windows at nighttime in warm seasons are more sensitive to noise and report less health-related quality of life as well as more annoyance by aircraft noise than residents with normally tilted or open windows. On the other hand acute annoyance as measured on an hourly basis is higher when windows are tilted or opened rather than closed. These results indicate that closing the window at nighttime on warm days seem to be partly a consequence of (higher) noise annoyance whereas acute noise annoyance indoor assessed in real-time can be seen as a result of noise exposure in conjunction with the acute window position.

Although to a smaller extent, noise annoyance also varies depending on particular socio-demographic factors such as age (middle-aged adults are more annoyed than younger and older persons), sex (women are slightly more annoyed than men) and social status (the upper-class is more annoyed than the middle- and lower-classes). When the interaction between different noise sources is observed, the total annoyance due to noise is apparently dominated by aircraft noise. Other additional noise sources hardly have an effect on the total annoyance and the specific annoyance due to air traffic noise.

## 2.2 Annoyance During the Course of the Day

In order to investigate how annoyance varies during the course of the day and if certain times of the day evoke greater annoyance, participants in the retrospective interview were asked to make annoyance judgments between 5:00 – 23:00. They were requested to evaluate their general annoyance due to noise during every hour, thus creating a *generalized* annoyance profile.

According to the interviewees, for equal noise level there is higher annoyance due to aircraft noise in the early morning (5:00-6:00) than in the morning hours afterwards. In the afternoon (from 15:00-16:00) aircraft noise annoyance again starts to increase while steadily climbing until the evening margin at 22:00-23:00. This finding holds for constant noise levels and applies to both weekdays and weekends. On weekends, the course of annoyance is smoother, since annoyance judgments for daytime hours are higher than during weekdays. According to the data of the supplementing secondary study, the increase in annoyance between 15:00 and 18:00 can be explained by an increase in the frequency of staying outside the house in line with higher noise exposure (in comparison to indoor aircraft noise level). The raised noise annoyance in the evening and night may refer to a higher demand of tranquillity at these times of day.

Assessing the daily profile of *acute* aircraft noise annoyance is an essential part of the secondary study (experience sampling study; ESS). Registered judgments on hourly annoyance from 7:00 – 23:00 as well as summarized reports on nighttime disturbances due to aircraft noise refer to acute impairments perceived by participants over a course of four successive days (acute annoyance profile) – see Figure 5. In general, the findings on acute annoyance during the course of the day confirm the results of the generalized annoyance profile. Figure 5 indicates higher annoyance at the border hours of daytime and nighttime (7:00-8:00 and late in the evening after 22:00) and a further increase in annoyance in the afternoon, likely due to an increase in the frequency of outdoor.

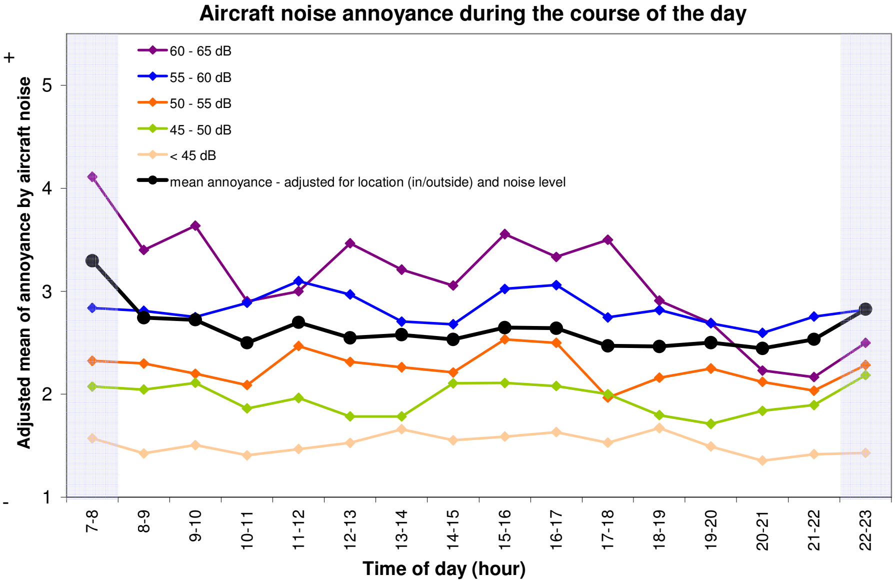


*Figure 5: Annoyance due to aircraft noise from 7:00 – 23:00. The different coloured lines represent hourly annoyance judgments (means) for constant aircraft noise levels, i.e. the same* $L_{eq3,1h}$ *noise group as shown on the left ordinate. All lines are adjusted for repeated measurements on four consecutive days. In addition, the black line represents mean annoyance after adjustment for noise level and location (indoor vs. outdoor).*

Regarding nighttime disturbances, data collected in both the survey study as well as the secondary study reveal that aircraft noise especially poses a problem by decreasing hours of sleep. In both studies, participants report having more difficulties falling asleep at night or waking up in the mornings than with remaining asleep in between.

The following was also discovered: Hourly based acute annoyance is more caused by landings in comparison to take-offs. The annoyance is also higher when windows are tilted or opened rather than closed. Correlations between parameters of aircraft noise exposure and annoyance show as in the first survey that annoyance correlate highest with the $L_{Aeq}$. The correlation between aircraft noise annoyance and the number of overflights (with $L_{max}$ > 55 dB(A)) is less, but higher than the $L_{max}$–annoyance correlation (see Table 1). In line with this, detailed regression analyses with total aircraft noise annoyance as criterion variable (assessed in the first survey) show that among the indicators of aircraft noise exposure in addition to the $L_{Aeq}$ only the number of overflights could be entered into regression models.

*Table 1: Pearson correlation for acute hourly annoyance by aircraft noise and acoustical parameters*

r= Pearson correlation; p= significance level; n= number of judgments

| | $L_{eq3,1h}$ | Number of overflights (with $L_{max}$ > 55 dB(A)) | $NAT_{70}$ | $L_{max70}$ | $L_{max55}$ |
|---|---|---|---|---|---|
| r | ,402 | ,385 | ,273 | ,209 | ,284 |
| p | ,000 | ,000 | ,000 | ,000 | ,000 |
| n | 7285 | 6756 | 7285 | 5040 | 6599 |

## 2.3 Subjective Health

Subjective health was measured by scales for health-related quality of life, health complaints, life satisfaction and subjectively perceived quality of sleep. These medical / psychological instruments do not encompass any items specifically related to noise. They may therefore be easily compared with results from other populations.

*Health-related Quality of Life (SF-36: Vitality and Mental Health / SF-12: Mental Health Subscale)*

With regard to quality of life assessed with subscales of the SF-36 and SF-12 one particular pattern of results is consistent and noteworthy: In the "Mental Health" Subscale as well as in the Subscales "Vitality" and "Mental Health", a prominent trend is observed. A subtle decrease in health-related quality of life is found in the mid-range noise level group 50-55 dB(A) ($L_{Aeq3, 06\text{-}22h}$). Interviewees in the noise level groups 55-60 dB(A) and > 60 dB(A) are less affected by aircraft noise when quality of life is considered. The same pattern is found when noise levels are differentiated using noise levels in 2.5 dB(A) steps, amounting to a total of nine instead of five groups, or when various noise level estimation measures are used (Real Noise Distribution, 100/100 Rule).

Extensive analyses of the medical/psychological tests SF36, GBB-24 and FLZ-A (German life satisfaction scale) were conducted in order to check whether socio-demographic variables, duration of residency (due to potential adaptation processes), direction, etc. could be responsible for the decrease in quality of life in the 50-55 dB(A) ($L_{Aeq3, 06\text{-}22h}$) group. No connections were found, which indicates that this systematic pattern cannot yet be explained with the cross-sectional data at hand.

Furthermore, significant moderator effects were registered: Multimorbid persons (having two or more diseases) report poorer mental well-being as aircraft noise levels increase. This connection is not witnessed in persons with fewer diseases. Older interviewees report poorer mental well-being if they reside in areas with higher air traffic (> 60 dB(A), $L_{Aeq3, 06\text{-}22h}$ 100/100 Rule).

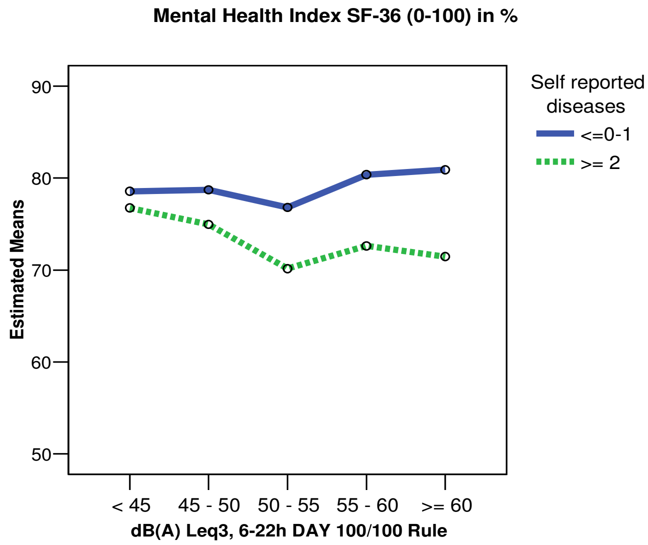


*Figure 6: Estimated Means for the Subscale Mental Health (SF-36). Significant interaction between morbidity (self-reported diseases) and noise level ($L_{Aeq3,\ 06\text{-}22h}$, 100/100 Rule).*

Another main effect was found in connection with expectations regarding the Frankfurt Airport extension: People expecting no worsening of their residential situation after the extension report a higher quality of life than those awaiting negative impact. Similar to results found by Kastka (1999) in the Frankfurt Airport area, people taking more action to change the air traffic situation report poorer well-being.

Besides the particular results presented above, the scales implemented here (SF-12: Mental Health Subscale, SF-36 Subscales: Vitality and Mental Health) do not show any major differences between noise levels. Dose-response relationships or thresholds for subjective health impairments were also not found. Aircraft noise effects do not appear to influence global measures of subjective health, such as quality of life, according to this study.

For the results on health-related quality of life, all scales and subscales reached standardized values. This finding was also discovered with other measures for subjective health. Therefore, a systematic pattern is generally registered for data on subjective health.

As sustained by international research on noise effects, results on quality of life under aircraft noise exposure have yet to be uniformly explained: A study investigating the Sydney Airport (Issarayangyun et al. 2005) discovered effects with the SF-36 Mental Health Scale in an extreme group comparison. However, another investigation of the Amsterdam Schiphol Airport (Houthuijs & v. Wiechen, 2006) could not find any direct effects of aircraft noise on the Mental Health Scale. In the latter study as in the present one, distinct coherences with values for annoyance by aircraft noise were discovered, which indicates that health instruments without noise-related items primarily assess subjective variables as opposed to objective ones.

*Health Complaints (GBB-24)*

Aircraft noise effects on subjective health complaints are quite weak. As discussed in the results on health-related quality of life, the strongest effects are found in the noise level groups between <45 dB(A) and 50 dB(A) - 55 dB(A). This was detected in the total complaint score as well as in the subscale “Exhaustion”. The latter subscale reveals the highest correlations with the mental health scales, especially with the SF-36 Subscale “Vitality”. Therefore, the pattern of results found for health-related quality of life was confirmed here as well, i.e. no negative effects were registered in higher noise level groups (above 60 dB(A)).

Again, annoyance measures correlated higher with health complaints than objective noise levels did, thus producing a consistent pattern of results.

If the results on not noise related psychosomatic complaints are compared with findings discovered by Kastka (1999) at the Frankfurt Airport, it becomes obvious both studies do not register reactions connected noise levels. In Kastka's study, a peak was also found, but around 50 dB(A) Leq Day. Additionally, initiative residents made more complaints than their more passive neighbors.

*Life Satisfaction (FLZ-A)*

Analyses of life satisfaction reveal that the sample in this study reports life satisfaction in a similar quality as the standardized population does.

When observing individual dimensions of life satisfaction, a particular finding is noteworthy: In the dimensions "Family", "Partnership / Sexuality" and "Friends / Acquaintances", the highest satisfaction evaluations are made by those living in the highest aircraft noise level group (Real Noise Distribution and 100/100 Rule). Results for satisfaction values in the Health dimension and in the entire life satisfaction index show a pattern similar to those found with both medical/psychological measures: Residents in middle noise level groups report the worst satisfaction with their health compared to others living in lower and higher noise level areas. Residential satisfaction, however, significantly depends on the noise level. The higher the air traffic noise level, the lower the weighted value for residential satisfaction.

Two other dimensions were added in order to compare life satisfaction with environmental satisfaction. The items "General Environment" and "Aircraft Noise" were used.

Distinct dose-response relationships are recognized between air traffic noise and weighted satisfaction. As the results for the differentiated levels in 2.5 dB(A) steps indicate, interviewees living in an area with 50 – 52,5 dB(A) are dissatisfied with the aircraft noise situation. Noise level groups higher than the latter give negative values to rate their satisfaction, indicating dissatisfaction. Contrary to items not specifically related to noise, distinct connections to the noise level are discovered here. All in all, effect sizes are in the middle to large range.

People expecting their situation to worsen due to the airport extension give negative satisfaction evaluations over all noise level groups. Those expecting no change or an improvement to their situation, on the other hand, only make dissatisfied judgments in the highest noise level group (>=60 dB(A)) .

*Subjectively Perceived Quality of Sleep*

Interviewees reported going to bed commonly between 22:00–23:00. There were no noticeable differences in bedtimes when compared with noise level groups. The effective duration of sleep amounted to 7.1h nightly.

Reported effects due to aircraft noise as measured by subjectively rating sleep quality with the Pittsburgh Sleep Quality Index (PSQI) are weak. In total, the examined sample reached better overall scores than the respective standardized sample. Only 23% can be classified as poor sleepers versus 32% in the reference population. Significant effects due to nightly aircraft noise were, however, confirmed for the subscales "Sleep Quality" and "Sleep Latency". The higher the aircraft noise level, the poorer the subjective evaluations of sleep quality and latency.

Much stronger effects were expected for this issue, when compared with different noise levels. The fact that little to no effects were registered may be due to the fact that the questions make no specific reference to noise. Sleep disorders due to noise disturbances are not confronted by this instrument. Dose-response relationships due to annoyance or disturbances at night revealed much stronger coherences.

## 2.4 Subjectively Perceived Residential and Environmental Quality

Analyses on residential satisfaction show that aircraft noise is a major issue in the Rhine-Main area. Although only disturbances due to “general living conditions” were investigated by open-end interview questions, 63% of those who admitted having disturbing living conditions mentioned aircraft noise as being one. The higher the aircraft noise level in the surveyed area is, the more interviewees named this source: In the highest noise level group 60 dB(A), 75% of those interviewed admitted air traffic noise to be a disturbing living condition in their area.

Significantly dependent on noise level, general satisfaction with the neighborhood and the surrounding area was predicted by the items “neighborhood appearance” and “quietness in the neighborhood”. They were detected from a 14-item list on residential satisfaction using stepwise regression analysis techniques.

After conducting a factor analysis, the 14-item list on residential satisfaction can be described by three factors: *Infrastructure* (F1), *Quietness* (F2) and *Attractiveness* (F3). While F1 and F3 do not represent noise-related items, F2 depicts satisfaction with the “quietness in the neighborhood”, “window sound insulation” and “house/apartment sound isolation”.

The entire scale on residential satisfaction is clearly dominated by the noise-specific factor *Quietness*, especially by the item “quietness in the neighborhood”, followed by satisfaction with “window sound insulation” and with “house/apartment sound isolation”.

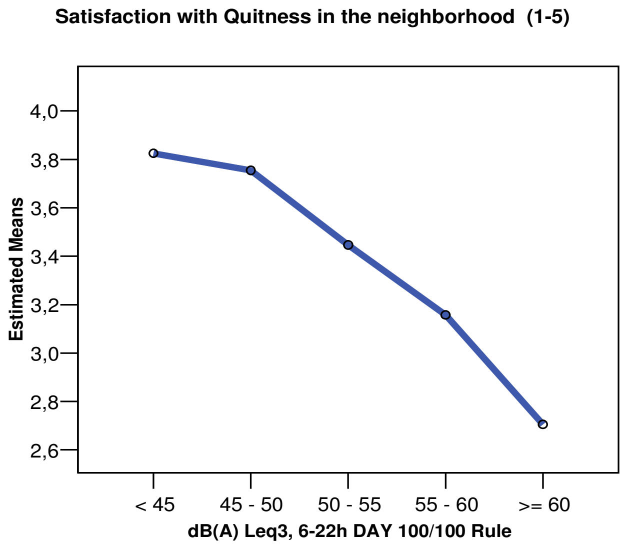


*Figure 7: Satisfaction with quietness in the neighborhood depending on noise level (LAeq3, 06-22h, 100/100 Rule)*

Analyses for residential satisfaction even showed that weaker effects occur when noise, quietness or aircraft noise are not mentioned. If, however, the noise issue or satisfaction with residential quietness is brought up, clear effects in terms of dose-response relationships are observed with noise level group as the stimulus.

Opposed to the medical/psychological term of health-related quality of life, however, analyses on residential satisfaction as a primary environmental issue conclude that subjective environmental quality is massively reduced in the Rhine-Main area the higher aircraft noise levels rises. This effect, dependent on noise level, was also confirmed in the highest noise level group even when aircraft noise annoyance was statistically controlled.

*Threats by Air Traffic*

Analyses of the threats posed by air traffic showed interviewees feel threatened the most by assumed health impairments due to kerosene, followed by a feared decrease in real estate value and low over flights. Using variance analysis techniques, a large main effect due to aircraft noise was demonstrated. As daytime aircraft noise levels increase (Real Noise Distribution and 100/100 Rule), highly noise-exposed interviewees feel more and more threatened by air traffic. Apart from aircraft noise level, the greatest main effect was found in interviewees expectations regarding their individual situation after the airport has been expanded. Those expecting a worsening feel the most threatened compared with those awaiting either no change or an improvement to their situation.

*Environmental and Social Problems*

A factor analysis for environmental and social problems in the Rhine-Main area around the Frankfurt Airport revealed five factors, namely “Street Traffic”, “Air Traffic”, “Economic Situation/Population”, “Misc. Environment Problems” and “Neighbors”. Analyses concentrating on aircraft noise as the stimulus again showed that air traffic is a dominant influence on these judgments. The noise level groups did not produce any systematic effects on the remaining four factors. Therefore, the issue of aircraft noise does not have a generalizing effect on other environmental or social problems. Otherwise, more distinct relationships would have emerged. The dominant factor “Air Traffic” consists of the items “hazardous waste from aircrafts”, “aircraft noise”, “danger due to hazardous waste in food and soil” and “air pollution”. The strongest item is “aircraft noise”, followed by “hazardous waste from aircrafts” and the remaining two. All four items are significantly dependent on noise level group.

In sum, clear dose-response relationships according to daytime aircraft noise levels are found for the factor “Air Traffic” and in particular for the item “aircraft noise”. Other environmental and social problems only play a minor role in these analyses.

# 3. Conclusion

This extensive study on noise effects revealed expected as well as unexpected results. It is by no means surprising that citizens residing in the Rhine-Main area feel disturbed and annoyed by air traffic noise. However, they are more annoyed and disturbed than mean values gathered for comparable populations in Hesse and the entire Republic of Germany dictate. Whereas according to the dose-response-curve published in the EU position paper on dose-response relationships for noise annoyance (EG/WG2, 2002) 25% of residents are highly annoyed by aircraft noise at a noise level of $L_{den}$= 64 dB(A), around Frankfurt Airport 25% are already highly annoyed at an aircraft noise level of $L_{den}$ = 54 dB(A). This is in line with several other recently published European studies (s. van Kempen & van Kamp, 2005; Wirth, 2004).

Scheuch et al. (2003) propose a concept of evaluation criteria for aircraft noise which contains a grading of assessment values: critical values of tolerance of noise effects that must not exceeded, guidelines of prevention as central criteria for taking actions to protect human beings by means of noise reduction measures and threshold values, where measurable physiological and psychological reactions due to aircraft noise can be observed. The authors suggest a noise level of $L_{eq,16h}$ = 55 dB(A) as the threshold value for noise annoyance. This means, that about 35% of the residents around Frankfurt Airport living under this (and higher) aircraft noise level are highly annoyed, according to the data of this study. The suggested guideline value of prevention ($L_{eq,16h}$ = 62 dB(A)) comprise a percentage of more than 50% highly annoyance for residents around Frankfurt Airport living with at least such aircraft noise exposure. The percentage of highly annoyance (%HA) accepted as a remaining effect of noise exposure cannot be defined from a scientific point of view. The tolerated limit value of %HA has to be determined in social discourse. This study offers the Regional Dialogue Forum Frankfurt Airport (RDF) the opportunity to enforce this discourse on the basis of actual scientific data, specific to the region around Frankfurt Airport.

In particular, nighttime aircraft noise contributes to the high judgments regarding annoyance and disturbances. In this context the correlation between disturbance and noise level is found to be higher, if noise levels are estimated according to the 100/100 Rule instead of the Real Noise Distribution Method. For noise reactions at daytime the differences in dose-response correlations with regard the estimation method are smaller. All in all, both of the two long term aircraft noise estimation methods can be seen appropriate for explaining/predicting aircraft noise annoyance or disturbance.

Even life outside one's own four walls is disrupted by aircraft noise. The interviewed residents in the Rhine-Main region report disturbances of outdoor activity due to aircraft noise and they therefore feel less satisfied with their vicinity. The opportunity to stay outside the house, in the garden, on the balcony and terrace or to open windows for ventilation without any disturbances is an integral part of habitation. Therefore, impairments of this opportunity due to aircraft noise (or noise in general) is integrated in the noise annoyance judgment.

The results of this study show, that on the one hand sound proof windows are necessary to reduce indoor aircraft noise. On the other hand, they are not sufficient to ensure reduced noise annoyance or disturbance in line with a decrease in noise level as a result of closing windows. This is due to the fact, that people in this study prefer tilted windows, and that those people with normally closed windows at nighttime in warm seasons are vulnerable residents reporting higher annoyance by aircraft noise than residents with normally tilted or open windows.

With noise levels constant, the marginal hours during the day, i.e. in the morning till 9:00 and 22:00-23:00, reveal increased annoyance due to aircraft noise, especially when compared with the hours directly after or before them. A further daily peak in annoyance is found in the afternoon from 15:00-17:00 due to an increase of frequency in staying outside the house. For the same noise level noise annoyance is higher at weekend than at weekdays. Regarding the daily course of annoyance, a closer relationship is determined between the number of flights and the corresponding decrease in tranquility (measured in time) than with air traffic loudness (maximum level). Moreover, landings are more annoying than take-offs.

The elderly and those encumbered by diseases have greater impairments than younger and healthier people. Anticipated health impairments due to kerosene, feelings of threat due to low over flights and fear of a decrease in real estate value all characterize the situation of those living near the Frankfurt Airport. The circumstance that the airport extension has been discussed and planned for years now intensifies the situation. In particular, residents expecting a worsening of their living situation after the extension feel especially impaired. Today, they are extremely disturbed and annoyed, report having a poorer quality of life and lower life satisfaction. This holds for those who should realistically expect a worsening, but a large number of people anticipate the worse although current prognoses estimate an improvement. Communication strategies are obviously necessary.

Overall, self-reported health impairments directly due to aircraft noise were not found in this study. In many areas (health complaints, health-related quality of life, life satisfaction, sleep quality) the results are compatible with others for the German population. A systematic association between health impairments and noise levels in terms of linear dose-response relationships was not found. However, in many areas, a dip in data was discovered: Those living in areas with mid-range noise levels have a lower subjective quality of life, less satisfaction with their health and make more health complaints. Whether regional circumstances are responsible for these findings and perhaps selection processes or coping strategies modeled the population living near the airport, cannot be explained by the date of this cross-sectional study design. It is even possible that those living in the highest noise level groups have developed a different frame of reference to evaluate their living environment or have adapted to particularly stressful situations. Longitudinal studies using more objective data such as the health monitoring programs carried out at the Amsterdam Airport are urgently recommended. A workshop with the evaluating team, medical experts and community representatives in order to reflect and interpret the results is therefore suggested.

While also incorporating expectations towards the airport extension, an additional hypothesis could be that people living in areas with mid-range aircraft noise exposure interpret the expected change to be a qualitative one, especially a worsening of their life circumstances. Compared with people living in other noise level exposure areas, they therefore express a lower general well-being regarding environmental and life quality before the extension takes place.

This assumption, however, cannot be confirmed with the present cross-sectional data. A further investigation, for instance as a combined monitoring program for aircraft noise effects and social parameters, is necessary.

The evaluators recommend initiating an aircraft noise effect monitoring program in connection with an already planned monitoring of the socio-economic situation in the Rhine-Main area. Therewith, existing issues still in need of clarification would be approached and annoyance and quality of life measures could be tracked in their chronological trend. The points still open for discussion include:

1. Changes in annoyance and disturbances due to aircraft noise should be monitored in the extension phases to come. A longitudinal monitoring program can examine whether annoyance adaptation processes as indicated in findings from the health monitoring program at the Amsterdam Schiphol Airport[3] (Houthuijs, van Wichen, 2006) could be observed in the Rhine-Main population during the extension phase or not.
2. The effect differences in aircraft noise measurements (Real Noise Distribution and 100/100 Rule) require more attention. Specific areas showing deviations should be observed.

[3] In 2003 the 5th runway, the so-called “Polderbahn”, was initiated at the Schiphol Airport in Amsterdam.

3. The relationship between annoyance and health-related effects needs to be causally clarified: Does chronic noise annoyance - not noise exposure - lead to further health impairments or do health-impaired persons express greater noise annoyance? Vulnerable groups should especially be included in this investigation.

Whether periodically measuring aircraft noise effects with a social and aircraft noise monitoring program is possible in the Rhine-Main area, needs to be examined. If such a program is conveyed to the public as a prevention program, a positive stance towards trust in the airport expansion can be expected.

In summary, the reviewers recommend the RDF to draw the attention in further discussions on the effects of aircraft noise at Frankfurt Airport to the following points: taking into account the specific situation at Frankfurt Airport with regard to the percentage of highly annoyance:

- Considering the higher degree of annoyance at weekend and specific times of day (marginal hours during the day) with noise level constant.
- Keeping in mind the well-known importance of active noise control relative to passive noise abatement measures like sound proof windows to ensure the possibility of poor disturbed outdoor stay.
- Taking care of vulnerable residents (the elderly, multimorbid persons, noise sensitive persons).
- Enforcing transparent information and risk communication to minimize gaps in population's knowledge, and to assure trust in and credibility of authorities seen as responsible for aircraft noise reduction.
- Monitoring the development in aircraft noise effects around Frankfurt Airport in line with the socio-economic situation of people in the Rhine-Main area. In this context: Evaluating the effectiveness and efficiency of technical noise abatement and communication measures. The effectiveness has to be definied not only in terms of reduction in noise exposure, but with regard to reduction of negative effects of noise on human being and improvements in residential situation and quality of life.

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