inter.noise HAMBURG 2016

The WHO evidence review on noise annoyance 2000-2014

Rainer GUSKI[1]; Dirk SCHRECKENBERG[2]; Rudolf SCHUEMER[3]

[1] Ruhr-University Bochum, Germany

[2]ZEUS GmbH, Hagen, Germany

[3]ZEUS GmbH, Hagen, Germany

ABSTRACT

WHO Europe commissioned a systematic evidence review on the effects of environmental noise on residential long-term annoyance. The main noise sources considered are aircraft, road traffic, railway traffic, combined transportation sources, and wind turbines.

Methods: Data sources and study eligibility criteria were defined, a systematic literature search was done, publication quality was assessed and selection criteria for the paper defined. In addition, study quality criteria were defined for each of the studies presented in the included papers.

Results: In general, there is a consistent effect of noise on annoyance; summary correlation coefficients range between 0.442 (combined sources), and 0.278 (wind turbines). The unadjusted OR with a 10 dB level increase, based on observed data, ranges between OR = 3.405 (aircraft), and 2.738 (road). The OR for a 10 dB level increase, based on modelled data, ranges between OR = 6.633 (combined sources), and 3.033 (road). A 5 dB level increase of wind turbine sounds is associated with an increase of 6.375 % Highly Annoyed (outdoor / home). Tentative exposure-response relations for studies published between 2000 and 2014 are presented for the three transportation noise sources, respectively. With respect to exposure-response functions for aircraft noise, we propose to distinguish between "high-rate change", and "low-rate-change" airports.

Keywords: Noise, Annoyance, Transportation I-INCE: 63.2, 66.2.

1. INTRODUCTION

Noise effects on residents do not seem to obey eternal natural laws – at least with respect to noise annoyance. From time to time, a new review appears showing that the relation between noise levels and annoyance has changed over the last 20 years, followed by protests from colleagues, based on methodological considerations, and debates about the indications of change and the possible causes of the change continue. In 2014 WHO Europe considered the review of Berglund, Lindvall & Schwela (1999) to be outdated and asked a group of experts for systematic reviews about the present scientific evidence with respect to the effects of environmental noise on humans, including effects on sleep, annoyance, cognitive impairment, mental health and wellbeing, cardiovascular diseases, and hearing impairment and tinnitus. This report is part of the process and gives an abridged version of the evidence review concerning noise annoyance.

2. THE WHO ANNOYANCE EVIDENCE REVIEW 2000-2014

2.1 Objectives

The main objectives of the present systematic review are to assess the strength of association between exposure to environmental noise and long-term noise annoyance, based on field research reported between the years 2000 and 2014, to quantify the increase of annoyance with an incremental increase in noise exposure, and to present an exposure-response relation for each noise source. In

[1] rainer.guski@ruhr-university-bochum.de
[2] schreckenberg@zeusgmbh.de
[3] ar-schuemer@t-online.de

accordance with the WHO guideline development group, the main noise sources considered are aircraft, road traffic, railway traffic, and wind turbines. In addition, effects of noise source combinations, and stationary sources are considered. A grading of the quality of evidence should be given for each annoyance effect.

2.2 Methods

Data sources and study eligibility criteria were defined, a systematic literature search was done, publication quality was assessed and selection criteria for the paper defined according to PRISMA guidelines (Moher et al., 2009). With respect to selection criteria, we included only studies which fulfil the following criteria:

1. Study type: cross-sectional or longitudinal surveys, using an explicit protocol for selecting respondents.
2. Participants: Studies including members of the general population (mainly residents of noise-exposed areas), and studies including specific segments of the population particularly at risk, such as children or vulnerable groups.
3. Exposure type: Long-term outside noise levels which are either expressed in $L_{Aeq,24h}$, L_{dn}, L_{den} or its components (L_{day}, $L_{evening}$, L_{night} and the duration in hours of L_{night}), or can be easily converted from similar acoustic variables **AND**:

   a. The level is based on a reliable calculation procedure, using as input the actual traffic volume, composition and speed per 24 hrs per road/railway /airport, or the type and sound power of an industrial installation and the size in terms of either production volume or persons employed, **OR**

   b. is based on measurements for a minimum of 1 week by qualified staff, and adjusted for data under point (a) as well as meteorological conditions when necessary.
4. Outcome measure: The base of the outcome measure is the individual annoyance response made during a standardized survey. The paper (or the authors on request) gives at least one original table, formula, or graph which can be used for an exposure-response relation.
5. Confounders: Papers containing a potential second risk factor besides noise (e.g., vibration) are included and got special remarks in the list of included papers.
6. Language: Papers in English, French, Dutch, and German were included as long as they met the selection criteria. These languages were selected according to the language understanding of the present authors.

We excluded all papers on interventions, because these are handled by another WHO group.

In addition, study quality criteria were defined for each of the studies presented in the included papers. Study data were extracted from the publications as well as from special questionnaires sent to the paper authors. Whenever possible, study synthesis for transportation and wind turbine noise studies was done by means of meta-analysis software with respect to three effect size indicators: correlations; the Odds Ratio (OR), calculated from the change in percent or rate of Highly Annoyed (%HA) per 5/10 dB noise level increase, based on observed data, and the OR for a 5/10 dB noise level increase, based on modelled data. If a quantitative analysis was not feasible, a narrative review is given.

2.3 Definition of annoyance

According to noise experts from 8 nations who scaled the long-term noise annoyance response obtained in community surveys to be highly associated with both disturbance, and nuisance (Guski et al., 1999), noise annoyance as observed in surveys is seen as a complex response, comprising three elements:

1. An often repeated disturbance due to noise (repeated disturbance of intended activities, e.g., communicating with other persons, listening to TV or music, reading, working, sleep), often combined with behavioral responses in order to minimize disturbances,
2. An attitudinal response (anger about the disturbance, and negative evaluation of the noise source), and
3. A cognitive response (the distressful insight that one cannot do much against this unwanted situation).

This multi-faceted response is seen by many researches as a stress-reaction (e.g., Stallen, 1999) involving an environmental threat and individual physiological, emotional, cognitive and behavioral responses which can partly be remembered and be integrated into a verbal long-term annoyance response. The noise annoyance response considered in the WHO review is related to long-term exposure, i.e. related to residents who live in a more or less noisy area for at least one year, and answer noise annoyance questions related to a long time. The participants of the systematic surveys considered here were selected according to specified procedures and answered at least one standardized noise annoyance question.

3. RESULTS

3.1 Results of the literature search

The literature search resulted in 1.694 papers, including many duplicates. Screening the abstracts of 223 papers left over resulted in 112 papers which were assessed for eligibility. The assessment was done independently by 3 experts. At the end, 34 publications (including 62 studies) were left over, of which 57 papers could be used for quantitative meta-analysis. A questionnaire asking for quantitative details of the studies was sent to the authors of the papers selected. Two reviewers extracted independently data from the publications and respective questionnaires of the individual studies included.

3.2 General results of the meta-analysis

In general, there is a consistent effect of noise level (L_{den}, L_{dn} or L_{24h}) on individual annoyance judgments made in surveys. Summary correlation coefficients range between 0.442 (combined sources), 0.436 (aircraft), 0.417 (rail), 0.325 (road) and 0.278 (wind turbines). The unadjusted Odds Ratio with a 10 dB level increase, based on observed data, ranges between OR = 3.405 (aircraft), 4.023 (railway), and 2.738 (road). The OR for a 10 dB level increase, based on modelled data, ranges between OR = 6.633 (combined sources), 4.778 (aircraft), 3.181 (railway), and 3.033 (road). A 5 dB level increase of wind turbine sounds is associated with an increase of 6.375 % Highly Annoyed (outdoor / home). Tentative exposure-response relations for studies published between 2000 and 2014 are presented for the three transportation noise sources, respectively.

3.3 Results related to aircraft noise annoyance

Data from 15 aircraft noise annoyance surveys around national and international airports were collected. The surveys took place between 2001 and 2014, and encompass a total of 18.947 respondents, and a noise level range between 22 and 74 dB LAeq,24h, i.e., from small airports with 34 regular flights per day until large international airports with more than 1.200 movements per day. Fortunately, most of the selected studies use the annoyance question and scales according to ICBEN/ISO, as well as several standard noise level descriptors. Except for one study, all studies define "Highly Annoyed" by the upper 27 % of the response scale, i.e., HA: >=73 %. Six of the studies show a restricted age range, and two Japanese studies show a restricted level range (12 dB in terms of L_{den}).

For 12 of the 15 aircraft noise studies, exposure-response functions of the relation between L_{den} and modelled %HA were available, aggregating data from 17.094 study participants. In all of the studies, HA is defined by a cutoff >= 73% of the response scale. We calculated the percentages for 5-dB steps between 40 and 75 dB in the level range which was actually used in the respective study. The calculation of the (predicted) percentages at the different exposure levels used the parameters of the regression function which the authors of a study reported. Different regression models were used in the respective studies. A binary logistic regression was performed in the majority of the studies; in some studies a polynomial regression model was used, and one study used a multilevel grouped regression.

The corresponding estimated data points for each of the 12 studies are plotted in Figure 1, together with the estimated Exposure-Response relation (ERR) for the aggregated data (black line). It should be noted that the „estimated data points" do not represent independent empirical observations. They are derived values which are estimated from the regression equation for each of the studies. This means (inter alia) that all estimates of the %HA values for the different exposure levels from the same study are not independent from one another. The estimated ERR shown is based on a quadratic regression between L_{den} and the aggregated (secondary) WHO data set, weighted according to the square root of the total sample size. The quadratic regression fits best to the data, as compared to linear or cubic regressions.

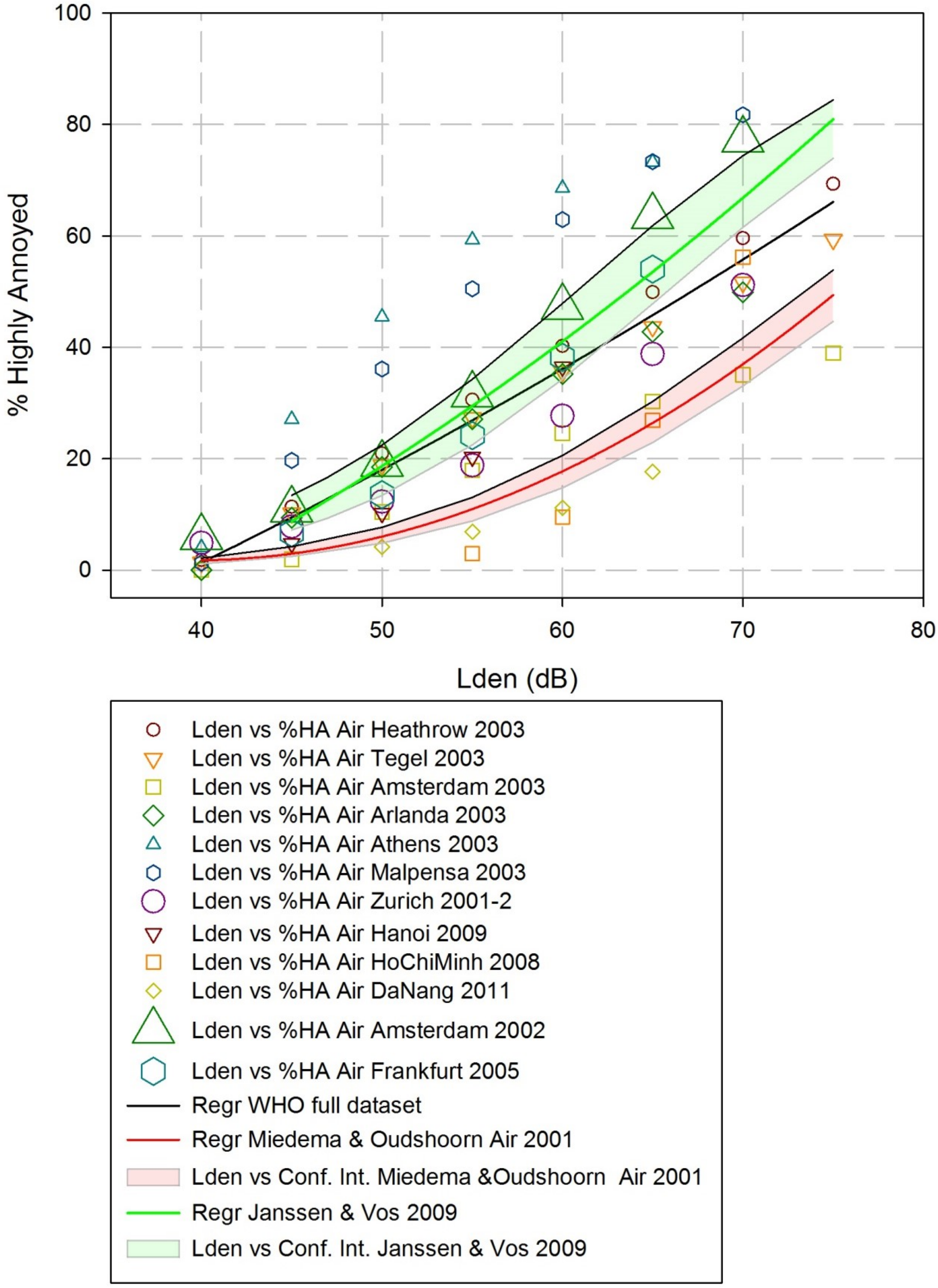

Figure 1: Scatterplot and quadratic regression of the relation between L_{den} and the calculated % Highly Annoyed for 12 aircraft noise studies (black), together with exposure-response functions by Miedema & Oudshoorn (2001, red), and Janssen & Vos (2009, green).

At a first glance, all three curves differ from each other in certain respects: the curves from recent studies (black and green curves) seem to lie considerably above the Miedema/Oudshoorn-curve, and the green and black curves seem to lie somewhat closer together, especially in the range from 40-50 dB, and then departing - with the black curve being less steep than the green one. For instance, at 55 dB L_{den} the WHO dataset has a weighted mean of 27.2 %HA, while Janssen and Vos (2009) report 28.1 %; at 60 dB, there are 36.6 % in the WHO dataset, and 40.96 % reported by Janssen and Vos (2009). While the slopes of both curves seem to be somewhat different, they have at least one aspect in common: there is no wide baseline without remarkable %HA at low noise levels of aircraft noise; a considerable percentage of people (e.g. about 10 %) is already highly annoyed at 45 dB L_{den}.

In line of the distinction between "high rate change airports" and "low rate change airports" of Janssen & Guski (submitted), we consider 5 of the 12 studies to be "low rate change" studies: Heathrow 2003, Tegel 2003, Hanoi 2009, HoChiMinh 2008, and DaNang 2011. In contrast, 5 studies are considered to be "high rate change" studies: Arlanda 2003, Athens 2003, Amsterdam 2002, Amsterdam 2003, and Frankfurt 2005. The calculation of separate ERRs for the two airport change classes points to higher %HA at high rate change airports, as compared to low rate change airports.

The meta-analysis based on correlations between annoyance raw scores and noise levels included 15 studies and did show clear indications that there is a significant effect (in terms of correlations) of long-term noise levels of the LAeq-type on annoyance raw scores. All correlations are positive and statistically highly significant ($p < 0.01$). The weighted summary correlation is r=0.436. However, there is a considerable spread (r between 0.21 and 0.74). There are indications of heterogeneity in our sample of studies when we compare correlations between studies: The Q-test is highly significant (Q = 397.877; df = 14; $p < 0.001$), and I^2, the ratio of true to total variance, is 96.481, which means that a large part of the total variance is due to "true" variance between studies with respect to annoyance/level correlations. Attempts to explore the between-study variance were only partially successful: The distinction between "face-to-face" vs. "no face-to-face" surveys shows "face-to-face" surveys to be connected with significantly higher correlations. The other potential moderators tested, overall study quality, response rate, noise level range, and rate of airport change, do not show significant relations to the observed exposure-response correlations.

The meta-analysis of Odds Ratios for a 10 dB level increase (50-60 dB L_{den}) based on original data was performed with 10 studies, All Odds Ratios are above 1.0, and the summary ratio is 3.4 and highly statistically significant ($p < 0.01$). The size of the summary OR shows that there is a strong aircraft noise effect – which is in line with the analysis based on correlations. On the other hand, five of the Odds Ratios are greater than 1 but not statistically significant and show a relatively broad confidence interval. In addition, attempts to explain the large degree of heterogeneity by means of subgroup analyses were not successful. Neither the range of noise levels, nor the response rate or the rate of airport change show a statistically significant influence on the OR.

The meta-analysis of ORs for a 10 dB level increase based on modelled data (4 studies) shows a somewhat higher summary OR (4.778) as compared to the analysis on observed data. The summary OR is greater than 1 and statistically highly significant ($p < 0.001$). However, the summary OR shows a wide confidence interval (between 2.272 and 10.048). This is wider than the summary confidence interval of the observed data. Due to the small number of studies, we could not explore the heterogeneity between studies.

3.4 Results related to road traffic noise annoyance

Data from 26 studies of road traffic noise annoyance (including 34.211 respondents) were used for several meta-analyses and a tentative exposure-response relation. Twenty-one studies were included in a correlational analysis, resulting in a statistically highly significant summary correlation between annoyance raw scores and L_{den} or L_{dn} (r = 0.325; $p < 0.001$). This summary correlation shows that about 11% of the variance of road traffic noise annoyance raw scores is accounted for by the variance of L_{den} or L_{dn}. Twelve studies provided observed data for the %HA increase at 50 and 60 or 55 and 65 dB L_{den} or L_{dn}. It turned out that there is an OR referring to the %HA-increase per 10 dB level increase which is greater than 1 and statistically highly significant (summary OR = 2.738, 95%CI = 1.880-3.987; $p < 0.001$). The slope parameters of a logistic regression of the exposure-response relationship were available for 19 road traffic noise annoyance studies. This parameter was used in order to estimate the OR for the %HA-increase per 10 dB increase of exposure. The summary effect of the 10 dB level increase from modelled data is somewhat greater (OR = 3.033; 95%CI = 2.592-3.549; $p < 0.001$) than the one obtained from observed data. If we take the two latter analyses together, we can state that the odds or chance to be highly annoyed is about three times higher when the road traffic noise level increases by 10 dB. The two funnel plots (for observed and for modelled data) both point to a certain bias in the direction of overestimation of the reported effects. There are statistically highly significant effects of the 10 dB increase, but the size of this increase may be overestimated in the studies analyzed here. Two tentative exposure-response relations are presented for road traffic noise annoyance, a set of 25 studies including Alpine Studies, and a set of 19 studies excluding them. The latter is located mainly within the confidence interval of the Miedema/Oudshoorn-curve for road traffic noise annoyance – except for noise levels 35-40 dB L_{den}.

3.5 Results related to railway noise annoyance

A total of 11 individual studies (including 12.477 respondents) on railway noise annoyance provided data for a series of meta-analyses. The correlational analysis, based on 7 studies, shows a summary correlation of 0.417 ($p < 0.001$; 95%CI = 0.263-0.550). This summary correlation shows that about 17% of the variance of railway noise annoyance raw scores is accounted for by the variance of $L_{Aeq,24h}$. However, a large percentage of the variance between studies could not be explained. The meta-analysis based on the observed %HA-difference at 10 dB difference (50 and 60 dB $L_{Aeq,24h}$) shows an Odds Ratio > 1 and statistically highly significant (OR = 4.023, 95%CI = 2.627-6.159; $p < 0.001$). In other words: the chance to be highly annoyed is more than three times higher when the railway noise level increases between 50 and 60 dB. However, a large part of between study variance is left unexplained. A similar analysis, based on modelled data, shows similar results. The exclusion of one study of the Japanese Shinkansen train decreased the heterogeneity somewhat. However, much of the between study variance is left unexplained. A factor which seems to be systematically related to the between-study variance is the noise level range: studies using a smaller range of noise levels were associated with higher ORs – but this effect is confounded with the larger mean height of the levels used in these studies.

A tentative exposure-response relation is given in the present report. It shows a steeper increase of the %HA with increasing L_{den}, as compared to the Miedema and Oudshoorn (2001) curves on railway noise annoyance. However, it should be noted that the definition of "High Annoyance" in our dataset is less stringent than the one used in the Miedema/Oudshoorn curves.

3.6 Results related to noise source combinations

We considered the question how the (long-term) "total annoyance" judgment in situations involving at least two different noise sources is related to the long-term energetically summated noise levels of the combination of two noise sources. Five studies were available for comparison, all studies include road traffic noise; two of the studies combine road and railway noise, two studies combine road and aircraft noise, and one combines road and industrial noise. The total dataset includes 1.949 respondents. Although the summary correlation between summated noise level and the judgment of "total annoyance" is highly significant ($r = 0.442$, $p < 0.001$), and the 10-dB-increase of the summated noise level shows a summary OR of 6.633 (95%CI = 1.706-25.785; $p = 0.006$), the variance between studies is largely unexplained. One plausible cause of between-study variance is the type of noise source combination: The Road+Aircraft combinations show larger effects on annoyance than any of the Road+Rail od Road+Industry combinations with respect to the two effect size measures used here: correlations between annoyance raw scores and noise level, as well as the OR for the %HA increase per 10 dB level increase.

It seems unwise to integrate different noise source combinations in a single analysis, but there were not enough studies available for the meta-analysis of a single source combination. With respect to the weights given for the separate noise levels in future combination studies, our results point to the importance of the dominant source in terms of annoyance: since aircraft noise annoyance generally is higher than road and rail traffic annoyance at comparable noise levels, any combination of aircraft noise with another noise source will produce higher annoyance effects than any other combination examined here.

3.7 Results related to wind turbine noise annoyance

The two publications included in the wind turbine noise annoyance analysis contain descriptions of a total of 4 individual studies (a total of 2.481 respondents). Although there are differences between studies with respect to the annoyance rating (e.g., spatial frame of reference, response scale) and noise descriptor, we performed a formal meta-analysis, based on correlations. The summary correlation is somewhat lower than the corresponding correlations from transportation noise annoyance studies ($r = 0.278$; $p = 0.001$; 95%CI = 0.110 – 0.430). The average increase of %HA with an increase of 5 dB (42.5

- 47.5 dB L_{den} or L_{dn}) is 6.375 percent (outdoor annoyance / unspecified wind turbine annoyance). A simple overlay of published exposure response relations shows considerable differences between the results of three European studies and one from Japan. However, it is evident that the level of wind turbine sounds is systematically related to noise annoyance, even at levels below 40 dB L_{den}.

4. LIMITATIONS

The review is completely based on secondary data (e.g., correlations and exposure-response functions reported by study authors), and noise descriptors (e.g., L_{den}, L_{dn}, and $L_{Aeq,24h}$) as well as annoyance judgments of residents which are not always fully comparable. Due to lack of original data, the tentative exposure-response relations could not be related to confidence intervals. This implicates that there is no statistical test to decide between “new” and “old” exposure-response curves. All of the meta-analyses show a considerable degree of heterogeneity between studies, which was explored by means of subgroup analyses.

5. IMPLICATIONS OF KEY FINDINGS

The results of the meta-analyses show noise annoyance to be a reliable noise effect, although differing in size between studies and noise sources. The tentative exposure-effect relations for aircraft noise are in line with the often reported trend to increased aircraft noise annoyance over the last years. In other words, they support the statement that aircraft noise annoyance today is higher than shown in the Miedema/Oudshoorn (2001) curves. We were not able to explain this trend, but our data support the distinction between high-rate changed and low-rate changed airports: Airports which underwent an abrupt change or expect such a change in the near future show higher annoyance as compared to steady-state (or low rate change) airports at comparable noise levels. Railway noise seems to have increased over time too, while there is no indication that road traffic noise annoyance has changed over time.

ACKNOWLEDGEMENTS

The original work was funded by WHO Europe.

REFERENCES

Berglund, B., Lindvall, T. & Schwela, D. H. (Eds., 1999). Guidelines for Community Noise. Geneva (CH): World Health Organization (WHO).

Guski, R., Felscher-Suhr, U. & Schuemer, R. (1999). The concept of noise annoyance: how international experts see it. Journal of Sound and Vibration, 223(4), 513-527.

Guski, R., Schreckenberg, D. & Schuemer, R. (submitted, 05.04.2016). WHO Systematic Evidence Review Concerning Noise Annoyance – Draft 9. Bonn, Germany.

Janssen, S. A. & Guski, R. (in press). Aircraft noise annoyance. In S. A. Stansfeld, B. Berglund, S. Kephalopoulos & M. Paviotti (Eds.), Evidence Review on Aircraft Noise and Health. Bonn (D): Directorate General Joint Research Center and Directorate General for Environment, European Union.

Janssen, S. A. & Vos, H. (2009). A comparison of recent surveys to aircraft noise exposure-response relationships TNO Report (Vol. TNO-034-DTM-2009-01799, pp. 14).

Miedema, H. M. E. & Oudshoorn, C. G. (2001). Annoyance from transportation noise: Relationships with exposure Metrics DNL and DENL and their confidence intervals. Environmental Health Perspectives, 109, 409-416.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G. & Group, T. P. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med, 6(7), e1000097. doi: 10.1371/journal.pmed.1000097

Stallen, P. J. (1999). A theoretical framework for environmental noise annoyance. Noise & Health, 1(3), 69-80.