*Environ Health Perspect*

DOI: 10.1289/EHP10197



## Supplemental Material

# Environmental Noise and Effects on Sleep: An Update to the WHO Systematic Review and Meta-Analysis

Michael G. Smith, Makayla Cordoza, and Mathias Basner

## Table of Contents

**Figure S2.** Funnel plots for aircraft, road, and railway noise, stratified by whether or not the sleep disturbance question mentioned noise. Odds ratios (OR) are calculated as the combined estimate for each individual study.

**Figure S3.** Proportion of respondents from European studies (hatched red) and non-European studies (solid blue) for each sleep disturbance question and noise source.

**References**

**Table S1 PRISMA 2020 checklist**

| Section and Topic | Item # | Checklist item | Location where item is reported |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review. | 1 |
| **ABSTRACT** | | | |
| Abstract | 2 | See the PRISMA 2020 for Abstracts checklist. | 1 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of existing knowledge. | 1-2 |
| Objectives | 4 | Provide an explicit statement of the objective(s) or question(s) the review addresses. | 2 |
| **METHODS** | | | |
| Eligibility criteria | 5 | Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses. | 2 |
| Information sources | 6 | Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted. | 2 |
| Search strategy | 7 | Present the full search strategies for all databases, registers and websites, including any filters and limits used. | Table S2 |
| Selection process | 8 | Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process. | 2 |
| Data collection process | 9 | Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process. | 2-3 |
| Data items | 10a | List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect. | 2-3 |
| | 10b | List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information. | 2-3 |
| Study risk of bias assessment | 11 | Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process. | 3-4 |
| Effect measures | 12 | Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results. | 4 |
| Synthesis methods | 13a | Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)). | 2 |
| | 13b | Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions. | 3 |
| | 13c | Describe any methods used to tabulate or visually display results of individual studies and syntheses. | 3 |
| | 13d | Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used. | 4 |
| | 13e | Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression). | n/a |
| | 13f | Describe any sensitivity analyses conducted to assess robustness of the synthesized results. | 4 |
| Reporting bias assessment | 14 | Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases). | 3 |

| Section and Topic | Item # | Checklist item | Location where item is reported |
|---|---|---|---|
| Certainty assessment | 15 | Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome. | 3-4 |
| **RESULTS** | | | |
| Study selection | 16a | Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram. | 4-5, Figs 1 & 2 |
| | 16b | Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded. | 5 |
| Study characteristics | 17 | Cite each included study and present its characteristics. | 5-10 |
| Risk of bias in studies | 18 | Present assessments of risk of bias for each included study. | Figs 3-5 |
| Results of individual studies | 19 | For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots. | Figs 3-5 |
| Results of syntheses | 20a | For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies. | 5, 12-15 |
| | 20b | Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect. | 12-15, Figs 6-8 |
| | 20c | Present results of all investigations of possible causes of heterogeneity among study results. | n/a |
| | 20d | Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results. | 12, Table S5 |
| Reporting biases | 21 | Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed. | 15 |
| Certainty of evidence | 22 | Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed. | 15, Table 6 |
| **DISCUSSION** | | | |
| Discussion | 23a | Provide a general interpretation of the results in the context of other evidence. | 15-17 |
| | 23b | Discuss any limitations of the evidence included in the review. | 15-20 |
| | 23c | Discuss any limitations of the review processes used. | 20 |
| | 23d | Discuss implications of the results for practice, policy, and future research. | 20-21 |
| **OTHER INFORMATION** | | | |
| Registration and protocol | 24a | Provide registration information for the review, including register name and registration number, or state that the review was not registered. | 2 |
| | 24b | Indicate where the review protocol can be accessed, or state that a protocol was not prepared. | 2 |
| | 24c | Describe and explain any amendments to information provided at registration or in the protocol. | n/a |
| Support | 25 | Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review. | 21 |
| Competing interests | 26 | Declare any competing interests of review authors. | 1 |
| Availability of data, code and other materials | 27 | Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review. | n/a |

# Electronic search strategy

**Table S2 Electronic search terms for each of the four databases searched in the systematic review**

| Database | Search terms | |
|---|---|---|
| Scopus | TITLE-ABS-<br>KEY ( "noise" W/5 ( "rail*" OR "aircraft" OR "airport*" OR "road*" OR "traffic*" OR "automobile*" OR "vehicle*" OR "motorcycle*" ) ) AND TITLE ( "sleep*" ) AND PUBYEAR > 2019 | |
| PubMed | ((noise[tiab] AND (rail*[tiab] or aircraft[tiab] or airport*[tiab] or road*[tiab] or traffic*[tiab] or automobile*[tiab] or vehicle*[tiab] or ″motor cycle*″[tiab] or motorcycle*[tiab] or transport*[tiab])) OR (″Transportation″[majr]) OR (″Aircraft″[mh:noexp] OR ″Airports″[mh:noexp] OR ″Railroads″[mh:noexp] OR ″Motor vehicles″[mh]) OR (″Noise,transportation″[mh])) AND ((noise[tiab] AND (rail*[tiab] or aircraft[tiab] or airport*[tiab] or road*[tiab] or traffic*[tiab] or automobile*[tiab] or vehicle*[tiab] or ″motor cycle*″[tiab] or motorcycle*[tiab] or transport*[tiab])) OR (″Noise″[mj:noexp]) OR (″Noise,transportation″[mh])) AND ((″Sleep″[mh] OR ″Sleep Wake Disorders″[mh]) OR (sleep*[ti])) AND 2019:2021[dp] | |
| Embase | **No.** | **Query** |
| | #11 | #10 AND [2019-2021]/py |
| | #10 | #6 AND #9 |
| | #9 | #7 OR #8 |
| | #8 | 'sleep*':ti |
| | #7 | 'sleep'/exp OR 'sleep disorder'/exp |
| | #6 | (#1 OR #2 OR #3 OR #5) AND (#1 OR #4 OR #5) |
| | #5 | 'traffic noise'/exp OR 'aircraft noise'/exp |
| | #4 | 'noise'/mj OR 'sound'/mj OR 'vibration'/mj |
| | #3 | ′aircraft′ OR ′airport′ OR ′railway′ OR 'motor vehicle'/exp |
| | #2 | 'traffic and transport'/exp/mj |
| | #1 | noise NEAR/5 (rail* OR aircraft OR airport* OR road* OR traffic* OR automobile* OR vehicle* OR motorcycle* OR transport*) |
| PsycINFO | (((TI,AB,TOC,MAINSUBJECT,IF,OTI,TM(noise n/5 (rail* or aircraft or airport* or road* or traffic* or automobile* or vehicle* or motorcycle*))) OR (TI,AB,TOC,MAINSUBJECT,IF,OTI,TM(traffic OR aircraft/ or railroad trains/ or transportation/ or motor vehicles/))) AND ((TI,AB,TOC,MAINSUBJECT,IF,OTI,TM(noise n/5 (rail* or aircraft or airport* or road* or traffic* or automobile* or vehicle* or motorcycle*))) OR (exp Noise Effects/) OR (exp Auditory Stimulation/) OR (exp vibration/)))AND ((exp Sleep Disorders/ OR (exp Sleep/) OR (exp Sleepiness/) OR (exp Sleep Deprivation/)) OR (TI,AB,TOC,MAINSUBJECT,IF,OTI,TM(sleep*))) AND YR(>2018) | |

**Table S3 Studies not included in meta-analysis.**

| Study | *N* | Location | Disturbance questions and responses | Noise metric (level range) | Exclusion reason |
|---|---|---|---|---|---|
| **Aircraft noise** | | | | | |
| Kwak 2016 [1] | 2831 | South Korea | Insomnia severity index items. Difficulty falling asleep: None, Mild, Moderate, Severe, Very Severe; Difficulty staying asleep: None, Mild, Moderate, Severe, Very Severe | Weighted Equivalent Continuous Perceived Noise Level (75-90 WECPNL) | Data could not be obtained |
| **Road traffic** | | | | | |
| Paiva 2019 [2] | 225 | Brazil | Difficulty falling asleep: Never, Sometimes, Always Waking up during the night: Never, Sometimes, Always | $L_{den}$ (52.5-77.5 dB) | No noise exposure data for residence of each individual respondent |

**Table S4 Bias assessment for individual studies. Parts of this table are reproduced from the WHO 2018 review.[3]**

| Study | Selection bias | | | Information bias (exposure assessment) | | | Bias due to confounding | | Reporting bias | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Response rate | Inclusion/exclusion criteria & sampling method | Bias rating | Metric | Assessment methodology | Bias rating | Included in analysis | Bias rating | Indication of bias | Bias rating |
| Bartels 2021 [4] | 51% & 38% | Women preschool teachers and randomly selected women from the general population in western Sweden | High | Lnight, outdoors | Nordic Prediction Method, modeled at the most exposed façade | Low | Adjusted for age, smoking, alcohol consumption, BMI, physical activity, noise sensitivity, education and income | Low | | Low |
| Basner 2019 [5] | ~2% | Field study participants recruited using a mix of randomized sample postal survey, public advertising and home visits. Study subjects needed to be indicate interest in the field study and could not meet any of the following exclusion criteria: use of sleep medication on a regular basis; a history of cardiac arrhythmia or a sleep, including sleep apnea, narcolepsy, restless leg syndrome, period limb movement syndrome; self-reported problems or difficulties with hearing; overnight shift work; aged <21 years; children in the household aged <5 years; BMI of >35 kgm−2; or pregnant | High | Lnight, outdoors | Noise models based on aircraft movements at nearby airport. Indoor (bedroom) and outdoor measurements made for the 3 consecutive study days | Low | Adjusted for age, sex, BMI, and study region | Low | All outcomes reported | Low |
| Bodin 2015 [6] | 54% | Participants were randomly sampled from 6 different noise strata | Low | Leq, 24 hr, outdoors | Data in modelling included geometries of roads, buildings, elevation, ground types, noise barriers and railways. | Low | Adjusted for age, gender, BMI, smoking, marital status, education, hearing, and quiet side | Low | | Low |
| Brink 2005 [7] | Unclear | Unclear | Unclear | Lnight, outdoors | Unclear | Unclear | Unclear | Unclear | German | Unclear |
| Brink 2011 [8] | ~68% | Random selection of residents throughout Switzerland | Low | Lnight, outdoors | SonBase, noise levels at the most exposed façade. | Low | Age, gender, BMI, socioeconomic status, financial satisfaction | Low | | Low |
| Brink 2019 [9] | 31% | Stratified random sample of all adults aged 19-75 years based on exposure | High | Lnight, outdoors | Noise levels modelled at most exposed façade | Low | Adjusted for sex, age, interview mode, and language of interview. | Low | All outcomes reported | Low |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | strata for road traffic, railway and aircraft noise | | | | | Tested effect modifications for intermittency ratio, bedroom window opening, orientation of bedroom towards street, level difference to quiet side façade, degree of urbanisation, habitual bedtime, sleep duration, sleep medication, season, and night air temperature | | | |
| Brown 2015 [10] | 75% | Random sample of individuals in Hong Kong. Individuals had to be 18 years or older to participate. | Low | Lnight, outdoors | Predicted for the most exposed façade, accounted for the height of the building | Low | Not in the reported analysis | High | | Low |
| Carugno 2018 [11] | 57.6% | Random sampling, during summer, of adults aged 45-70 based on noise exposure. Exclusions due to unspecified health problems. | High | LVA, outdoors | Based on noise maps for the nearby airport. No measurements made. Cannot tell if noise maps based on actual traffic movements | Unclear | Adjusted for gender, age, education, BMI, smoking, last occupation, airport-related job, and annoyance score from traffic noise at night | Low | All measured outcomes reported | Low |
| Evandt 2017 [12] | 48% | Oslo inhabitants born in the years 1924–1925, 1940–1941, 1955, 1960, and 1970 | High | Lnight, outdoors | Nordic Prediction Method, modeled at the most exposed façade | Low | Adjusted for age, sex, marital status, alcohol use, smoking status, physical activity, night-shift work, educational level, and household income. | Low | All outcomes reported | Low |
| Frei 2014 [13] | 31.4% | Questionnaire was sent to randomly selected residents from Basal who were between 30 and 60 years old. Participants were selected from a cohort on electromagnetic field exposure. | High | Lnight, outdoors | Modeled at the most exposed façade for the most exposed floor, reflections, absorptions, and noise protection walls are accounted for in the model. | Low | Models were adjusted for sex, age, education level, marital status, average daily physical activity, smoking status, average alcohol intake, body mass index, and a stress score. | Low | | Low |
| Halonen 2012 [14] | Unclear | Participants were from the Finish Public Sector Study. The participants were selected among working | Unclear | Lnight, outdoors | Noise levels were modeled for highways and main streets. | Low | Adjusted for age, gender, occupational status, residence size, | Low | | Low |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | employees in 10 towns and 6 hospital districts. | | | | | marital status, chronic disease, trait anxiety, and neighborhood socioeconomic disadvantage and population density. | | | |
| Hong 2010 [15] | ~65% | Convenience sample, recruited people that were going in and out of buildings within the sample regions. | High | Lnight, outdoors | 3 nights of measurements at the most exposed façade of a building | High | Not in the reported analysis | High | | Unclear |
| Martens 2018 [16] | 16% | Participants were recruited through general practices, and were 31–65 years old at baseline | High | Lden | Calculated using STAMINA model, with input variables traffic intensity, speed, composition and type of road surface, building data and ground type. | Low | Adjusted for sex, age, education, smoking, neighborhood income level, and for year of filling in the questionnaire | Low | All outcomes reported | Low |
| Nguyen 2009 [17] | 88% | Adults 18 year or older were included. | Low | Lnight, outdoors | Measured for 7 consecutive days | Low | Not in the reported analysis | High | | High |
| Nguyen 2010 [18] & 2011 [19] | 91.6% | Adults 18 year or older were included. | Low | Lnight, outdoors | Measured for 7 consecutive days | Low | Not in the reported analysis | High | | Low |
| Nguyen 2012 [20] | 84% | Adults 18 year or older were included. | Low | Lnight, outdoors | Measured for 7 consecutive days | Low | Not in the reported analysis | High | | Unclear |
| Nguyen 2015 [21] | 90% | Adults 18 year or older were included. | Low | Lnight, outdoors | Measured for 7 consecutive days | Low | Not in the reported analysis | High | | Unclear |
| Nguyen 2020 [22] | 95.8% (2017) | Sampling derived from face-to-face interviews conducted in the order of father, mother, and adults other than parents in each house | High | Lnight, outdoors | Measured for 7 consecutive days | Low | Effects of noise on insomnia outcome adjusted for sex, age, noise sensitivity, length of residence, floor area and sound insulation | Low | All outcomes reported | Low |
| NORAH 2015 [23] | Unclear | Unclear | Unclear | Lnight, outdoors | Unclear | Unclear | Unclear | Unclear | Unclear | Unclear |
| Phan 2010 [24] & Shimoyama 2014 [25] | 55.5% & 74.4% | In the two cities, 8 sites were selected based on traffic volume and residential and commercial characteristics. | Low | Lnight, outdoors | 24-hour measurements were conducted at select sites. | High | Not in the reported analysis | High | Underreported statistical methods | High |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ristovska 2009 [26] | 72% | Sample was randomly selected from population living in Skopje. Inclusion criteria included age (18-65 years) and 1 year of residence at current living address. | Low | Lnight, outdoors | Performed short term measurements of 5 minutes in various locations within the city. | High | Adjusted for employment, educational level, residential period, time spent at home during working days and on the weekend. | Low | | Low |
| Rocha 2019 [27] | 10.1% | Stratified random sample of adults (≥21 years) in all households based on exposure strata for aircraft noise | High | Lnight, outdoors | Noise models based on aircraft movements at nearby airport | Low | Adjusted for income, age, sex, BMI, noise sensitivity and hearing problems | Low | All outcomes reported | Low |
| Sato 2002 [28] | 68.8%, 69.3% & 57.5% | Respondents were between 20-75 years old, randomly selected on a one-per-family basis | Low | LAEq,24h, outdoors | Measured for 24 hours | High | Not in the reported analysis | High | | Unclear |
| Sato 2004 [29] | 70.2% & 66.6% | Respondents were between 20-75 years old and were randomly selected from voter lists | Low | Lnight, outdoors | Measurements were made close to the railway. Then measurements were made at 5, 10, 20, and 40 m from the train line and equations for estimating the decay of the noise with distance was calculated and used to estimate the level at each house. | High | Not in the reported analysis | High | | Unclear |
| Schreckenberg 2009 [30] | 64% | Random sample based on stratification of LAeq, 16h | Low | LAeq, 16 hr and Lnight outdoors | The aircraft noise levels were calculated for the address of each subject on the base of the flight movements of the 6 busiest months of the year 2005 according to the German aircraft noise calculation procedure AzB. Individual road traffic noise levels were taken from noise maps. | Low | Not in the reported analysis | High | Sleep outcomes not/poorly described | Unclear |
| Schreckenberg 2013 [31] | 41% | Random sample | High | Lnight, outdoors | Railway noise was predicted using the German railway noise model. The calculated noise levels were | Low | Not in the reported analysis | High | | Unclear |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | validated by comparing them to measured noise levels from a monitoring station. | | | | | |
| Smith 2020 [32] | 9.1% | Field study participants recruited using a randomized sample postal survey. Study subjects needed to be indicate interest in the field study and could not meet any of the following exclusion criteria: use of sleep medication ≥3 times per week over the past month; diagnosed by a health professional with a sleep disorder, including but not limited to sleep apnea, narcolepsy, restless leg syndrome, period limb movement syndrome, or insomnia; diagnosed by a health professional with arrhythmia; self-reported problems or difficulties with hearing; overnight shift work; aged <21 years; children in the household aged <5 years; BMI of >35 or <17 kgm−2; or pregnant | High | Lnight, outdoors | Noise models based on aircraft movements at nearby airport. Indoor (bedroom) measurements made for the 5 consecutive study days | Low | Adjusted for number of noise events, sex, age and window closing | Low | All outcomes reported | Low |
| SoNA 2017 [33] | 57% | Random probability sample stratified sampling by noise band. Only respondents living at current address >6 months answered sleep disturbance question. Wouldn't have lived there in summer! | Low | Lnight, outdoors, summer | Noise models based on aircraft movements at nearby airport. | Low | Unclear | Unclear | All measured data reported | Low |
| Yano 2015 [34] | 68.5% | 13 survey sites were selected based on their location relative to the runways. | Low | Lnight, outdoors | Measured for 7 consecutive days. | Low | Not in the reported analysis | High | | Unclear |

**Table S5 Odds Ratios (OR) for the probability of being highly sleep disturbed when exposed to road or railway traffic noise, stratified by studies that were judged to have a low or high risk of bias (ROB) in the noise exposure assessment.** Analyses were restricted to combined estimates of sleep disturbance derived from different studies that were judged to have both low and high ROB.

| Source of sleep disturbance | Low ROB studies | | | High ROB studies | | |
|---|---|---|---|---|---|---|
| | Studies *n* [a] | Sample size *n* [a] | OR (95% CI) | Studies *n* [a] | Sample size *n* [a] | OR (95% CI) |
| Road traffic, noise mentioned | 4 [b] | 24,618 | 2.71 (2.43-3.00) | 9 [c] | 4,735 | 2.00 (1.57-2.57) |
| Railway traffic, noise mentioned | 4 [d] | 5,576 | 3.25 (2.76-3.81) | 3 [e] | 2,918 | 2.35 (1.89-2.89) |

[a] In the $L_{night}$ range 40-65 dB for which ORs were calculated

[b] Includes Brown 2015,[10] Bodin 2015,[6] Evandt 2017,[12] and Brink 2019[9]

[c] Includes Sato 2002 (Gothenburg, Kumamoto, Sapporo),[28] Ristovska 2009,[26] Hong 2010,[15] and Phan 2010 (Hanoi, Da Nang, Hue, Thai Nguyen)[24]

[d] Includes Schreckenberg 2013,[31] Bodin 2015,[6] Brink 2019,[9] and Evandt 2017[12]

[e] Includes Sato 2004 (Hokkaido and Kyushu),[29] and Hong 2010[15]

ORs were calculated in logistic regression models with $L_{night}$ as the only fixed effect and study included as a random effect, restricted to the noise exposure range 40-65 dB $L_{night}$. Models were run separately for each traffic mode and for each ROB categorisation. Disturbance data shown are the combined estimates, calculated using average responses of the awakening, falling asleep and/or sleep disturbance questions within studies.

**Table S6 Odds Ratios (OR) for the probability of being highly sleep disturbed when exposed to traffic noise, including study location as a fixed effect in the logistic regression.**

| Outcome | Exposure | $L_{night}$ OR per 10 dB | Study location OR (95% CI) [a] |
|---|---|---|---|
| Combined estimate; Noise mentioned | Aircraft | 2.18 (2.03-2.34) | 0.95 (0.43-2.11) |
| | Road | 2.53 (2.31-2.77) | 0.55 (0.26-1.15) |
| | Railway | 2.96 (2.63-3.34) | 1.61 (0.81-3.21) |
| Combined estimate; Noise not mentioned | Aircraft | 1.51 (1.24-1.84) | 2.04 (0.44-9.40) |

[a] Reference category: European

ORs were calculated in logistic regression models with $L_{night}$ and study location included as fixed effects and study included as a random effect, restricted to the noise exposure range 40-65 dB $L_{night}$. Models were run separately for each traffic mode and for sleep questionnaire outcomes that did or did not mention noise. The combined estimate was calculated using average responses of the awakening, falling asleep and/or sleep disturbance questions within studies.

**Table S7 Polynomial equations for the probability of being highly sleep disturbed by traffic noise.**

| Traffic mode | Outcome | Polynomial equation |
|---|---|---|
| Aircraft | Awakenings, noise mentioned [a] | $\%HSD = 0.03132\times(L_{night})^2 - 1.80203\times(L_{night}) + 31.28079$ |
| | Falling asleep, noise mentioned [a] | $\%HSD = 0.02204\times(L_{night})^2 - 0.86230\times(L_{night}) + 12.42449$ |
| | Sleep disturbance, noise mentioned [a] | $\%HSD = 0.02664\times(L_{night})^2 - 1.17389\times(L_{night}) + 16.46165$ |
| | Combined estimate, noise mentioned [a] | $\%HSD = 0.02502\times(L_{night})^2 - 1.12624\times(L_{night}) + 17.07421$ |
| | Awakenings, noise not mentioned [b] | $\%HSD = 0.00053\times(L_{night})^2 + 0.12813\times(L_{night}) + 14.43511$ |
| | Falling asleep, noise not mentioned [b] | $\%HSD = 0.01025\times(L_{night})^2 - 0.54125\times(L_{night}) + 11.80883$ |
| | Sleep disturbance, noise not mentioned [b] | $\%HSD = 0.00072\times(L_{night})^2 + 0.00286\times(L_{night}) + 1.91913$ |
| | Combined estimate, noise not mentioned [b] | $\%HSD = 0.00752\times(L_{night})^2 - 0.29007\times(L_{night}) + 8.12177$ |
| Road | Awakenings, noise mentioned [a] | $\%HSD = 0.00651\times(L_{night})^2 - 0.42090\times(L_{night}) + 8.89988$ |
| | Falling asleep, noise mentioned [a] | $\%HSD = 0.01398\times(L_{night})^2 - 1.08596\times(L_{night}) + 22.81190$ |
| | Sleep disturbance, noise mentioned [a] | $\%HSD = 0.02193\times(L_{night})^2 - 1.74538\times(L_{night}) + 36.85986$ |
| | Combined estimate, noise mentioned [a] | $\%HSD = 0.01851\times(L_{night})^2 - 1.47351\times(L_{night}) + 31.18323$ |
| | Awakenings, noise not mentioned [b] | $\%HSD = 0.00046\times(L_{night})^2 + 0.12354\times(L_{night}) + 14.99528$ |
| | Falling asleep, noise not mentioned [b] | $\%HSD = 0.00083\times(L_{night})^2 + 0.07495\times(L_{night}) + 7.12275$ |
| | Sleep disturbance, noise not mentioned [b] | $\%HSD = 0.00077\times(L_{night})^2 + 0.06372\times(L_{night}) + 6.25956$ |
| | Combined estimate, noise not mentioned [b] | $\%HSD = 0.00081\times(L_{night})^2 + 0.08484\times(L_{night}) + 8.02339$ |
| Railway | Awakenings, noise mentioned [a] | $\%HSD = 0.02336\times(L_{night})^2 - 1.83801\times(L_{night}) + 38.59201$ |
| | Falling asleep, noise mentioned [a] | $\%HSD = 0.02874\times(L_{night})^2 - 2.28953\times(L_{night}) + 48.19288$ |
| | Sleep disturbance, noise mentioned [a] | $\%HSD = 0.04580\times(L_{night})^2 - 3.79660\times(L_{night}) + 81.18761$ |
| | Combined estimate, noise mentioned [a] | $\%HSD = 0.03717\times(L_{night})^2 - 3.00711\times(L_{night}) + 63.56140$ |
| | Awakenings, noise not mentioned [b] | $\%HSD = 0.00035\times(L_{night})^2 + 0.10416\times(L_{night}) + 14.54910$ |
| | Falling asleep, noise not mentioned [b] | $\%HSD = 0.00223\times(L_{night})^2 + 0.01385\times(L_{night}) + 4.96486$ |
| | Sleep disturbance, noise not mentioned [b] | $\%HSD = 0.00166\times(L_{night})^2 - 0.00809\times(L_{night}) + 3.41917$ |
| | Combined estimate, noise not mentioned [b] | $\%HSD = 0.00094\times(L_{night})^2 + 0.06255\times(L_{night}) + 6.03940$ |

[a] Shown in Figure 6

[b] Shown in Figure 8

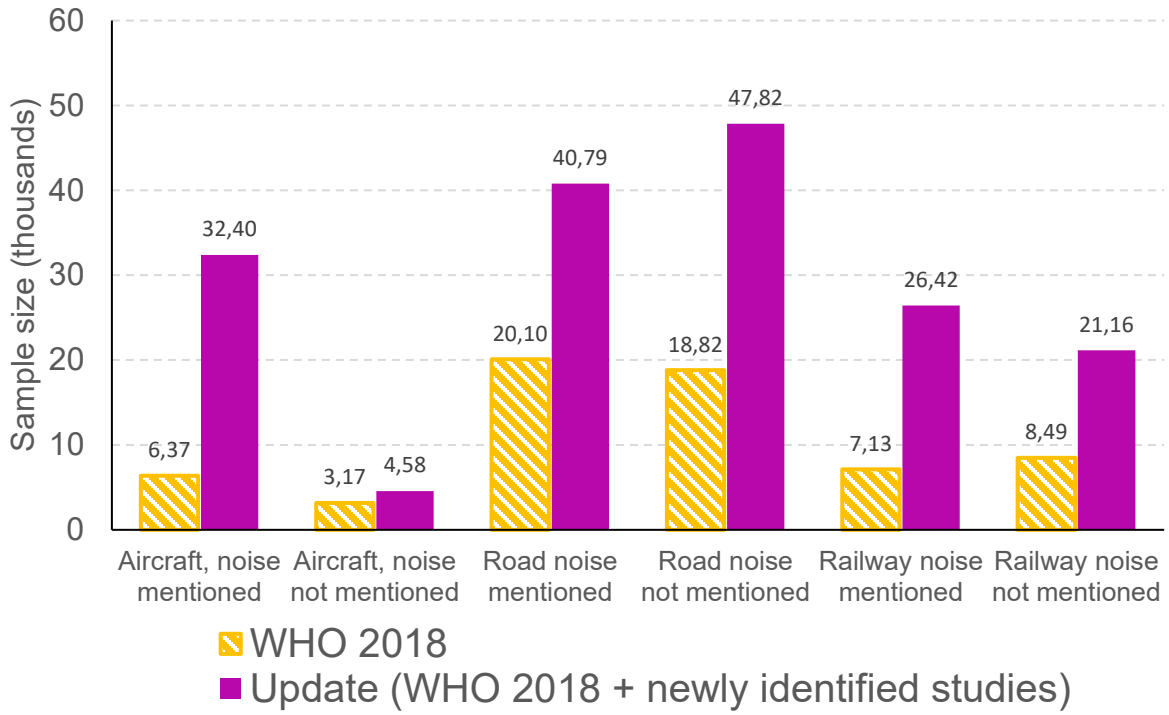


**Figure S1 Effective sample sizes for combined estimate in the updated analysis compared to the WHO 2018 review** [3]. The combined estimate was calculated as the average of sleep disturbance questions within individual studies. There were a total n=64,090 responses in the WHO review and n=170,972 responses (n=106,882 new) in the updated analysis.

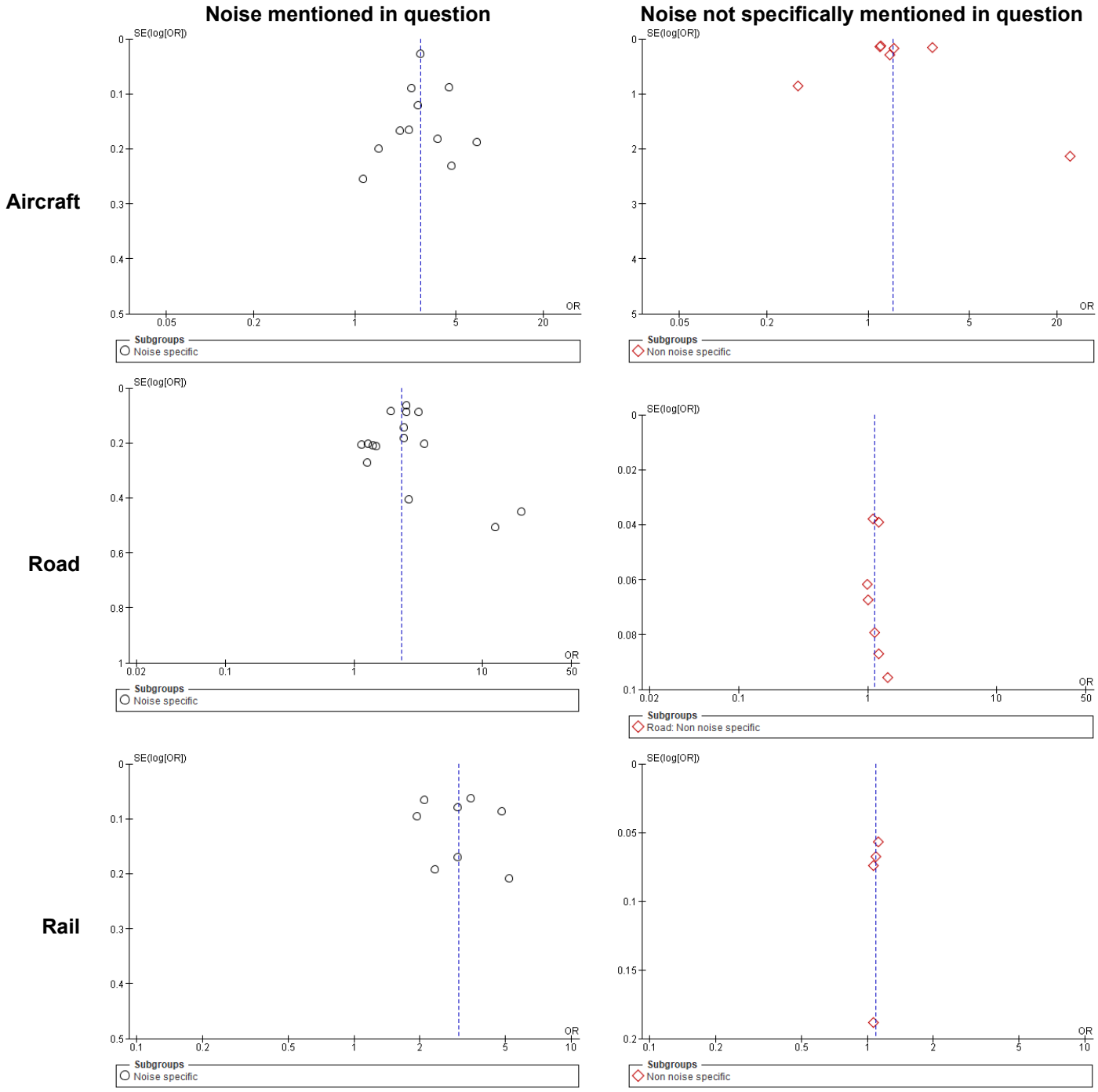


**Figure S2 Funnel plots for aircraft, road, and railway noise, stratified by whether or not the sleep disturbance question mentioned noise.** Odds ratios (OR) are calculated as the combined estimate for each individual study.

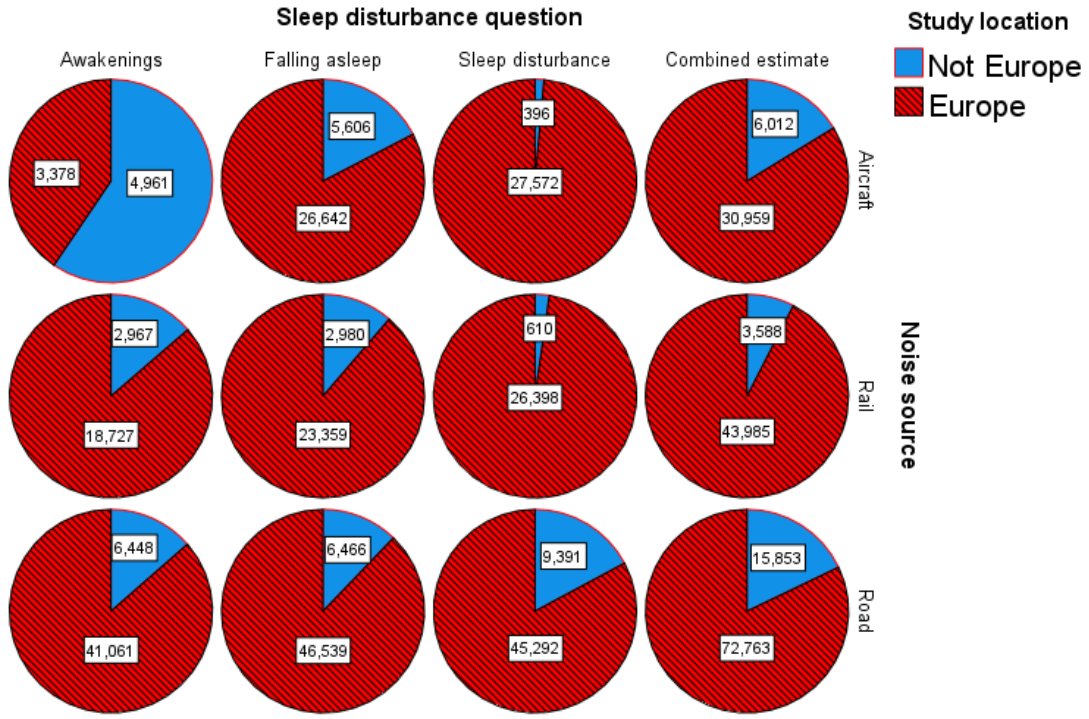


**Figure S3 Proportion of respondents from European studies (hatched red) and non-European studies (solid blue) for each sleep disturbance question and noise source.**

# Supplemental references


1. Kwak KM, Ju Y-S, Kwon Y-J, et al. The effect of aircraft noise on sleep disturbance among the residents near a civilian airport: a cross-sectional study. *Ann Occup Environ Med*. 2016;28(1):38-38. doi:10.1186/s40557-016-0123-2
2. Paiva KM, Cardoso MRA, Zannin PHT. Exposure to road traffic noise: Annoyance, perception and associated factors among Brazil's adult population. *Sci Total Environ*. Feb 10 2019;650(Pt 1):978-986. doi:10.1016/j.scitotenv.2018.09.041
3. Basner M, McGuire S. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep. *Int J Env Res Pub He*. Mar 2018;15(3)doi:10.3390/ijerph15030519
4. Bartels S, Ögren M, Kim J-L, Fredriksson S, Persson Waye K. The impact of nocturnal road traffic noise, bedroom window orientation, and work-related stress on subjective sleep quality: results of a cross-sectional study among working women. *International archives of occupational and environmental health*. 2021/10/01 2021;94(7):1523-1536. doi:10.1007/s00420-021-01696-w
5. Basner M, Witte M, McGuire S. Aircraft noise effects on sleep—Results of a pilot study near Philadelphia International Airport. *Int J Env Res Pub He*. 2019;16(17):3178.
6. Bodin T, Bjork J, Ardo J, Albin M. Annoyance, sleep and concentration problems due to combined traffic noise and the benefit of quiet side. *Int J Environ Res Public Health*. Jan 29 2015;12(2):1612-28. doi:10.3390/ijerph120201612
7. Brink M, Wirth K, Rometsch R, Schierz C. *Lärmstudie 2000 Zusammenfassung. ETH Zürich, Zentrum für Organisations- und Arbeitswissenschaften*. Institute for Organizational and Occupational Sciences (ZOA); 2005.

8. Brink M. Parameters of well-being and subjective health and their relationship with residential traffic noise exposure — A representative evaluation in Switzerland. *Environ Int*. 2011/05/01/ 2011;37(4):723-733. doi:https://doi.org/10.1016/j.envint.2011.02.011
9. Brink M, Schaffer B, Vienneau D, et al. Self-Reported Sleep Disturbance from Road, Rail and Aircraft Noise: Exposure-Response Relationships and Effect Modifiers in the SiRENE Study. *Int J Environ Res Public Health*. Oct 29 2019;16(21)doi:10.3390/ijerph16214186
10. Brown AL, Lam KC, van Kamp I. Quantification of the exposure and effects of road traffic noise in a dense Asian city: a comparison with western cities. *Environ Health*. Mar 7 2015;14:22. doi:10.1186/s12940-015-0009-8
11. Carugno M, Imbrogno P, Zucchi A, et al. Effects of aircraft noise on annoyance, sleep disorders, and blood pressure among adult residents near the Orio al Serio International Airport (BGY), Italy. *Med Lav*. Aug 28 2018;109(4):253-263. doi:10.23749/mdl.v109i4.7271
12. Evandt J, Oftedal B, Hjertager Krog N, Nafstad P, Schwarze PE, Aasvang GM. A Population-Based Study on Nighttime Road Traffic Noise and Insomnia. *Sleep*. Feb 01 2017;40(2)doi:10.1093/sleep/zsw055
13. Frei P, Mohler E, Roosli M. Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality. *International journal of hygiene and environmental health*. Mar 2014;217(2-3):188-95. doi:10.1016/j.ijheh.2013.04.003
14. Halonen JI, Vahtera J, Stansfeld S, et al. Associations between Nighttime Traffic Noise and Sleep: The Finnish Public Sector Study. *Environmental health perspectives*. 2012;120(10):1391-1396. doi:doi:10.1289/ehp.1205026
15. Hong J, Kim J, Lim C, Kim K, Lee S. The effects of long-term exposure to railway and road traffic noise on subjective sleep disturbance. *J Acoust Soc Am*. Nov 2010;128(5):2829-35. doi:10.1121/1.3493437
16. Martens AL, Reedijk M, Smid T, et al. Modeled and perceived RF-EMF, noise and air pollution and symptoms in a population cohort. Is perception key in predicting symptoms? *Sci Total Environ*. Oct 15 2018;639:75-83. doi:10.1016/j.scitotenv.2018.05.007
17. Nguyen TL, Yano T, Nishimura T, Sato T. Social survey on community response to aircraft noise in Ho Chi Minh city. presented at: Internoise 2019; 23-26 August 2009; Ottawa, ON, Canada.
18. Nguyen TL, Yano T, Nguyen HQ, et al. Community response to aircraft and combined noises in Hanoi. presented at: Internoise 2010; 13-16 June 2010; Lisbon, Portugal.
19. Nguyen TL, Yano T, Nguyen HQ, et al. Community response to aircraft noise in Ho Chi Minh City and Hanoi. *Applied Acoustics*. 2011/11/01/ 2011;72(11):814-822. doi:https://doi.org/10.1016/j.apacoust.2011.05.002
20. Nguyen TL, Yano T, Nguyen HQ, et al. Aircraft and road traffic noise annoyance in Da Nang City, Vietnam. presented at: Internoise 2012; 19-22 August 2012; New York, NY, USA.
21. Nguyen LT, Nguyen TL, Yano T, et al. Social surveys around Noi Bai Airport before and after the opening of a new terminal building. presented at: Internoise 2015; 2015; San Franciso, CA, USA.
22. Nguyen TL, Trieu BL, Hiraguri Y, Morinaga M, Morihara T, Yano T. Effects of Changes in Acoustic and Non-Acoustic Factors on Public Health and Reactions: Follow-Up Surveys in the Vicinity of the Hanoi Noi Bai International Airport. *Int J Environ Res Public Health*. Apr 10 2020;17(7)doi:10.3390/ijerph17072597
23. Overview NORAH-study, methodology and results. Accessed 6 April, 2021. http://www.laermstudie.de/en
24. Phan HYT, Yano T, Phan HAT, Nishimura T, Sato T, Hashimoto Y. Community responses to road traffic noise in Hanoi and Ho Chi Minh City. *Applied Acoustics*. 2010/02/01/ 2010;71(2):107-114. doi:https://doi.org/10.1016/j.apacoust.2009.08.004
25. Shimoyama K, Nguyen TL, Yano T, Morihara T. Social surveys on community response to road traffic in five cities in Vietnam. presented at: Internoise 2014; 16-19 November 2014; Melbourne, Australia.

26. Ristovska G, Gjorgjev D, Stikova E, Petrova V, Cakar MD. Noise induced sleep disturbance in adult population: Cross sectional study in Skopje urban centre. *Maced J Med Sci*. 2009;2:255-260.
27. Rocha S, Smith MG, Witte M, Basner M. Survey Results of a Pilot Sleep Study Near Atlanta International Airport. *Int J Env Res Pub He*. 2019;16(22):4321.
28. Sato T, Yano T, Björkman M, Rylander R. Comparison of community response to road traffic noise in Japan and Sweden—Part I: Outline of surveys and dose–response relationships. *Journal of Sound and Vibration*. 2002/02/07/ 2002;250(1):161-167. doi:https://doi.org/10.1006/jsvi.2001.3892
29. Sato T, Yano T, Morihara T, Masden K. Relationships between rating scales, question stem wording, and community responses to railway noise. *Journal of Sound and Vibration*. 2004/10/22/ 2004;277(3):609-616. doi:https://doi.org/10.1016/j.jsv.2004.03.023
30. Schreckenberg D, Heudorf U, Eikmann T, Meis M. Aircraft noise and health of residents living in the vicinity of Frankfurt airport. presented at: Euronoise 2009; 26-28 October 2009; Edinburgh, UK.
31. Schreckenberg D. Exposure-response relationship for railway noise annoyance in the Middle Rhine Valley. presented at: Internoise 2013; 15-18 September 2013; Innsbruck, Austria.
32. Smith MG, Rocha S, Witte M, Basner M. On the feasibility of measuring physiologic and self-reported sleep disturbance by aircraft noise on a national scale: A pilot study around Atlanta airport. *Science of The Total Environment*. 2020/05/20/ 2020;718:137368. doi:https://doi.org/10.1016/j.scitotenv.2020.137368
33. Civil Aviation Authority. *Survey of noise attitudes 2014: Aircraft. CAP 1506*. 2017. CAP 1506. http://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=7744
34. Yano T, Nguyen TL, Nguyen TL, et al. Community response to a step change in aircraft noise exposure: The first socio-acoustic survey around Noi Bai Airport in Hanoi. presented at: 22nd International Congress on Sound and Vibration; 12–16 July 2015; Florence, Italy.