Systematic review of evidence on the effect of environmental noise on cognition

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ABSTRACT
This paper reports a review of the strength of the evidence for the effect of environmental noise on cognition, carried out for the World Health Organisation Europe. Using a systematic review methodology, quantitative non-experimental studies of the effect of environmental noise exposure on child and adult cognitive performance published up to June 2015 were sought from citation databases. A total of 34 papers were identified, all of which were of child populations. 82% of the papers were of cross-sectional design, with fewer studies of longitudinal or intervention design. The most commonly reported cognitive outcomes were tests of reading and oral comprehension as assessed by direct testing (41%) or Standardised Achievement Test (SATS) data (38%). Studies also assessed short-term and long-term memory (35%); attention (38%); and executive function (26%). The strength of the evidence varied across outcomes. There was a lack of longitudinal and intervention studies across most outcomes, and studies examining exposure-effect relationships are required across the cognitive outcomes. Studies of adult populations remain a priority for future research. The lack of evidence for noise effects in some cognitive domains does not necessarily mean that there are no effects: rather, that more studies are required.

Keywords: Noise and health  I-INCE Classification of Subjects Number(s): 62.5, 63.3, 63.5

1. INTRODUCTION
The World Health Organisation Guidelines for Community Noise have been influential since their first publication in 2000 (1) and are currently in the process of being updated by the World Health Organisation Europe (WHO Europe). To inform this process, the WHO Europe commissioned a systematic review of the scientific evidence for environmental noise effects on cognition.

2. METHOD

2.1 Scope of the Review
The review sought to identify original research papers of quantitative design, on the effect of environmental noise on cognition published up to June 2015. Search terms covering different sources of environmental noise (aircraft, road traffic, railway, wind-turbine), different study designs (cross-sectional, longitudinal), and different cognitive outcomes (reading, memory, attention) were included in database searches of Medline/Pubmed; Scopus (includes E beautybase); PsycInfo, Web of Science Database and ScienceDirect. See Table 1 for the complete list of search terms included.

2.2 Search Strategy
Quantitative papers in all languages were sought but due to time constraints, conference proceedings were not additionally searched. The reference lists of identified papers were also checked for further relevant citations. Grey-literature, already known to the authors was also included in the

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2.3 Review Process

Papers were reviewed in two stages. First, all the titles and abstracts of the identified papers were reviewed by two reviewers (CC, NS) separately to assess eligibility for inclusion in the review. Second, the full text of eligible papers was retrieved and two reviewers (CC, KP) read the paper and re-assessed eligibility for inclusion. At both stages, where there was disagreement between the reviewers discussion was held until consensus reached.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Search term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental noise</td>
<td>environmental noise; community noise; traffic noise; wind turbine noise; wind turbine sound; wind farm sound; aircraft noise; airport noise; railway noise; road traffic noise; transportation noise; train noise; leisure noise; leisure-time noise; neighbourhood noise; neighborhood noise; household noise; low frequency noise; classroom noise; school noise; high-volume music; high-volume noise; noise from personal electronic devices; noise from mp3 players; noise from children's toys; hospital noise; combined noise exposure; noise nuisance; noise exposure; truck noise; motor vehicle noise; noise load; entertainment noise; noise from mobile phones; noise from personal audio devices; noise from personal music players; combined exposure to noise and vibration; combined exposure to noise and air pollution.</td>
</tr>
<tr>
<td>Study design</td>
<td>prospective and retrospective cohort studies, case-control studies, observational or experimental cross-sectional studies</td>
</tr>
</tbody>
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| Cognitive outcome            | learning impairment, such as reading and oral comprehension in children, short-term and long-term memory in children, measures of attention in children, impairment assessed through standardized assessments such as standard assessment tasks, cognitive impairment in the elderly and working age population (reduced concentration, speech intelligibility, etc.), executive function deficit (working memory capacity,
2.4 Data Extraction

Data extraction was undertaken by both reviewers (CC, KP) identifying key features of the study including, design (e.g. cross-sectional, longitudinal), population-setting (e.g. children or adults/ home or school), exposure (source, range of exposure, comparison groups), confounding (factors analyses adjusted for), outcome examined (e.g. which test and which cognitive skill), findings (estimated effect on cognition per 1dB increase in exposure, where possible). Again, data extraction tables were compared across the two reviewers and discussed where there was disagreement until consensus was reached.

Each paper was assessed for the following types of bias:

1. Study design: cohort, case-control, or cross-sectional, with the former being less biased than the latter.
2. Noise exposure assessment leading to information bias: evaluating whether the paper uses established noise metrics in dB; the time-frame of noise measurements, if applicable; 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 noise exposure and cognitive performance.
4. Bias due to selection of participants: whether participants are randomly sampled from a known population and a response rate higher than 60%.
5. Outcome assessment leading to bias: assessment of whether the cognitive outcome of interest is objectively measured and assessed using a known scale or validated assessment method.

Bias was also considered present for each aspect noted above, if this information was omitted from the paper.

2.5 Evaluating the Strength of the Evidence

The study design and methods used within each cognitive ability domain varied widely in terms of noise exposure (and how defined) and in terms of which test of cognition had been employed and how effects had been estimated. For these reasons, this is a narrative systematic review, rather than a systematic review including meta-analyses. Unfortunately, the studies are not uniform in how they define exposure or in how they measure specific cognitive abilities to enable meta-analyses within each cognitive ability domain.

In order to assess the quality of the evidence for each cognitive outcome required for appropriate recommendations, we used the GRADE methodology which ranks the quality of evidence as high, moderate, low, or very low (2). This review adapted the GRADE methodology, which traditionally assigns high quality evidence only to evidence from studies of a randomized control study design: this is inappropriate for this field where the authors felt that studies of a longitudinal design should be assigned the highest quality of evidence available.

3. RESULTS

3.1 Papers Identified

In total, 1006 citations were identified from a search of the databases, but there was a degree of overlap in citation identification between the databases. Screening of the citations identified 55 that
were potentially relevant, of which 20 were duplicates, 20 were included and 15 were excluded after full text retrieval, mainly because they did not measure noise exposure or cognition, were review papers, or were experimental studies. We were unable to extract one paper, which was in Italian. After data extraction, two papers were excluded as they did not meet our inclusion criteria despite initial appearances that they did and 18 papers were included in the systematic review.

Following this systematic process of searching for papers, the authors felt that some key papers from the field had not been retrieved by the database searches and added a further 26 papers to the data extraction process. These papers were identified from reference lists of existing narrative reviews and were papers identified by the authors undertaking the review, relating to older or very recent studies and reports in the field. The authors have published previous narrative reviews of the field so were familiar with the existing literature. It is thought that the database searches missed some of these papers as they were older or because they were reports not yet published in peer-reviewed journals. Of the 26 additional papers put forward for review by the authors, 16 papers fulfilled the eligibility criteria for the review and inclusion in the review. This led to a grand total of 34 primary research papers for inclusion in the review: 18 identified from the systematic database search and 16 identified from our search of additional papers (see Figure 1).

![Flow chart showing the review process for the cognitive papers](image)

**Figure 1 - Flow chart showing the review process for the cognitive papers**

### 3.2 Summary of Papers

The majority of the studies were of cross-sectional design (82%); there were far fewer studies of more robust quantitative design such as longitudinal studies (21%) and intervention studies (15%).

7709
All of the studies were of children, with most studies sampling in mid-childhood (aged 8-12 years). Most studies examined aircraft noise exposure (74%), with a further 11 studies examining road traffic noise exposure (32%). Few studies examined rail noise or ambient noise exposure, and there were few studies of noise and co-occurring air pollution exposure. The majority of studies focused on noise exposure in the school environment (88%), as opposed to the home environment (35%), using annual average noise exposure metrics (L_Aeq – 79% or Ldn 12%). Few studies examined other metrics such as LAMax.

A range of cognitive abilities had been examined. The most commonly reported were tests of reading and oral comprehension as assessed by direct testing (41%) or Standardised Achievement Test (SATS) data (38%). Studies had also assessed short-term and long-term memory (35%); attention (38%); and working memory/executive function (26%).

Most of the studies took adequate account of sociodemographic confounding between noise exposure and cognitive performance: however some older studies from the 1970s and 1980s were less likely to have taken socioeconomic confounding into account.

3.3 Strength of the Evidence

This paper will present an evaluation of the strength of the evidence for environmental noise effects on the following cognitive domains:

1. Reading and oral comprehension
2. Short-term and long-term memory
3. Attention
4. Impairment assessed through standardized assessments such as SATs
5. Executive function deficit (working memory, capacity etc)

We will review the evidence in terms of the number of studies in the field; findings for different noise sources; the consistency of findings across studies; the study design (e.g. whether there is longitudinal evidence or intervention evidence); whether there is evidence for exposure-effect relationships between noise exposure and the cognitive outcome; and the presence of bias in the available evidence.

4. DISCUSSION

The conclusions of this review regarding the strength of the evidence for environmental noise effects on cognition will be used by the World Health Organisation Europe’s Guideline Development Group (GDG) to inform revised guidelines for environmental noise exposure. The current guidelines (3) specify that the background sound pressure level in school classrooms should not exceed L_Aeq 35dB during teaching sessions to protect from speech intelligibility and disturbance of information extraction. The WHO guidelines also suggest that school playgrounds outdoors should not exceed 55dB L_Aeq during the recess period, to protect from annoyance.

Preliminary conclusions suggest a lack of longitudinal and intervention studies across most outcomes, and a lack of studies examining exposure-effect relationships across the different cognitive domains. Studies of adult populations still remain a priority for future research.

A major limitation to this systematic review is the lack of homogeneity of methods and reporting between the studies, even within cognitive domains, which has meant that it has not been possible to conduct meta-analyses across the studies. Such meta-analyses would enable the effect across studies to be estimated, which would inform uncertainty relating to the study findings. Unfortunately, this is not yet possible for several reasons. Studies often use different tests of the same cognitive ability: combining estimates across studies that use different outcomes is challenging and often not possible. Further, many studies group exposure into high and low, using different thresholds for high and low, which again makes combining study data challenging as the range of noise exposure within the high and low categories is unknown and cannot be estimated reliably from the data provided. The potential to be able to conduct meta-analyses within this field will be greatly enhanced if future studies report...
effect estimates for a 1dB and 5dB increment in noise exposure and if studies report the range of noise exposure in their population even if their design involves selecting samples based on high and low noise exposure. It would also help the field if a standard battery of tests were used where possible, to enable data from studies to be combined: the RANCH project provides such a test battery (4). Whilst acknowledging that such a battery may constrain the cognitive abilities examined in studies, further cognitive tests of interest to individual research groups can easily be added to the test battery, if of interest.

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REFERENCES