SIENA Consortium

Sustainable Infrastructure and Evidence for Noise and Air

EVIDENCE REVIEW FOR EFFECTS OF SOUNDPROOFING ON RESIDENTS' MENTAL WELLBEING AND ALTERNATIVE DESIGNS

VOLUME I: Systematic Review

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1. SCOPE OF THE REVIEW

Search method

The methodology mirrors that used in the systematic reviews carried out to inform the World Health Organization's (WHO) Environmental Noise Guidelines for the European Region (World Health Organization, 2018) and the Defra review in 2020 (Clark et al., 2020), where possible. The review sought to identify original/primary quantitative and qualitative research papers, where available.

Research question

What are the effects of indoor sound environments on mental health, wellbeing, quality of life, annoyance and sleep?

Search terms

The search terms were designed to cover both positive and negative effects of sound: noise terms were included (albeit, whilst usually examined in relation to negative effects) as well as sound to ensure that papers covering both negative and positive aspects were identified. The review approached sound environments from a neutral standpoint. The focus was on indoor sound environments but also included studies which examined how external noise sources are perceived within the indoor residential environment. Papers were not limited in terms of research design, with the aim to identify epidemiological (cohort studies, cross-sectional surveys), as well as experimental, laboratory and qualitative research studies. The broad range of study types included means that the effects of acute and chronic noise exposure would be included within the search. This differs from the WHO and Defra reviews, which excluded experimental and laboratory studies focused on acute noise exposure.

The search terms included the following domains:

- Context;
- Sound;
- Noise;
- Health (wellbeing, mental health, quality of life, annoyance, sleep);
- Perception & Evaluation of sound or noise;
- Non-acoustic factors; and
- Sound insulation/treatment.

(see

Table *1* for details of the search terms included for each domain).

Timeframe & Databases

We searched for papers published in English only. The searches were carried out for the period 1st January 2019-31st January 2023[1] in the following databases:

- Web of Science
- PubMed[2]

Whilst originally within the scope of the project, we did not search abstracts from relevant acoustics conferences. Such searches would have exponentially increased the number of papers identified, taking the project beyond the budget and time-constraints. Such searches could be the focus of further research, but it should be noted that these publications have not undergone rigorous peer-review.

Context	Resident* OR internal soundscape* OR "indoor soundscape*" OR (indoor AND (noise OR sound)) AND (2019:2023[pdat])
Noise	Noise AND (Motorcycle* OR environment* OR traffic OR road OR airport OR aircraft OR railway OR industr* OR build* OR vent* OR (mechanic* AND service) OR (air condition*) OR neighbor* OR neighbour* OR transport* OR train OR "leisure activities" OR "low frequency" OR classroom OR school* OR combined OR nuisance OR "air pollution" OR "source heat pump*" OR household OR wind turbine OR wind farm OR gym OR entertain* OR music OR venue)
Sound	Sound* OR psychoacoustic* OR loudness OR fluctuation OR sharpness OR roughness OR (sound AND level) OR frequency OR spectrum OR intermitan* OR strike OR bang

[1] This timeframe was chosen to balance the project aims, budget, and timescales.

[2] Previous Defra reviews searched PubMed and Science Direct. We have replaced Science Direct with Web of Science with the aim of broadening the journals searched to additionally include engineering and acoustics focused journals.

Health	"mental health" OR (emotion* AND disease OR disorder) OR psycholog* OR anxiety OR "depressive disorder" OR depression OR health OR wellbeing OR "well being" OR satisfaction OR "quality of life" OR helplessness OR "Attention Deficit Hyperactivity Disorder" OR ADHD OR annoy* OR sleep* OR "obsessive compulsive disorder" OR OCD OR autism OR Lonel* OR Isolat* OR vulnerab* OR "social interaction" OR neglect OR connect*
Perception	"acoustic quality" OR "sound quality" OR pleasant OR unpleasant OR vibrancy OR tranquil* OR psychosocial OR "psycho-social" OR "acoustic demands" OR "sound preference" OR restoration OR "acoustic comfort" OR "complaint" OR control OR coping
Non-acoustic factors	"perceived control" OR "non-acoustic factors" OR "non acoustic factors" OR "aural diversity" OR Demographic* OR attitude* OR "noise sensitivity" OR ageing OR aging OR illness OR "poor health" or "neural divers*"
Sound insulation/treatment	insula* OR "good acoustic* design" OR facade OR vent* OR build* OR envelope OR "noise mitigation" OR "thermal efficiency" OR window* OR glaz* OR "structure borne noise" OR vibrat* OR overheat* OR transfer OR privacy OR (noise AND insulation) OR (noise AND ingress) OR (internal AND ambient AND noise) OR (sleep AND disturbance) OR (thermal AND efficiency AND noise) OR (sound AND transfer) OR ("structure borne" AND noise AND transfer) OR (airborne AND noise AND transfer) OR (entertain* AND noise AND protection) OR (Neighbour AND sound AND transfer) OR (Neighbor AND sound AND transfer)

*denotes a search term that will look for all endings of the word with that stem.

Table 1: Search terms by domain

Data screening and review process

Papers were reviewed in two stages. First, all the titles and abstracts of the identified papers were reviewed by two reviewers (KW, CC) to assess eligibility for inclusion in the review. Second, the full text of eligible papers was retrieved, and one reviewer (KW or EM) read the paper and re-assessed eligibility for inclusion. At both stages, 10% of the titles and abstracts and full text papers were reviewed by a second reviewer (KW, EM, CC), with any disagreement between the reviewers' discussed and consensus reached.

Data extraction

The eligibility criteria matched those used by the reviews undertaken for the WHO and Defra covering the aspects listed below. Papers which failed to meet any one of the (PECO) inclusion criteria or which met one of the exclusion criteria were excluded from the review. Given the broader focus on indoor sound and noise for the current review compared to previous reviews, the criteria for 'Exposure' were adapted from the previous WHO and Defra reviews which had focused on robust calculated or measured noise exposure levels. We also excluded the criteria of 'Comparator' for some papers as the research question did not require that the study has a comparator group with no noise exposure or a lower level of noise exposure.

- Population: the inclusion criteria will be studies of the general population or specific sub-groups of the population in any residential and home settings (including care homes).

- Exposure: the inclusion criteria will be any exposure to sound or noise, from the sources specified above in

- Table *1*. Included studies could either measure or calculate noise exposure levels expressed in decibel values at an appropriate location for the study participants' residence or be subjective ratings of noise and sound.

- Assessment of outcome: the inclusion criteria was that the outcome data came from medical records or interviews using a known scale or validated standardised assessment method or that the outcome was self-reported from a questionnaire or interview.

Papers were identified for inclusion in the systematic review regardless of the study findings, i.e., all papers, regardless of whether they found a significant positive or negative association between noise or sound and the health outcome or whether they found no effect are considered in the review.

Evaluation
Quantitative studies
Quantitative studies were assessed for potential bias using the following criteria (as used by previous WHO and Defra reviews):

- **Noise exposure assessment leading to information bias**: evaluating whether the paper used established noise metrics in dB; the timeframe of noise measurements, if applicable; and quality of noise modelling, if applicable.[3]

- **Bias due to confounding**: evaluating whether the study used matching or adjustment in the analysis for potential confounding factors, such as socioeconomic status, which can influence both noise/sound exposure and the health outcome.

- **Bias due to selection of participants**: whether participants are randomly sampled from a known population and whether the response rate was higher than 60%. Consideration of bias associated with drop out for longitudinal studies.

- **Outcome assessment leading to information bias I**: whether the assessment of the outcome is objectively measured using a known scale or validated measure.

- **Outcome assessment leading to information bias II**: whether the assessment is blinded for exposure information in cohort.

[3] This criteria would not always be relevant for studies, particularly for studies using a soundscape methodology or qualitative methodology.

Ratings for each type of bias were 'low bias', 'unclear', or 'high bias'. Bias is considered present if the required information was omitted from the paper.

For quantitative studies, we then applied the GRADE methodology, recommended by the WHO Handbook for Guideline Development (Guyatt et al., 2008) and adapted for use in the WHO Environmental Noise Guidelines for the European Region (World Health Organization, 2018) to interpret the body of evidence. The GRADE methodology ranks the quality of evidence as 'high', 'moderate', 'low', or 'very low' (See Table 2).

The GRADE methodology was established to evaluate evidence including randomised control trials. The GRADE methodology was therefore adapted by the WHO for use in the Environmental Noise Guidelines (ENG) so it assigns the highest quality of evidence to intervention or longitudinal studies as opposed to randomised control trials. Where only cross-sectional studies are available the evidence is initially judged as being of low quality.

Grade	Definition
High	We are very confident that the true effect lies close to that of the estimate of the effect.
Moderate	We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low	Our confidence in the estimate is limited: The true effect may be substantially different from the estimate of the effect.
Very Low	We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of the effect.

Table 2: Definitions of quality of evidence for GRADE

The GRADE methodology does not rate individual studies but is used to rate the **overall quality of evidence available for a specific noise/sound source and health outcome**—that is all the quantitative studies available, regardless of whether they find a significant statistical effect of noise/sound on a specific health outcome or not. The

GRADE assessment was undertaken individually for each noise/sound and health outcome, even if only one study was available, with the approach adapted to include the concept of sound alongside noise.

The GRADE methodology allows for the initial evidence ratings to be further upgraded or downgraded according to a number of criteria (Guyatt et al., 2008, Clark and Paunović, 2018). Upgrades can be made based on the magnitude of the risk estimate; or for there being evidence for an effect despite confounding working towards the null. However, previous applications of GRADE to the noise and health evidence have rarely made any upgrading of the evidence.

Downgrades can be made on the following criteria:

- **Bias risk -** risk of bias in individual studies;

- **Inconsistency -** inconsistent findings between studies;
- **Indirectness of the evidence -** studies not comparing the same outcomes or populations;
- **Precision -** effect estimate confidence interval containing 25% harm or benefit;
- **Publication bias-** as assessed statistically by a funnel plot.

The last two criteria (precision and publication bias) can only be assessed in systematic reviews where meta-analyses are conducted. As this is a narrative systematic review, it is not possible to assess precision or publication bias.

Qualitative studies

Qualitative studies were assessed for bias using the CASP checklist for qualitative research which has the following criteria (CASP):

- Was there a clear statement of the aims of the research?
- Is a qualitative methodology appropriate?
- Was the research design appropriate to address the aims of the research?
- Was the recruitment strategy appropriate to the aims of the research?
- Was the data collected in a way that addressed the research issue?
- Has the relationship between the researcher and participants been adequately considered?
- Have ethical issues been taken into consideration
- Was the data analysis sufficiently rigorous?
- Is there a clear statement of findings?
- How valuable is the research?

Ratings for each statement were 'Yes', 'Can't tell', 'No'. To match the bias ratings undertaken for the quantitative studies, a final assessment based on the CASP checklist was made for the study, quantifying if the bias was 'high', 'unclear' or 'low'.

For qualitative studies, the GRADE-CERQual method for assessing how much confidence to place in findings from systematic reviews of qualitative research was used (Lewin et al., 2018). This assesses the following aspects of the evidence:

- Methodological limitations - the extent to which there are concerns about the design or conduct of the primary studies that contributed evidence to an individual review finding;
- Coherence – the extent to which the data from the primary studies is clear and supported is the data from the primary studies and a review finding that synthesises that data;
- Adequacy of data - the degree of richness and quantity of data supporting a review finding; and
- Relevance - the extent to which the body of evidence from the primary studies supporting a review finding is applicable to the context (perspective or population, phenomenon of interest, setting) specified in the review question.

The approach for qualitative studies is comparable to that for quantitative evidence reviews. Confidence in the evidence is rate as ‘high’, ‘moderate’, ‘low’ and ‘very low’.

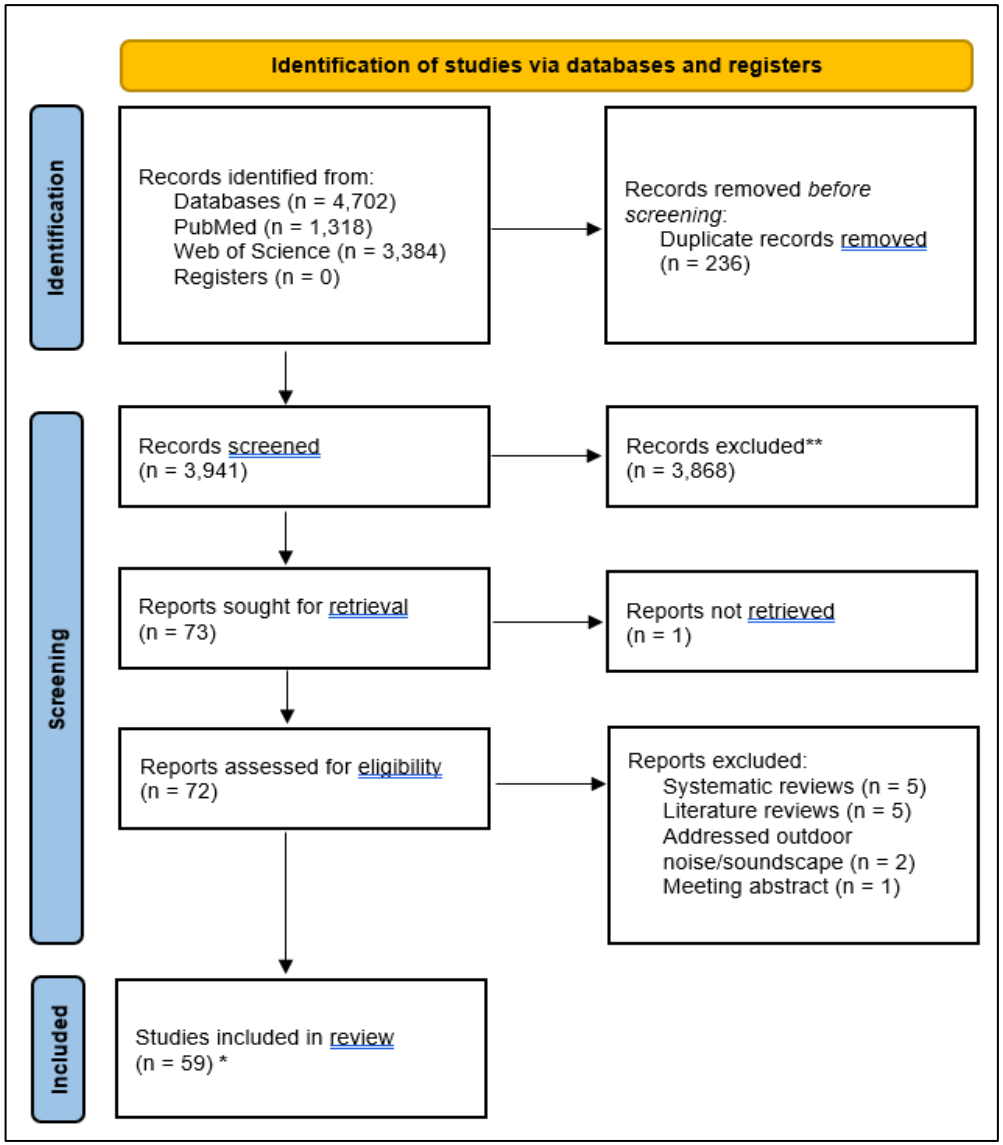
2. RESULTS

2.1. OVERVIEW

The systematic review identified 59 studies which examined the effects of indoor sound environments on mental health, wellbeing, quality of life, annoyance and sleep.

The systematic review process is shown in detail in Figure 1 (Page et al., 2021). Initially, 73 papers were sought for retrieval, one paper could not be located and appeared not to exist in publication form, despite having been listed on the databases. From the 72 remaining papers, 13 were excluded after full paper review: 5 because they were systematic reviews and not primary papers; 5 because they were narrative reviews; 2 because they addressed only outdoor noise or soundscapes; and one because it was a meeting abstract. No further studies were identified by the project team for inclusion in the review, after the search had been conducted.

The detailed data extraction table is published here (Clark et al., 2023).



***** two papers have been merged in the extraction table as they report on the same study. See: *Torresin et al. 2020; 2022.*

Figure 1: PRISMA 2020 flow diagram for the systematic review

The identified studies used two methodologies: 1) surveys and 2) experimental studies. Most studies used quantitative approaches, with fewer studies employing qualitative or mixed-method (combining quantitative and qualitative) approaches.

As a whole, the studies present a varied collection. We noted the following.

- The studies were conducted across a range of continents and countries including Asia (China, Japan, Singapore, South Korea), Europe (Bulgaria, Italy, the Netherlands, Slovakia, Sweden, Spain), Afghanistan, Australia, India, and Canada. Only a few studies were from the United Kingdom. We did not exclude any country or geographical area from the review, but it should be noted that some of the building types or geographical areas included may have limited applicability when considering the UK context.

- Most studies were of adult populations. A few studies examined elderly populations, living in residential care settings and/or with dementia.

- Many studies used the term 'soundscapes' but only a few studies reported using the ISO Soundscape approaches and methods (ISO 12913-1:2014, 2014, ISO/TS 12913-2:2018, 2018, ISO/TS 12913-3:2019, 2019).

- A range of wellbeing measures and perceptions were examined as outcomes including annoyance, stress, anxiety, loneliness, pleasantness, eventfulness, satisfaction, anxiety, and quality of life. Few studies assessed physiological outcomes such as heart rate. Many studies did not use or report using the ISO annoyance methodology (ISO/TS15666:2003, 2003, ISO/TS15666:2021, 2021).

- Many studies were unclear about the population of interest and the sampling framework and failed to report response rates.

- A few papers focused on how COVID-19 changed people's experience of sound in their dwellings but few studies used longitudinal 'before and after' methodologies to examine these issues.

- Very few studies examined interventions.

- Very few studies collect detailed information about the residential building type or design and building factors that might influence sound/noise and wellbeing.

- The quality of the statistical analysis and qualitative analyses was often poor. For the quantitative studies the statistical analyses were often unsophisticated, presenting only descriptive statistics. Analyses often failed to account for potential confounding. Few studies reported multivariate statistical analyses.

The following sections describe the studies, the bias ratings, and the GRADE assessments for each topic.

2.2. RESIDENTIAL SOUNDSCAPES AND WELLBEING.

Most studies identified in the systematic review examined the role of sound and noise on wellbeing, broadly defined here to include annoyance, quality of life, loneliness, satisfaction, sleep and health outcomes, and perceptions in residential environments.

The evidence covered the following topics:

1. Surveys of residential settings and effects on wellbeing and perceptions:
    a. In general adult populations;
    b. In elderly populations;
    c. In working from home populations; and
    d. Effects and changes to sound and noise associated with COVID-19.
2. Experimental studies of residential settings and effects on wellbeing

The following section evaluates the evidence for each of these topics.

Survey studies of residential soundscapes on wellbeing and perceptions: general adult populations

18 studies examined the influence of sound and noise in residential settings on wellbeing and perceptions on general adult populations using survey methods (Amiryar and Asano, 2022, Argalasova et al., 2022, Benz et al., 2021, Dance and Gomez-Agustina, 2021, Gilani and Mir, 2021, Kou et al., 2021, Lee et al., 2020, Mohamed and Dokmeci Yorukoglu, 2020, Park and Lee, 2019b, Park and Lee, 2019a, Pedersen et al., 2021, Qu and Tsuchiya, 2021, Santurtún et al., 2022, Walsh et al., 2021, Warner et al., 2022, Hasegawa and Lau, 2022, Hasegawa et al., 2022, Wang and Norbäck, 2021, Xie et al., 2021). These studies were from Australia, Afghanistan, Brazil, China, India, Singapore, Slovakia, South Korea, Spain, Sweden, Turkey, and the UK. These studies used quantitative, qualitative, and mixed-method approaches. The studies were cross-sectional.

For the quantitative studies the ratings of bias were mostly ‘high’, with a few studies rated as having ‘unclear’ bias (Table 3). The studies often failed to report the sampling framework or had low-response rates. Many studies failed to use or report standardised assessments of annoyance or wellbeing. Most studies failed to adjust analyses for potential confounding factors and, in general, conducted unsophisticated statistical analyses.

For the qualitative studies the ratings of bias were 'high' (Table 4). Studies often did not report the sampling framework, data collection framework, or present rigorous robust qualitative data analysis methods.

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
Amiryar & Asano, 2022	Urban Sci	High	High	Low	High	High	High
Argalasova et al., 2022	Civ Environ Eng	Low	High	High	High	Unclear	High
Benz et al., 2021	Int J Environ Res Public Health	High	Low	High	Low	Unclear	Unclear
Dance & Gomez, 2021	Noise Health	Low	High	High	High	Unclear	High
Gilani & Mir, 2021	Environ Sci Pollut Res	Low	Low	Low	Low	High	Low
Mohamed & Yorukoglu, 2022	Build Acoust	High	High	High	Unclear	High	High
Park & Lee, 2019	Appl Acoust	Low	Low	High	Low	Unclear	Unclear
Pederson et al., 2021	Build Environ	Unclear	Low	High	Unclear	High	Unclear
Qu & Tsuchiya, 2021	Front Psychol	Low	Low	High	Low	Unclear	Unclear
Santurtún et al., 2022	Int J Environ Res Public Health	High	Low	High	Low	Unclear	Unclear
Hasegawa & Lau, 2022	Landsc Urban Plan	Low	Low	Unclear	Low	Unclear	Unclear
Hasegawa et al., 2022	Landsc Urban Plan	Low	Low	Unclear	Low	Unclear	Unclear
Wang & Norback, 2021	BMC Public Health	High	High	High	High	High	High
Xie et al., 2021	Indoor Built Environ	High	High	Unclear	Unclear	Unclear	High

Table 3: Rating of bias for the quantitative survey studies of residential soundscapes and wellbeing/perceptions: general adult populations

Reference	Journal	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	Overall risk of bias
Kou et al., 2021	Geoforum	Yes	Yes	Yes	Can't tell	Can't tell	No	No	No	No	High
Park & Lee, 2019	JCOP	Yes	Yes	Yes	No	Can't tell	No	No	Can't tell	Yes	High
Warner et al., 2022	Environ Justice	Yes	Yes	Yes	Can't tell	No	No	No	No	No	High
Walsh et al., 2021	Hous.Theory Soc	No	Yes	Can't tell	Yes	Can't tell	No	No	No	No	High

Table 4: Rating of bias for the qualitative survey studies of residential soundscapes and wellbeing/perceptions: general adult populations

For the quality of the evidence across the quantitative studies, adapting the GRADE approach, we considered longitudinal or intervention studies the ideal study design. The highest level of evidence available for the survey studies of effects of residential soundscapes on wellbeing and perceptions in general adult populations was cross-sectional, so we initially judged the evidence to be of low quality based on the lack of longitudinal or intervention studies (Table 5). This was further downgraded to '**very low' quality** due to risk of bias. No upgrades were made.

Domains	Criterion	Assessment
Start level	Cross-sectional	Low quality
1. Study design	Majority of studies have high or unclear risk of bias	Downgrade
2. Inconsistency	Fairly consistent evidence for an effect of sound/noise on wellbeing	No downgrade
3. Indirectness	Studies comparing similar outcomes	No downgrade
4. Precision	Not assessed	n.a.
5. Publication bias	Not assessed	n.a.
Overall judgement after downgrading process	n.a.	Very low quality
6. Dose-response	Not assessed	No upgrade
7. Magnitude of effect	Generally less than RR >2	No upgrade
8. Confounding adjustment	Omits control for range of confounding factors	No upgrade
Overall judgement after upgrading process	n.a.	Very low quality

Table 5: GRADE for the quality of the evidence for quantitative survey studies of effects of residential soundscapes on wellbeing and perceptions in general adult populations.

For the quality of the evidence across the qualitative studies, using the GRADE CERQual approach, we evaluated several findings across the evidence (see Table 6). All of the findings were rated as having **'very low' confidence**, given the small number of studies available, and the methodological limitations associated with the evidence.

Key findings	Studies contributing to the finding	Methodological Limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual Assessment
Neighbour noise interfering with privacy	Kou et al., 2021; Park & Lee, 2019; Walsh et al., 2021	Serious concerns about methodological concerns. All studies had unclear recruitment strategies and lack robust data analysis	No or very minor concerns about coherence. Studies report similar findings	Major concerns about adequacy: Studies found in small number of papers, in studies with small number of participants	Major concerns about relevance. Small geographical range of areas	Very low confidence	Data from 3 small scale studies from 3 countries, with serious methodological limitations.
Perceptions that indoor environmental noise has health impacts (annoyance, sleep, stress)	Kou et al., 2021; Warner et al., 2022; Walsh et al., 2021	Serious concerns about methodological concerns. All studies had unclear recruitment strategies and lack robust data analysis	No or very minor concerns about coherence. Studies report similar findings	Major concerns about adequacy: Results found in small number of papers, in studies with small number of participants	Major concerns about relevance. Small geographical range of areas	Very low confidence	Data from 3 small scale studies from 3 countries, with serious methodological limitations.
Poor sound proofing and insulation contributes to neighbour noise	Walsh et al., 2021	Serious concerns about methodological concerns. Study had unclear recruitment strategies and lacked robust data analysis	Unable to assess n=1	Major concerns about adequacy: only reported in one study with a small number of participants	Major concerns about relevance. One study conducted in two Australian cities.	Very low confidence	Data from 1 small scale study, with serious methodological limitations.
Those with poor mobility more exposed to neighbour noise and its impacts	Kou et al., 2021	Serious concerns about methodological concerns. Study had unclear recruitment strategies and lacked robust data analysis	Unable to assess n=1	Major concerns about adequacy: only reported in one study with a small number of participants	Major concerns about relevance. One study conducted in China.	Very low confidence	Data from 1 small scale study, with serious methodological limitations.
Attitudes to neighbours an important modifier of perceptions and reactions to neighbour noise	Park & Lee, 2019; Walsh et al., 2021	Serious concerns about methodological concerns. Study had unclear recruitment strategies and lacked robust data analysis	No or very minor concerns about coherence. Studies report similar findings	Major concerns about adequacy: Results found in small number of papers, in studies with small number of participants	Major concerns about relevance. Small geographical range of areas	Very low confidence	Data from 2 small scale studies from two countries, with serious methodological limitations.

Table 6: GRADE-CERQual for the quality of the evidence for qualitative survey studies of effects of residential soundscapes on wellbeing and perceptions in general adult populations.

Survey studies of residential soundscapes on wellbeing and perceptions: elderly populations

Four studies examined the influence of sound and noise in residential settings on wellbeing and perceptions in elderly populations using survey methods (Wu et al., 2022, Xie et al., 2020, Mu et al., 2021, Cui et al., 2021). Three of these studies were quantitative and one was qualitative (Wu et al., 2022). All the studies were conducted in China. Some studies used the ISO soundscape approach in care homes. Some studies used standardised health outcomes to assess links of sound and noise on depression and loneliness.

The bias rating for the individual quantitative papers was 'high' and 'unclear' (Table 7). Studies often failed to report how the residential care homes and participants had been selected for the study, raising issues of representativeness of the sample and the generalisability of the findings. Response rates were not reported. One paper was rated as having 'high' bias for not taking confounding into account, in addition to the reasons mentioned above. Similar issues with bias were identified for the qualitative paper (Table 8).

For the quality of the evidence across the quantitative studies, adapting the GRADE approach, we considered longitudinal or intervention studies the ideal study design. The highest level of evidence available for the survey studies of effects of residential soundscapes on wellbeing and perceptions in elderly populations was cross-sectional (Table 9), so we initially judged the evidence to be of low quality based on the lack of longitudinal or intervention studies. This was further downgraded to '**very low' quality** due to risk of bias.

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
Xie et al., 2020	Build Acoust	High	High	High	Unclear	Unclear	High
Mu et al., 2021	Appl Acoust	Low	Unclear	High	Unclear	Unclear	Unclear
Cui et al., Front Psychol, 2021	Front Psychol	Unclear	Unclear	Unclear	Low	Unclear	Unclear

Table 7: Rating of bias for the quantitative survey studies of residential soundscapes and wellbeing/perceptions: elderly populations

Reference	Journal	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	Overall risk of bias
Wu et al., 2022	Buildings	Yes	Yes	Yes	Can't tell	Yes	No	Yes	Yes	Yes	Unclear

Table 8: Rating of bias for the qualitative survey studies of residential soundscapes and wellbeing/perceptions: elderly populations

Domains	Criterion	Assessment
Start level	Cross-sectional	Low quality
1. Study design	Studies have high or unclear risk of bias	Downgrade
2. Inconsistency	Fairly consistent evidence for an effect of sound/noise on wellbeing	No downgrade
3. Indirectness	Studies comparing similar outcomes	No downgrade
4. Precision	Not assessed	n.a.
5. Publication bias	Not assessed	n.a.
Overall judgement after downgrading process	n.a.	Very low quality
6. Dose-response	Not assessed	No upgrade
7. Magnitude of effect	Generally less than RR >2	No upgrade
8. Confounding adjustment	Omits control for range of confounding factors	No upgrade
Overall judgement after upgrading process	n.a.	Very low quality

Table 9: GRADE for the quality of the evidence for survey studies of effects of residential soundscapes on wellbeing and perceptions in elderly populations.

For the quality of the qualitative evidence, using the GRADE CERQual approach, we evaluated the finding that blind residents and nursing staff had strong preferences for natural sounds (see Table 10). The evidence was rated as having **'very low' confidence**, given that only one study was available, and the methodological limitations associated with the evidence.

Key findings	Studies contributing to the finding	Methodological Limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual Assessment
Blind residents and nursing staff had strong preferences for natural sounds	Wu et al., 2022	Minor concerns about methodology due to lack of detail of methodology and role of the researcher.	Unable to assess n=1	Major concerns about adequacy: only reported in one study with a small number of participants	Major concerns about relevance. One study conducted in China	Very low confidence	Data from 1 small scale study, with some methodological limitations.

Table 10: GRADE-CERQual for the quality of the evidence for qualitative survey studies of effects of residential soundscapes on wellbeing and perceptions in elderly populations.

Survey studies of residential soundscapes on wellbeing and perceptions: WFH populations

Seven studies examined the influence of sound and noise in residential settings on wellbeing and perceptions in working from home populations using survey methods (Andargie et al., 2021, Boegheim et al., 2022, Natomi et al., 2022, Torresin et al., 2022a, Torresin et al., 2021, Torresin et al., 2022b, Torresin et al., 2022c). These studies were quantitative and were carried out in Canada, Italy, Japan, the Netherlands, and the UK. The four UK studies were Torresin et al. (2021), Torresin et al. (2022b), Torresin et al. (2022a), and Torresin et al. (2022c). The studies were all quantitative and cross-sectional, except (Torresin et al., 2022c) which was qualitative. The studies examined sound and noise, wellbeing, stress, comfort, and perceived productivity in WFH populations. Some of these studies were conducted to

examine how sound and noise had changed at home during COVID-19[4]. Only one study was a longitudinal before and after studies, albeit of an extremely small sample (n=47) (Andargie et al., 2021).

Table 11 shows the bias ratings for the quantitative studies. Most studies were rated as having 'high' bias. Studies often failed to report enough detail about how the sample had been identified and recruited and failed to report response rates. Some studies used snowballing techniques to identify participants introducing risk of further bias in terms of the representativeness of the sample and generalisability of the findings.

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
Andargie et al., 2021	Building Acoust	High	High	High	High	High	High
Boegheim et al., 2022	Facilities	Low	High	High	Low	Unclear	Unclear
Natomi et al., 2022	Int J Environ Res Public Health	High	High	High	Low	Unclear	High
Torresin et al., 2022	Build Serv Eng Res Technol	High	High	High	Low	Unclear	High
Torresin et al., 2021	Appl Acoust	High	High	High	Low	Unclear	High
Torresin et al., 2022	Appl Acoust	High	High	High	Low	Unclear	High

Table 11: Rating of bias for the quantitative survey studies of residential soundscapes and wellbeing/perceptions: WFH populations

The qualitative evidence was rated as having 'unclear' bias for similar reasons of sampling and generalisability.

[4] These studies are also evaluated under the 'Survey studies of residential soundscapes and wellbeing during COVID-19' topic.

Reference	Journal	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	Overall risk of bias
Torresin et al., 2022	Front Psychol	Yes	Yes	Yes	Can't tell	Can't tell	Can't tell	Yes	Yes	Yes	Unclear

Table 12: Rating of bias for the qualitative survey studies of residential soundscapes and wellbeing/perceptions: WFH populations

For the quality of the evidence across the quantitative studies, adapting the GRADE approach, we considered longitudinal or intervention studies the ideal study design. The highest level of evidence available for the survey studies of effects of residential soundscapes on wellbeing and perceptions in WFH populations was longitudinal, albeit on an extremely small sample, so we initially judged the evidence to be of high quality (Table 13). This was downgraded to **low quality** due to risk of bias and indirectness, as some studies did not use standardised assessments and the outcomes varied across the evidence base.

Domains	Criterion	Assessment
Start level	Longitudinal	High quality
1. Study design	Studies have high or unclear risk of bias	Downgrade
2. Inconsistency	Fairly consistent evidence for an effect of sound/noise on wellbeing	No downgrade
3. Indirectness	Studies not always comparing similar outcomes	Downgrade
4. Precision	Not assessed	n.a.
5. Publication bias	Not assessed	n.a.
Overall judgement after downgrading process	n.a.	Low quality
6. Dose-response	Not assessed	No upgrade
7. Magnitude of effect	Generally less than RR >2	No upgrade
8. Confounding adjustment	Omits control for range of confounding factors	No upgrade
Overall judgement after upgrading process	n.a.	Low quality

Table 13: GRADE for the quality of the evidence for quantitative survey studies of effects of residential soundscapes on wellbeing and perceptions in WFH populations.

For the quality of the qualitative evidence, using the GRADE CERQual approach, we evaluated the finding the ideal WFH soundscape was a quiet, well-sound insulated environment, with access to positive sounds (i.e., natural sounds, music, urban background), ensuring privacy, intimacy, and self-expression (see

Table 14). The evidence was rated as having **'very low' confidence**, given that only one study was available, and the methodological limitations associated with the evidence.

Key findings	Studies contributing to the finding	Methodological Limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual Assessment
The ideal WFH soundscape was described as a quiet, well-sound insulated environment, with access to positive sounds (i.e., natural sounds, music, urban background), ensuring privacy, intimacy, and self-expression.	Torresin et al., 2022	Minor concerns about methodology due to lack of detail of methodology.	Unable to assess n=1	Major concerns about adequacy: only reported in one study albeit with a high number of participants	Major concerns about relevance. One study conducted in London	Very low confidence	Data from 1 study, with some methodological limitations.

Table 14: GRADE-CERQual for the quality of the evidence for qualitative survey studies of effects of residential soundscapes on wellbeing and perceptions in WFH populations.

Effects and changes to sound and noise associated with COVID-19

Nine studies examined the influence of sound and noise in residential settings on wellbeing and perceptions in relation to COVID-19 (Torresin et al., 2022a, Torresin et al., 2021, Andargie et al., 2021, Bower et al., 2023, Caniato et al., 2021, Mimani and Nama, 2022, Dzhambov et al., 2021, Torresin et al., 2022b, Torresin et al., 2022c). These studies were cross-sectional, asking respondents to reflect on changes in exposures associated with COVID-19, with one exception (Andargie et al., 2021), which had a very small longitudinal sample (n=47) drawn from two consecutive cross-sectional surveys. These studies were conducted in Australia, Bulgaria, Canada, India, Italy, and the UK. Four papers were from the UK (Torresin et al., 2021, Torresin et al., 2022a, Torresin et al., 2022b, Torresin et al., 2022c). Studies examined annoyance, and several studies used high quality standardised assessments of GAD (Generalised Anxiety Disorder), depression and loneliness. The studies were all quantitative, except Bower et al. (2023) which was mixed-methods (quantitative and qualitative) and Torresin et al. (2022c) which was qualitative.

Table 15 shows the bias ratings for the studies. Most of the studies were rated as having 'high' bias, with only one as having 'unclear' bias. Most studies failed to report adequate details in relation to the sampling framework or failed to sample in a way to ensure a representative sample with generalisable results. Some studies conducted basic statistics and failed to account for potential confounding factors. Similar issues regarding sampling and the robustness of analysis were identified for the qualitative evidence (Table 16).

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
Andargie et al., 2021	Building Acoust	High	High	High	High	High	High
Boegheim et al., 2022	Facilities	Low	High	High	Low	Unclear	Unclear
Natomi et al., 2022	Int J Environ Res Public Health	High	High	High	Low	Unclear	High
Torresin et al., 2022	Build Serv Eng Res Technol	High	High	High	Low	Unclear	High
Torresin et al., 2021	Appl Acoust	High	High	High	Low	Unclear	High
Torresin et al., 2022	Appl Acoust	High	High	High	Low	Unclear	High
Bower et al., 2023	Int J Hous Policy	High	Low	High	Unclear	High	High
Caniato et al., Sci Rep, 2021	Sci Rep	Unclear	High	High	High	High	High
Mimani & Nama, 2022	J Acoust Soc Am	High	High	High	Unclear	Unclear	High
Dzhambov et al., 2021	Int J Environ Res Public Health	High	High	High	Low	Unclear	High

Table 15: Rating of bias for the quantitative survey studies of effects and changes to sound and noise associated with COVID-19

Reference	Journal	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	Overall risk of bias
Bower et al., 2023	Int J Hous Policy	Yes	Yes	No	Can't tell	No	Can't tell	Yes	Can't tell	Yes	High
Torresin et al., 2022	Front Psychol	Yes	Yes	Yes	Can't tell	Can't tell	Can't tell	Yes	Yes	Yes	Unclear

Table 16: Rating of bias for the qualitative survey studies of effects and changes to sound and noise associated with COVID-19

For the quality of the evidence across the quantitative studies, adapting the GRADE approach, we considered longitudinal or intervention studies the ideal study design. The highest level of evidence available for the survey studies of effects of residential soundscapes effects and changes to sound and noise associated with COVID-19 was longitudinal, albeit on an extremely small sample, so we initially judged the evidence to be of high quality. This was downgraded to **moderate quality** due to risk of bias.

Domains	Criterion	Assessment
Start level	Longitudinal	High quality
1. Study design	Studies have high or unclear risk of bias	Downgrade
2. Inconsistency	Fairly consistent evidence for an effect of sound/noise on wellbeing	No downgrade
3. Indirectness	Studies comparing similar outcomes	No downgrade
4. Precision	Not assessed	n.a.
5. Publication bias	Not assessed	n.a.
Overall judgement after downgrading process	n.a.	Moderate quality
6. Dose-response	Not assessed	No upgrade
7. Magnitude of effect	Generally less than RR >2	No upgrade
8. Confounding adjustment	Omits control for range of confounding factors	No upgrade
Overall judgement after upgrading process	n.a.	Moderate quality

Table 17: GRADE for the quality of the evidence for quantitative survey studies of effects and changes to sound and noise associated with COVID-19.

For the quality of the qualitative evidence, using the GRADE CERQual approach, we evaluated the finding that noise experienced in the home from neighbours during Covid decreased comfort and relaxation (see**Error! Reference source not found.**). The evidence was rated as having **'very low' confidence**, given that only two studies were available, and the methodological limitations associated with the evidence.

Key findings	Studies contributing to the finding	Methodological Limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual Assessment
Noise experienced in the home from neighbours during Covid decreased comfort and relaxation.	Torresin et al., 2022 ; Bower et al., 2023	Major concerns about methodology due to lack of detail of methodology .	No or very minor concerns about coherence. Studies report similar findings	Minor concerns about adequacy: Results found in small number of papers.	Major concerns about relevance. Two studies conducted in London and Australia.	Very low confidence	Data from 2 studies with some methodological limitations.

Table 18: GRADE-CERQual for the quality of the evidence for qualitative survey studies of effects and changes to sound and noise associated with COVID-19.

Experimental studies of residential soundscapes on wellbeing and perceptions

16 studies examined the influence of sound and noise in residential settings on wellbeing and perceptions using experimental methods (Asakura and Hashimoto, 2020, Chung et al., 2019, Frescura and Lee, 2021, Frescura et al., 2022, Jeon and Jo, 2019, Jeon et al., 2019, Jeong, 2021, Jo and Jeon, 2019, Lu et al., 2023, Torresin et al., 2020b, Wang et al., 2022, Yang et al., 2019, Yang and Moon, 2019, Mu et al., 2023, Frescura and Lee, 2022, Torresin et al., 2020a). Most of these studies were carried out in Asia, but some studies were from the UK (Torresin et al., 2020b, Frescura and Lee, 2021, Frescura and Lee, 2022). The studies examined a range of different residential features, and some considered how the link between sound, noise and wellbeing might be influenced by other environmental features such as temperature and visual factors. Some studies used virtual reality to present and assess different residential environments. One study examined an elderly population (Mu et al., 2023). These were quantitative and cross-sectional studies.

Table 19 shows that these studies were rated as having 'high' or 'unclear' bias. This was often because the studies provided little information about how the participants were sampled; conducted simplified statistical analyses that did not adjust for the potential confounding by other factors; or did not use or state that they used standardised assessments of annoyance or health outcomes. These studies also often had small sample sizes.

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
Asakura & Hashimoto, 2020	Appl Acoust,	Low	High	High	High	Unclear	High
Chung et al., 2019	Build Environ	High	Low	High	Low	Unclear	Unclear
Frescura & Lee, 2021	Build Environ	Low	Unclear	High	Unclear	Unclear	Unclear
Frescura & Lee, 2022	Build Environ	Low	Unclear	High	Unclear	Unclear	Unclear
Frescura et al., 2022	Build Environ	Low	High	High	Low	Unclear	Unclear
Jeon & Jo, 2019	Build Environ	Low	High	High	Unclear	Unclear	Unclear
Jeon et al., 2019	Appl Acoust	Low	High	High	Unclear	Unclear	Unclear
Jeong, 2021	Int J Environ Res Public Health	Unclear	High	High	Unclear	Unclear	Unclear
Jo & Jeon, 2019	Build Environ	Low	High	High	Unclear	Unclear	Unclear
Lu et al., 2023	J Acoust Soc Am	Low	Unclear	High	Low	Unclear	Unclear
Torresin et al., 2020;	Build Environ;	Low	Unclear	High	Low	Unclear	Unclear
Torresin et al., 2022	IAQ 2020						
Wang et al., 2022	Appl Acoust	Unclear	Unclear	High	Low	Unclear	Unclear
Yang et al., 2019	Indoor Built Environ	Unclear	High	High	Low	Unclear	Unclear
Yang & Moon, 2019	Appl Acoust	Unclear	High	High	Low	Unclear	Unclear
Mu et al., 2023	HERD	Low	High	High	Low	Unclear	Unclear

Table 19: Rating of bias for the quantitative studies of experimental studies of residential soundscapes and wellbeing/perceptions

For the quality of the evidence across the quantitative studies, adapting the GRADE approach, we considered longitudinal or intervention studies the ideal study design. The highest level of evidence available for experimental evidence for the effects of residential soundscapes on wellbeing and perceptions was cross-sectional, so we initially judged the evidence to be of low quality based on the lack of longitudinal or intervention studies. This was further downgraded to **very low quality** due to risk of bias and indirectness of study outcomes.

Domains	Criterion	Assessment
Start level	Cross-sectional	Low quality
1. Study design	Studies have high or unclear risk of bias	Downgrade
2. Inconsistency	Fairly consistent evidence for an effect of sound/noise on wellbeing	No downgrade
3. Indirectness	Studies do not compare similar outcomes	Downgrade
4. Precision	Not assessed	n.a.
5. Publication bias	Not assessed	n.a.
Overall judgement after downgrading process	n.a.	Very low quality
6. Dose-response	Not assessed	No upgrade
7. Magnitude of effect	Generally less than RR >2	No upgrade
8. Confounding adjustment	Omits control for range of confounding factors	No upgrade
Overall judgement after upgrading process	n.a.	Very low quality

Table 20: GRADE for the quality of the evidence for quantitative studies of experimental studies of residential soundscapes and wellbeing/perceptions.

Residential care homes & dementia

Six studies examined the influences of soundscapes in care homes for patients with dementia (De Pessemier et al., 2023, Graham, 2019, Graham, 2020, Kosters et al., 2023, Kosters et al., 2022, Houben et al., 2020). These studies were carried out in the Netherlands and Canada. Two studies used ethnographic methods (Graham, 2019, Graham, 2020), and some studies evaluated soundscape interventions on social relations and symptoms of dementia in care homes (De Pessemier et al., 2023, Kosters et al., 2023, Houben et al., 2020). These studies included qualitative and quantitative methodologies.

The ratings of bias for the quantitative studies is shown in Table 21 and for the qualitative studies in Table 22. The quantitative studies were rated as having 'high' or 'unclear' bias, due to poor reporting of the sampling framework and recruitment processes, and concerns about the representativeness of the sample and generalisability of the findings. The qualitative evidence was rated as having high bias, due to concerns about sampling and generalisability, and the lack of robust qualitative analyses.

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
De Pessemier et al., 2023	Multimed Tools Appl	Unclear	High	High	Low	High	High
Kosters et al., 2023	J Am Med Dir Assoc	High	Low	High	Low	High	Unclear
Kosters et al., 2022	Front Psychol	Unclear	High	High	Unclear	Unclear	High

Table 21: Rating of bias for the quantitative studies of residential care homes and dementia

Reference	Journal	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	Overall risk of bias
Graham, 2019	Sound Studies	No	Can't tell	Can't tell	Can't tell	No	No	Yes	No	Can't tell	High
Graham, 2020	Building Acoustics	Can't tell	Can't tell	Can't tell	Can't tell	No	Can't tell	Yes	No	Can't tell	High
Houben et al., 2020	CHI '20	Yes	Yes	Yes	Can't tell	No	No	Yes	No	Yes	High

Table 22: Rating of bias for the qualitative studies of residential care homes and dementia

For the quality of the evidence across the quantitative studies, adapting the GRADE approach, we considered longitudinal or intervention studies the ideal study design. The highest level of evidence available for the effects of residential care homes and dementia was longitudinal, so we initially judged the evidence to be of high quality (Table 23). This was downgraded to **moderate quality** due to risk of bias.

Domains	Criterion	Assessment
Start level	Longitudinal	High quality
1. Study design	Studies have high or unclear risk of bias	Downgrade
2. Inconsistency	Fairly consistent evidence for an effect of sound/noise on wellbeing	No downgrade
3. Indirectness	Studies do not compare similar outcomes	No downgrade
4. Precision	Not assessed	n.a.
5. Publication bias	Not assessed	n.a.
Overall judgement after downgrading process	n.a.	Moderate quality
6. Dose-response	Not assessed	No upgrade
7. Magnitude of effect	Generally less than RR >2	No upgrade
8. Confounding adjustment	Omits control for range of confounding factors	No upgrade
Overall judgement after upgrading process	n.a.	Moderate quality

Table 23: GRADE for the quality of the evidence for quantitative studies of residential care homes and dementia.

For the quality of the qualitative evidence, using the GRADE CERQual approach, we evaluated the finding that sound was important for social relationships, engagement and reducing loneliness in care homes for dementia patients (see Table 24). The evidence was rated as having **'very low' confidence**, given that only three studies were available, and the methodological limitations associated with the evidence and concerns about data analysis for some studies.

Key findings	Studies contributing to the finding	Methodological Limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual Assessment
Sound important for social relationships, engagement and reducing loneliness in care homes for dementia patients	Graham, 2019; Graham, 2020; Houben et al., 2020	Serious concerns about methodological concerns. All studies had unclear recruitment strategies and lack robust data analysis	No or very minor concerns about coherence. Studies report similar findings	Minor concerns about adequacy: Results found in small number of papers.	Major concerns about relevance. One study conducted in the Netherlands, the two in Canada.	Very low confidence	Data from 3 studies with some methodological limitations.

Table 24: GRADE-CERQual for the quality of the evidence for qualitative studies of residential care homes and dementia.

Other areas of research

There were a number of individual studies identified which did not fit into the GRADE evaluations of the evidence base as a whole. Lenzi et al. (2021) conducted a study of soundscapes recorded before, during and after COVID which were rated for soundscape quality by 'soundscape experts'. Liu et al. (2021) conducted a study of architects and non-architects' opinions of acoustic environments, which included some discussion of health. Torresin et al. (2020c) conducted a qualitative study with 'soundscape experts' on the characterization, management, and design of indoor soundscapes and health-related outcomes. Yildirim and Arefi (2020) conducted a qualitative study of stakeholder opinions on transit-oriented developments. The bias rating for these papers is shown in Table 25 and Table 26

Reference	Journal	Bias due to exposure/sound assessment (physical assessment of sound/noise)	Bias due to confounding	Bias due to selection of participants	Bias due to assessment of health or wellbeing or soundscape outcome	Bias due to non-blinded assessment outcome	Total Bias Rating
Lenzi et al., 2021	Front Psychol	Unclear	Unclear	High	Low	Unclear	Unclear

Table 25: Rating of bias for the remaining quantitative papers

Reference	Journal	Was there a clear statement of the aims of the research?	Is a qualitative methodology appropriate?	Was the research design appropriate to address the aims of the research?	Was the recruitment strategy appropriate to the aims of the research?	Was the data collected in a way that addressed the research issue?	Has the relationship between researcher and participants been adequately considered?	Have ethical issues been taken into consideration?	Was the data analysis sufficiently rigorous?	Is there a clear statement of findings?	Overall risk of bias
Liu et al., 2021	Appl Acoust	Yes	Yes	Yes	Can't tell	Yes	No	Yes	Can't tell	Yes	Unclear
Torresin,et al., 2020	Sustainability	Yes	Yes	Yes	Can't tell	Yes	No	Can't tell	Yes	Yes	Unclear
Yildirim & Arefi, 2020	Transp Res D: Transp Environ	No	Yes	Yes	Can't tell	Yes	No	No	No	No	High

Table 26: Rating of bias for the remaining qualitative papers

3. SUMMARY

Relationship	GRADE evidence rating
Surveys of residential settings and effects on wellbeing and perceptions: general adult populations	Very low quality
Surveys of residential settings and effects on wellbeing and perceptions: elderly populations	Very low quality
Surveys of residential settings and effects on wellbeing and perceptions: WFH populations	Low quality
Effects and changes to sound and noise associated with COVID-19	Moderate quality
Experimental studies of residential settings and effects on wellbeing	Very low quality
Residential care homes and dementia	Moderate quality

Table 27: Summary of the strength of the quantitative evidence

Relationship	GRADE-CERQual evidence rating
Qualitative survey studies of effects of residential soundscapes on wellbeing and perceptions in general adult populations.	Very low confidence
Qualitative survey studies of effects of residential soundscapes on wellbeing and perceptions in elderly populations.	Very low confidence
Qualitative survey studies of effects of residential soundscapes on wellbeing and perceptions in WFH populations	Very low confidence
Qualitative survey studies of effects and changes to sound and noise associated with COVID-19.	Very low confidence
Qualitative studies of residential care homes and dementia	Very low confidence

Table 28: Summary of the strength of the qualitative evidence

4. DISCUSSION

This systematic review has examined the effects of indoor sound environments on mental health, wellbeing, quality of life, annoyance, and sleep. Focusing on studies published in the past three years, this review has identified both quantitative and qualitative evidence. This section discusses the findings for the quantitative and qualitative evidence, and gaps in knowledge.

In terms of the effects of indoor sound environments on mental health, wellbeing, quality of life, annoyance, and sleep this review has found that the quality of the quantitative evidence when considered across the studies is of moderate quality for a couple of outcomes, e.g., the effects and changes to sound and noise associated with COVID-19 and residential care homes & dementia, but is of weaker quality, indicative of effects for other outcomes, e.g., residential settings and effects on wellbeing and perceptions for general adult populations (both survey and experimental studies), the elderly, and WFH populations.

This review has found that the quality of the qualitative evidence when considered across the studies is of 'very low quality' for effects on wellbeing and perceptions for general adult populations, the elderly and WFH populations, as well as for the effects and changes to sound and noise associated with COVID-19 and residential care homes & dementia.

These conclusions, about the quality of the evidence are impacted by the low number of studies available for most of the outcomes. This lack of evidence does not necessarily mean that there are no effects of sound on mental health, wellbeing, quality of life, annoyance, and sleep, rather that they have not yet been the focus of enough methodologically robust studies. As well as a need for more studies, future survey studies also need to ensure they are assessing mental health, wellbeing, quality of life, annoyance and sleep using standardised questions, where available. It is not always clear that the ISO15666 annoyance technical standard has been followed when annoyance is being assessed. There is an emerging trend for more recent studies to use standardised psychological scales to assess mental health and wellbeing. This is positive and should in time, lead to studies being able to compare effects across studies. It is important that researchers in the field appreciate the importance of how mental health, wellbeing, quality of life, annoyance and sleep are assessed in their studies. It is not the intention to constrain the development of new outcome measures for the field, but the development of any new measures should take place alongside use of established, psychometrically robust measures.

The GRADE and GRADE-CERQual evaluations are also impacted by the sampling methodologies employed by studies in this field. This could reflect an inherent tension between the methodologies typically employed with 'soundscape' research to date in terms of selecting a sample versus the rigorous quantitative approach to population sampling expected by GRADE. Whilst it is true that soundscape standards recommend smaller sample sizes than typically reported in other allied fields examining sound, noise and health, there remains a need to clearly report the approach to sampling. Some researchers argue that this is of less concern for soundscape research, however, given the ambition to inform design population and sampling are important. Further, given the time-frame of the systematic review search it is likely that some of the sampling approaches were impacted by COVID-19. However, some omissions are easily addressed despite these inherent tensions. Both authors and peer-reviewers have a duty to ensure that the reporting of sampling for studies is clear and detailed. There are some aspects of sampling methods that could potentially improve how the evidence was evaluated by GRADE.

These include:

- Providing a clear definition of the 'target' population for the study;
- Providing details of how the population were identified for sampling;
- Considering how the population can be accessed to provide a representative sample;
- Reporting the response rate[5];
- Considering how 'representative' the achieved sample were of the 'target' population; and
- Including discussion of how sampling may have influenced the findings in the discussion and for which populations they are and are not potentially valid.

It is accepted that for qualitative evidence the approach to sampling will differ. However, there is still a need for these studies to consider their sample and whether the recruitment strategy was appropriate for the aims of the study. Reflection upon the sample in relation to the generalisability of the findings would also be of use.

The GRADE and GRADE-CERQual evaluations are also impacted by the quality of the analysis undertaken in many of the studies. Many of the quantitative studies are limited to reporting simplistic descriptive statistics, and most studies fail to adequately account for confounding factors that may influence the relationship observed between sound and mental health, wellbeing, quality of life, annoyance, and sleep. Both physical and mental health are influenced by an individual's history of ill-health, ability to cope, annoyance responses and appraisal of the noise. Most studies do not adequately account for these factors.

The small samples in some studies would lack statistical power for more sophisticated multivariate analyses, further highlighting the need for methodologically robust surveys of adequately powered samples. The qualitative analyses varied in quality, highlighting the need to improve reporting of the analysis undertaken and to ensure that high quality qualitative analysis methodologies are being employed. summarises the recommendations for reporting identified by this systematic review.

[5] It is surprising how many survey papers fail to report a response rate. The rating of bias requires response rates above 60%; any paper that fails to report a response rate gets rated as having 'high bias' due to selection of participants.

Study aspect	Reporting
Outcome assessment[6]	
Soundscapes	ISO/TS 12913-2:2018 protocols including scales such as pleasantness, calmness, vibrancy, etc.
Mental health, wellbeing, quality of life, sleep	Use standardised, psychometrically robust questions, where available. For example, established psychological scales measuring a specific psychological outcome or concept, or established sleep disturbance questions assessing awakenings, time to sleep, sleep quality, etc. This will improve and ensure the validity of assessments, and the potential to compare findings across studies.
Annoyance	Use the ISO15666 annoyance technical standard(ISO/TS15666:2021, 2021, Clark et al., 2021) to assess annoyance. This will improve and ensure the validity of assessments, and the potential to compare findings across studies.
Sampling	
Target population, or approach to sampling for the study.	Provide a clear definition of the 'target' population for the study in the method.
	Provide details of how the population were identified for sampling in the method (Could the sampling be undertaken to improve the generalisability of the findings?)
	Report the response rate in the method section (NB: this will not be possible for 'snowball' sampling approaches).
	Include a statement about the choice of sample size (power calculations, if relevant) in the method. Include a statement in the discussion about how the sample size might have influenced the findings.
	Make a clear statement in the discussion about how 'representative' the achieved sample were of the 'target' population.
	In the discussion include a statement about how sampling may have influenced the findings in the discussion and for which populations they are and are not potentially valid.
Statistical analysis for quantitative studies	
Hypotheses	Clearly state which hypotheses are being tested.
Analysis plan	Ensure an analysis plan is developed at the start of the project.
Statistical testing	Report multivariate statistical analyses that address clearly stated hypotheses. Limit descriptive analyses to describing the sample and outcomes, where possible.

[6] It is intended that researchers choose which outcomes are of interest, not that all these outcomes should or must be included in a study.

Study aspect	Reporting
Confounding factors	Analyses should adjust for confounding factors that may influence the relationship observed between sound and mental health, wellbeing, quality of life, annoyance, and sleep, as well as factors that may influence residential and dwelling aspects.
Analysis for qualitative studies	
Method of analysis	Report the method of qualitative analysis used to address the research aims and hypotheses
	Clearly evidence the analysis process, including evidencing how the qualitative data was undertaken and analysed (e.g., if undertaking thematic analysis, provide a thematic framework linked to data).

Table 29: Checklist for reporting quantitative and qualitative studies about sound and residential wellbeing.

There were few studies that related perception or experience of sound in the dwelling to aspects of the built environment. Few studies evaluated the effect of interventions, such as insulation, on the perception or experience of sound in the dwelling. There are few longitudinal studies or studies evaluating effects for different population groups. Further quantitative and qualitative studies examining the specific question of 'which indoor sounds effect mental health, wellbeing, quality of life, annoyance, and sleep' are required to build knowledge in this area. Studies also need to evaluate effects in relation to specific aspects of the dwelling/built environment.

The review has not examined conference papers published during the past three years, grey literature or systematic reviews published during the same time period. However, we consider the papers identified in the search to be a comprehensive and realistic review of the field at present, representing the current state of the evidence, albeit acknowledging that it is a field that is emerging and developing.

5. CONCLUSION

In terms of sound effects on mental health, wellbeing, quality of life, annoyance, and sleep, this review has found that there is 'moderate' quality evidence for effects and changes to sound and noise associated with COVID-19 and residential care homes & dementia, but that evidence for other effects is of 'low' or 'very low' quality for other effects including residential settings and effects on wellbeing and perceptions for general adult populations, the elderly, and WFH populations. This review highlights research needs within the field to improve the evidence base going forward, to build knowledge about how specific physical features of residential dwellings influence sound perception, and further knowledge about how sound perception in dwellings influences mental health, wellbeing, quality of life, annoyance, and sleep.

6. EXCLUDED PAPERS

Author	Year	Title	Journal	Reasons for exclusion
Zhang & Wang	2021	Influence of Indoor Environment Design on Occupants' Experience	J Environ Prot Ecol	Cannot retrieve full text
Asensio, Pavon & de Arcas	2022	How the COVID-19 Pandemic Muted and Remixed the World's Acoustics for a While	Curr Pollut Rep	Literature review
Clark et al.	2022	Assessing community noise annoyance: Two decades of the international technical specification ISO/TS 15666:2003	JASA	Literature review
Harvie-Clark et al.	2019	How loud is too loud? noise from domestic mechanical ventilation systems	Int J Vent	Literature review
Hu, Zayed & Cheng	2022	A critical review of acoustic modeling and research on building façade	Build Acoust	Literature review
Torresin et al.	2019	Acoustic Design Criteria in Naturally Ventilated Residential Buildings: New Research Perspectives by Applying the Indoor Soundscape Approach	Appl Sci (Basel)	Literature review
Torresin et al.	2022	The effect of indoor soundscape on sexual wellbeing during the COVID-19 lockdown in London: a thematic analysis of remote workers' experiences	Lancet	Meeting abstract
Ren, Tang & Cai	2022	A comfortable soundscape perspective in acoustic environmental planning and management: a case study based on local resident audio-visual perceptions	J Environ Plan Manag	Addressed outdoor noise/soundscape
Cheng	2020	Evaluation of Acoustic Environment of High-Rise Residential Space	IOP Conference Series: Materials Science and Engineering	Addressed outdoor noise/soundscape
Balderrama et al.	2022	Effects of Facades on Urban Acoustic Environment and Soundscape: A Systematic Review	Sustainability	Systematic review
Hasegawa & Lau	2021	Audiovisual Bimodal and Interactive Effects for Soundscape Design of the Indoor Environments: A Systematic Review	Sustainability	Systematic review
Janus et al.	2021	Sounds in nursing homes and their effect on health in dementia: a systematic review	Int Psychogeriatr	Systematic review
Schweiker et al.	2020	Review of multi-domain approaches to indoor environmental perception and behaviour	Build Environ	Systematic review
Torresin et al.	2019	Assessment Methods and Factors Determining Positive Indoor Soundscapes in Residential Buildings: A Systematic Review	Sustainability	Systematic review

Table 30: Table of excluded papers

7. ABOUT THE AUTHORS

The lead author for this volume was Charlotte Clark who is a Professor of Environmental Epidemiology at St George's, University of London. Charlotte is President of the International Commission on Biological Effects of Noise (ICBEN) and has an international reputation for conducting robust policy relevant research on the effects of environmental noise on health, wellbeing, and quality of life. She has produced influential evidence reviews on the effects of environmental noise on health, wellbeing, and learning for the World Health Organization, the International Civil Aviation Organization and the Department for Environment, Food and Rural Affairs (UK). She has advised on the health impacts of large infrastructure projects (e.g., Heathrow Expansion; High Speed 2 Railway). She has published over 80 papers in the field of environmental noise and health epidemiology. Charlotte currently leads the UK Department for Transport's Aviation Night Noise Effects (ANNE) study, which is examining the effect of night-time aviation noise on annoyance and sleep disturbance.

Charlotte was supported in her work by Kathryn Willis and Dr. Elena Marcus.

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