

Article

The Impact of Noise on Learning in Children and Adolescents: A Meta-Analysis

Gabriela Fretes *  and Ramon Palau 

Department of Pedagogy, Universitat Rovira i Virgili, 43007 Tarragona, Spain; ramon.palau@urv.cat

* Correspondence: gabriela.fretes@estudiants.urv.cat

Abstract: Given the growing body of research on the impact of noise, synthesizing these findings is crucial to gaining a comprehensive understanding of the influence of noise on student performance. This meta-analysis investigates the effects of environmental and classroom noise on learning, with a focus on cognitive and academic performance in elementary and secondary school students. A systematic review and meta-analysis were conducted on 21 studies comprising 152 effect sizes. Different noise types were analyzed in relation to cognitive functions such as attention, memory, comprehension, and overall academic performance. The Restricted Maximum Likelihood (REML) method was used to estimate the overall effect size, resulting in a value of -0.46 (95% CI: -0.54 to -0.38), indicating the moderate negative impact of noise on performance. The negative effects were particularly significant in children aged 6 to 12. Despite high heterogeneity across the studies, likely due to variations in noise types and study designs, model fit measures confirmed the adequacy of the meta-analytic model. These findings underscore the importance of mitigating noise in educational settings to improve students' cognitive and academic outcomes.

Keywords: noise impact; student performance; meta-analysis; cognitive functions; educational environment



Academic Editors: Nikolaos Vryzas and Lazaros Vrysis

Received: 29 January 2025

Revised: 31 March 2025

Accepted: 4 April 2025

Published: 9 April 2025

Citation: Fretes, G.; Palau, R. The Impact of Noise on Learning in Children and Adolescents: A Meta-Analysis. *Appl. Sci.* **2025**, *15*, 4128. <https://doi.org/10.3390/app15084128>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Noise, defined as any unwanted sound, has been a growing concern in modern society [1]. It is regarded as the third most pressing environmental concern after water and air pollution [2]. In this context, it is important to consider the impact of noise on learning and cognitive performance in children and adolescents, as this population is particularly vulnerable to its effects [3].

The impact of noise on academic and cognitive performance has been a significant area of research. Several systematic reviews and meta-analyses have addressed different aspects of this issue, providing a still-varied understanding of how noise affects different population groups and types of cognitive skills as well as health and well-being. Below is a brief description of key studies that have explored this relationship, highlighting their main findings and how they differ from the present meta-analysis.

One study [4] conducted a comprehensive meta-analytic synthesis on the effects of noise on human performance, highlighting noise as a significant stressor affecting cognitive and motor responses. This study, which included only adult participants, revealed that the type of noise and the nature of the task were key moderators. Investigating the effects of aircraft noise on children's reading comprehension and psychological health, Ref. [5] analyzed data from three studies conducted in 106 schools near major airports. They found aircraft noise was associated with a decrease in reading comprehension and an increase in

hyperactivity, with no effects on emotional symptoms or conduct problems. The authors of [6] evaluated the effects of everyday environmental noise on non-pathological cognitive abilities in individuals, presenting an updated systematic review of noise pollution and human cognition. Their study covered the entire lifespan and used epidemiological studies to inform policies on noise pollution. In a systematic review and meta-analysis, Ref. [7] found that low-frequency noise had a significant negative impact but only on higher-order cognitive functions.

More recently, Fernández-Quezada et al. conducted a meta-analysis on the effects of noise on cognitive performance in young populations, providing additional insights into how different noise sources influence cognitive functions. While this study contributes to the growing body of research on noise-related impacts, the present meta-analysis focuses specifically on academic and cognitive performance in school settings, employing strict inclusion criteria that prioritize experimental and quasi-experimental studies with objective measurements [8].

Our meta-analysis differs from previous studies by assessing how both environmental and classroom noise affect the cognitive and academic performance of children and adolescents. The use of meta-analytic techniques allows us to synthesize findings from multiple independent studies, providing a more comprehensive and statistically robust estimate of the overall effect of noise. This is particularly important given the variability in study designs, noise exposure conditions, and outcome measures found in individual research efforts.

By integrating data from diverse studies, a meta-analysis increases their statistical power, enhances the generalizability of findings, and helps identify potential moderating factors, such as types of noise and student characteristics like age. This systematic approach not only strengthens the validity of the studies' conclusions but also provides valuable synthesized information that can guide educational policies and future research on mitigating the impact of noise in learning environments.

The aim of this study is to analyze the impact of noise on learning in a learning environment through assessing the academic and/or cognitive performance of non-university students. To achieve this objective, this study will address the following research questions:

- (a) What is the overall effect of noise on learning in terms of the academic or cognitive performance of students?
- (b) How do characteristics such as noise intensity, noise type, and the age of students influence this effect?

2. Materials and Methods

2.1. Research Protocol

A systematic review of the literature and meta-analyses was conducted following the stages of identification, screening, eligibility, and inclusion outlined in the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses, 2020) [9].

For the search procedure, Scopus and Web of Science databases were used. The keywords for the search in this study were as follows: (acoustics OR noise) AND (academic AND performance OR cognitive AND performance OR learning) AND (classroom OR school). Restrictions were applied such that the search fields included were "Title, Abstract, and Keywords".

To address publication bias, we contacted experts in the field. Specifically, we reached out to an author through the ResearchGate network to request unpublished studies but the author sent a study that turned out to have been published.

2.2. Inclusion and Exclusion Criteria

The search for articles and sources was conducted exhaustively and systematically. Studies that met the following criteria were included: (a) the influence of noise on the cognitive and/or academic performance of students is examined in a school context; (b) the effects of noise analyzed include cognitive processes such as memory, attention, problem-solving, or reading comprehension and are measured through validated instruments or scales, not based on participants' perceptions; (c) academic performance grades are also included; (d) participants are non-university students from regular schools who do not have apparent hearing or learning difficulties; (e) the study design is experimental or quasi-experimental; (f) sufficient data are provided to calculate the effect size; (g) the study is written in English, Catalan, Spanish, or Portuguese; (h) the study is on the effect of noise on behavior, comfort, or speech perception and comprehension.

2.3. Codification of Studies

A protocol was developed to record the characteristics of the studies and determine which factors might influence the results. For this purpose, methodological characteristics, the characteristics of the study object, participant characteristics, and extrinsic characteristics were separated. Below are the indicators for each set of characteristics:

- (a) Methodological characteristics: type of design, cross-sectional or longitudinal study, instrument for measuring cognitive processes, or measure of academic performance.
- (b) Characteristics of the study object: cognitive process evaluated (attention, memory, comprehension, reading, etc.), academic subject or type of noise detected.
- (c) Participant characteristics: age, academic grade, sample size, country.
- (d) Extrinsic characteristics: year of publication, source.

2.4. Analysis of Information

For each selected study, we calculated Cohen's d effect size using the provided means and standard deviations (SDs). In some cases, we also used the partial eta squared (η^2_p) to calculate Cohen's d . Additionally, we calculated the standard error (SE) of each effect size using a formula based on sample sizes. These calculations are necessary to integrate and compare the results of multiple studies in a meta-analysis.

In the process of synthesizing and interpreting the effect sizes of various studies, it was necessary to adjust the signs of some effect sizes to ensure consistency in the interpretation. Specifically, in our meta-analysis, a positive effect size consistently indicates better performance or a less negative impact under the experimental condition, whereas a negative effect size indicates worse performance or a more significant negative impact under the experimental condition. For example, if a study reported a positive effect size for an experimental condition that led to poorer performance compared to the control condition, we reversed the sign to maintain uniformity.

3. Results

3.1. Qualitative Synthesis

A summary of the studies and their characteristics and findings is provided in Table S1 (the effect sizes, sample sizes, and age ranges covered, etc.), which serves as a reference for the analyses that follow.

This meta-analysis included a diverse range of studies examining the influence of noise on students. Most of the studies focused on elementary school students, like those in [10,11], which examined students aged 7–11 and 10–12, respectively. Secondary school students were also well represented, as seen in studies [12,13], which focused on children

aged 11–16 and 14–18. This broad age range and the different stages of learning provide a comprehensive view of how noise impacts children differently.

There is considerable variability in the sample sizes of the studies. The smallest samples consist of 17 participants [14] and 20 participants [15]. Intermediate sample sizes were common, as seen in [10,16], which featured samples ranging from 142 to 186 participants. Large-scale studies such as those in [12,17] included extensive sample sizes of 976 and 989 participants, respectively. Additionally, some studies report data based on the number of schools rather than individual participants, indicating potentially large sample sizes, such as 142 primary schools in central London [10] and 96 secondary schools in Greater London [18].

The studies were conducted in various countries, including Australia, Italy, the United Kingdom, Korea, the United States, Brazil, China, Germany, and Sweden. However, this reveals that certain regions, such as Africa, South America (excluding Brazil), and large parts of Asia, are underrepresented in this body of research.

In the analysis of the studies included, various effects of noise on different cognitive and academic performance were identified.

3.1.1. Impact of Classroom Noise

The impact of classroom noise on students' cognitive and academic performance is significant and multifaceted. Studies indicate that classroom noise affects various cognitive functions and academic outcomes. For instance, ref. [19] found that classroom noise significantly impacts students' reading fluency. Similarly, ref. [20] observed that noise affects sentence comprehension, with variations depending on children's selective attention. Children with low selective attention exhibited a significant increase in response time under noisy conditions.

The authors of [15] investigated the effects of classroom noise on writing, arithmetic, and reading skills. Their findings showed moderate effects favoring the experimental group exposed to noise in most assessments. In addition, ref. [14] found that noise had a significant impact on nonword repetition accuracy and verbal processing time. They observed reduced accuracy and increased processing times under noisy conditions.

In their report, the authors of [16] highlighted improvements in listening comprehension, nonverbal processing, and spelling with classroom sound field systems, implying that well-managed classroom acoustics can mitigate some of the negative effects of noise. Similarly, [17] found high aircraft noise exposure resulted in small yet noteworthy variations in reasoning, vocabulary, and perception scores when compared to low-noise-exposure groups.

The study [21] focused on speech perception and listening comprehension, finding significant differences under varying classroom noise conditions. In [22], it was demonstrated that adequate acoustic conditions improve verbal working memory and reduce errors such as omissions and intrusions.

The study [19] revealed a noteworthy influence of classroom noise on students' reading fluency, with an effect size of 0.34. In [20], it was noted that sentence comprehension, both in terms of accuracy and response time, was variably impacted depending on children's selective attention. Children with high selective attention showed no significant differences in accuracy under different noise conditions, while those with low selective attention exhibited a significant increase in response time under noisy conditions.

3.1.2. Impact of Environmental Noise

Previous findings highlight the complex relationship between environmental noise and cognitive and academic performance. In [23], it was highlighted that environmental noise

negatively influences cognitive flexibility and general executive control, with the effect sizes of noisy environments ranging from 0.54 to 0.62. The study [24] examined calculation performance and found that performance is marginally better in silent conditions and worse in the presence of traffic and classroom noise. Similarly, Ref. [12] reported that the effect of noise level on students' reading comprehension had an effect size of 0.29 and that there was an interaction between noise and age.

In terms of studies on overall academic performance, ref. [13] identified a moderate negative correlation between urban school noise and GPA and MAP scores, indicating that higher noise levels are associated with poorer academic performance. Additionally, ref. [11] investigated various cognitive and academic domains, including arithmetic, vocabulary, and block design, observing effect sizes ranging from 0.12 to 0.47. Regarding visual selective attention errors, ref. [11] also found that background noise affects divided and selective attention, although not all differences were statistically significant.

A study on the impact of classroom noise found moderate effects on writing, arithmetic, and reading skills favoring the experimental group in most assessments [15]. Previous research has examined nonword repetition accuracy and verbal processing time, observing significant reductions in accuracy, with reduced bandwidth and differences in processing time, under various SNR conditions [14].

Small to moderate improvements in listening comprehension, nonverbal processing, and spelling were reported in a study on classroom sound field systems [16]. The relationship between noise and academic performance was examined in a study that found weak positive and negative correlations depending on the specific variables analyzed [18]. Significant negative effects on reading and mathematics were observed, particularly among students with socioeconomic disadvantages and those with English as an additional language [10].

Small but significant differences in reasoning, vocabulary, and perception scores were found between high- and low-aircraft-noise-exposure groups [17]. Speech perception and listening comprehension were investigated, with significant differences observed under different classroom noise conditions [21]. The impact of noise on verbal memory was explored, demonstrating that adequate acoustic conditions improve working memory and reduce omissions and intrusions [22].

Ref. [25] found a negative relationship between higher environmental noise levels (LAeqN) and math and reading scores, but it also identified positive links with a better signal-to-noise ratio (SNR). It was found that a better SNR significantly improves children's auditory comprehension [26]. Another study highlighted the importance of a good SNR for sentence recognition, with significantly better performance observed under favorable acoustic conditions [27]. The effects of traffic noise and irrelevant speech on reading comprehension and speed, as well as basic mathematics and mathematical reasoning skills, were investigated, showing that traffic noise moderately impairs reading comprehension and speed, while irrelevant speech has minimal effects [28]. Chronic aircraft noise exposure was found to have a small negative effect on students' reading comprehension and sustained attention [29]. Noise level and type were observed to have small effects on attention, short-term memory, and performance in calculation and reading tasks [30].

3.1.3. Cognitive and Academic Processes

This meta-analysis examined a variety of processes that affected learning when students were exposed to noise. These processes were classified into larger categories:

1. Language comprehension and processing—reading fluency, listening comprehension, writing skills, and spoken word perception.

2. Processing speed—response times during reading, verbal processing, and selective attention tasks.
3. Executive control—cognitive flexibility, problem-solving, and interference management (e.g., the Stroop test).
4. Attention—selective and sustained attention in visual and auditory tasks.
5. Mathematical skills—arithmetic, problem-solving, and mathematical reasoning.
6. Academic performance—overall achievement as tested through standardized tests (e.g., NAEP) and GPAs.
7. Visuospatial skills—pattern recognition and spatial organization.
8. Memory—working memory, verbal and visual recall, and spatial memory.

3.2. Quantitative Synthesis

The Restricted Maximum Likelihood (REML) method was used to estimate random effects. REML is a robust and suitable technique for meta-analyses when variability is expected between studies, as it adjusts the estimation of the variance of random effects, providing a more precise estimate compared to less sophisticated methods. This method is particularly useful when sample sizes vary between studies and an unbiased estimation of heterogeneity is desired. However, REML assumes that effect sizes follow a normal distribution, which may not always hold in cases of strong skewness or extreme heterogeneity. Additionally, its accuracy depends on the correct specification of its moderators.

The Omnibus Test of Model Coefficients was performed to evaluate the overall significance of the model. The test yielded a Q value of 36.921 with 17 degrees of freedom, and the result was statistically significant ($p < 0.001$). This indicates that the model coefficients all collectively contribute to the prediction of the outcome variable, as shown in Table 1.

Table 1. Fixed and random effects.

	Q	df	p
Omnibus Test of Model Coefficients	36.921	17	<0.001

Note. Q = Omnibus test statistic; df = degrees of freedom; p = p-value. The model was estimated using Restricted ML method.

The fit measures for the REML estimation method indicate the adequacy of the model in explaining the data's variability (Table 2). The Log-Likelihood value was -95.417 , the Deviance was 190.834, the Akaike Information Criterion (AIC) was 228.834, the Bayesian Information Criterion (BIC) was 283.893, and the Corrected Akaike Information Criterion (AICc) was 235.500. These measures suggest that the model provides a reasonable fit for the data, with lower AIC, BIC, and AICc values indicating good model performance.

Table 2. Fit measures.

	REML
Log-Likelihood	-95.417
Deviance	190.834
AIC	228.834
BIC	283.893
AICc	235.500

In the analysis of the coefficients (see Table 3, and note that it is split across two pages due to space limitations), the intercept was statistically significant, with an estimate of -0.352 ($p = 0.020$), indicating a negative baseline effect when all other variables are held constant. This suggests that even in the absence of specific moderating factors such as noise type or student age, noise exposure has a detrimental impact.

Table 3. Coefficients.

	Estimate	S.E	Z	p
Intercept	−0.352	0.152	−2.319	0.020
Noise (Environmental noise)	0.136	0.177	0.765	0.444
Noise (Classroom noise)	−0.161	0.206	−0.780	0.436
Noise (High environmental noise)	−0.045	0.197	−0.227	0.820
Noise (Traffic noise)	0.477	0.280	1.704	0.088
Age_sta (Children)	−0.350	0.129	−2.714	0.007
Age_sta (Younger)	0.029	0.167	0.173	0.863
Age_sta (Other)	0.291	0.373	0.781	0.435
Age_sta (Older)	−0.041	0.208	−0.198	0.843
Age_sta (Teen)	−0.015	0.493	−0.031	0.975
Level (Secondary)	0.094	0.171	0.549	0.583
Function (Executive control)	−0.062	0.203	−0.307	0.759
Function (Processing speed)	0.011	0.190	0.058	0.954
Function (Memory)	−0.127	0.172	−0.738	0.461
Function (Mathematical skills)	0.217	0.120	1.805	0.071
Function (Attention)	−0.032	0.192	−0.168	0.866
Function (Language comprehension and processing)	−0.152	0.153	−0.998	0.318
Function (Visuospatial skills)	−0.064	0.352	−0.181	0.856

Note. Wald test. Estimate = estimated effect size; S = standard error; E = expected value; Z = Z-score; p = p-value.

The age category “Children” (6–12 years) showed a highly significant negative effect (-0.350 , $p = 0.007$), reinforcing previous findings that younger students are more vulnerable to noise-related disruptions. This may be attributed to the developing of executive functions in this age group, making it harder for them to filter out auditory distractions.

Regarding noise type, traffic noise exhibited a positive effect (0.477 , $p = 0.088$), which is unexpected given the typically negative effects of environmental noise on learning. Although this result does not reach statistical significance, it may reflect complex compensatory mechanisms, where students exposed to traffic noise over time develop adaptive cognitive strategies. Alternatively, it could indicate that certain studies included in the meta-analysis measured background traffic noise differently, leading to variability in the reported effects. Further research is needed to explore whether low-level traffic noise could serve as a masking noise, reducing the impact of disruptive intermittent sounds, as observed in some studies on white noise.

On the other hand, classroom noise exhibited a negative effect (-0.161 , $p = 0.436$), consistent with expectations that higher noise levels within the learning environment can impair student concentration and performance. However, the high p -value indicates substantial variability across studies, suggesting that not all types of classroom noise have the same effect. Factors such as the source of noise (e.g., teacher vs. students talking, external disturbances), classroom design (acoustics, size), and task complexity could be influencing the degree of impairment observed.

Similarly, memory (-0.127 , $p = 0.461$) and language processing (-0.152 , $p = 0.318$) showed negative trends, though they did not reach statistical significance. The lack of significance may stem from differences in study designs, noise exposure conditions, or measurement tools used across studies.

Finally, high environmental noise (-0.045 , $p = 0.820$) and visuospatial skills (-0.064 , $p = 0.856$) were not significantly impacted, which suggests that not all cognitive functions are equally affected by noise exposure. It is possible that tasks relying on visual processing and spatial reasoning are less dependent on auditory conditions, making them more resistant to external distractions.

The analysis of the residual heterogeneity estimates presented in Table 4 revealed significant residual heterogeneity among the studies, as indicated by a τ^2 value of 0.207 and an I^2 value of 96.943%. This high I^2 value suggests that approximately 97% of the variability in effect sizes is due to differences between the studies rather than sampling errors. The test of residual heterogeneity (Q) further supports this, with a value of 8320.079 ($df = 134, p < 0.001$), indicating that the heterogeneity is statistically significant. These results highlight the variation in the effects of noise on cognitive and academic performance across these studies. The heterogeneity could be attributed to several factors, including the large number of reported effect sizes; differences in participant ages, academic levels, and types of noise; and the variety of cognitive and academic processes assessed.

Table 4. Residual heterogeneity estimates.

Parameter	Estimate
τ^2	0.207
T	0.455
I^2 (%)	96.943
H^2	32.715

3.3. Visualization of Meta-Analysis Results

The following section presents the graphical tools used to visualize the results of the meta-analysis, specifically, the funnel plot (Figure 1). A forest plot is included in the Supplementary Materials (Figure S1). The effect size of -0.46 indicates an effect of a moderate magnitude according to Cohen's guidelines. This suggests that the independent variable (in this case, noise) has a negative impact on the dependent variable (academic or cognitive performance). In other words, as noise increases, academic or cognitive performance decreases. The 95% confidence interval (-0.54 to -0.38) indicates that since the interval is below zero and does not include zero, we can affirm that the negative effect of noise is significant and not due to chance.

Most effect sizes are located on the left side of the line, indicating a negative impact of noise on performance. The most substantial negative values correspond to -3.01 [$-3.07, -2.95$], reported by [17], with a small confidence interval; -2.98 [$-3.50, -2.46$] and -2.40 [$-2.92, -1.88$], reported [14]; -2.63 [$-3.06, -2.20$], reported by [21]; and -2.0 [$-2.56, -1.44$], reported by [27].

The study [17] reported a large effect size, demonstrating that there was a significant difference in perception scores between the high exposure and control groups in a large sample of 989 participants. Similarly, ref. [14] highlighted a significant reduction in accuracy with reduced bandwidth, noting higher accuracy at a 9 dB SNR compared to a 3 dB SNR in nonword repetition accuracy, although its sample size was limited to 17 subjects. In another study, ref. [21] discovered that noise negatively affects speech perception in children aged 6–8 years. Their comparison of silence to binaural conditions ($LA_{eq} = 63$ dB, SNR-3dB) revealed a significant negative effect, underscoring the detrimental impact of noise on young children's ability to understand speech. Moreover, ref. [27] demonstrated a significant negative impact of classroom noise and reverberation on comprehension performance in elementary-aged students. The study used a simulated classroom environment with varied reverberation times and background noise levels, showing that both reduced performance in comprehension tasks.

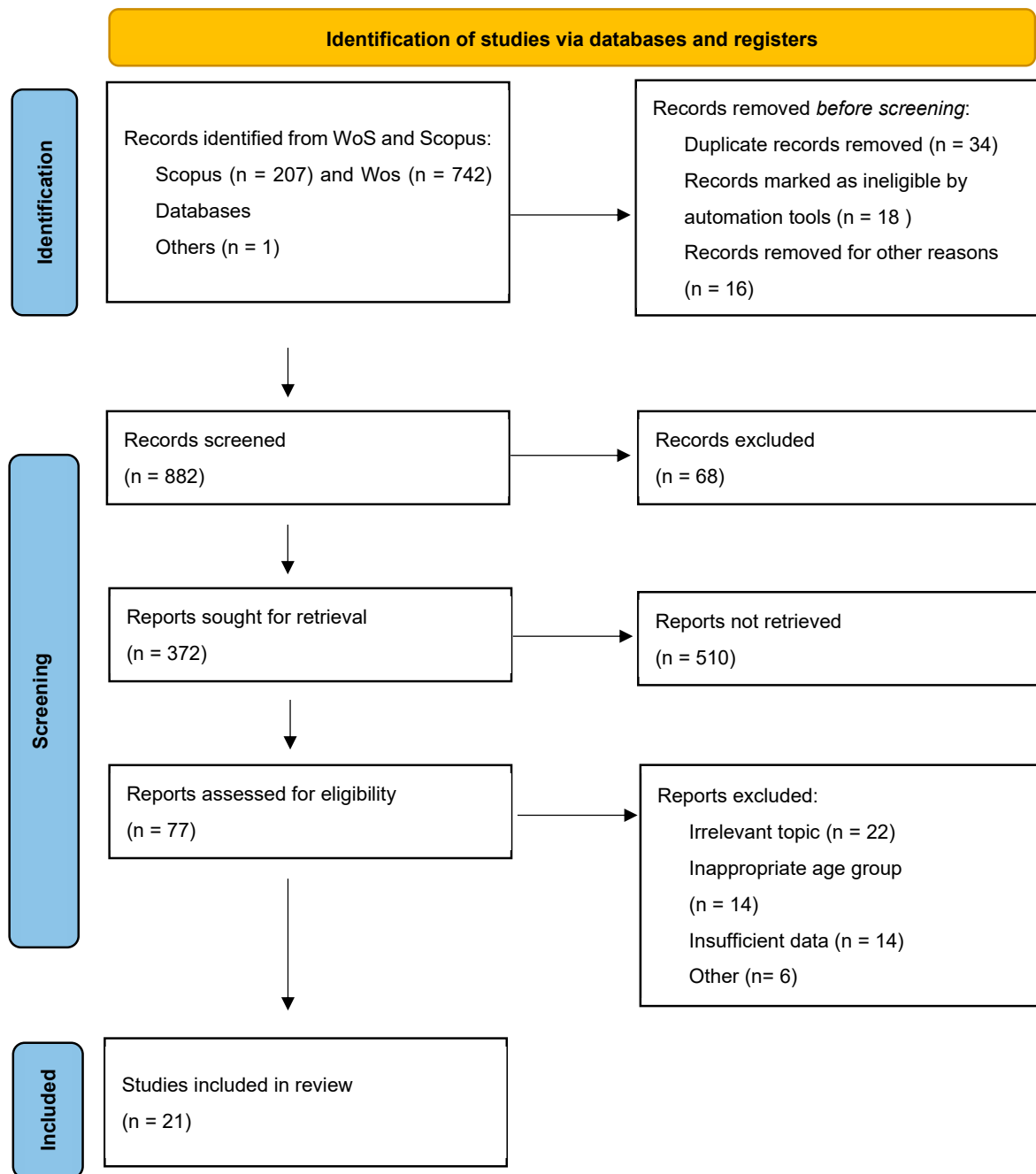


Figure 1. PRISMA flow diagram.

In contrast, the positive effects reported were small and not significant, as they included 0. Ref. [28] reported a small effect of irrelevant speech on reading comprehension, with LAeq = 66 dBA and background babble around 62 dBA and with the dominant frequency range between 500 and 1500 Hz, indicating that irrelevant speech slightly improves reading comprehension, although the effect size was small. Ref. [15] compared classroom noise in a control versus experimental group in the first evaluation of 8-year-old participants it conducted. The results showed a slight favoring of the control group, but this difference was not significant, and the authors could not explain this outcome.

The funnel plot (Figure 2) showed a reasonably symmetrical distribution of points around the mean effect value, suggesting a partial absence of publication bias. Most studies clustered around the center, indicating that the estimated effect sizes are generally

consistent and reliable. However, some asymmetry was observed in the lower part of the plot, which may indicate the presence of small-study effects or potential publication bias.

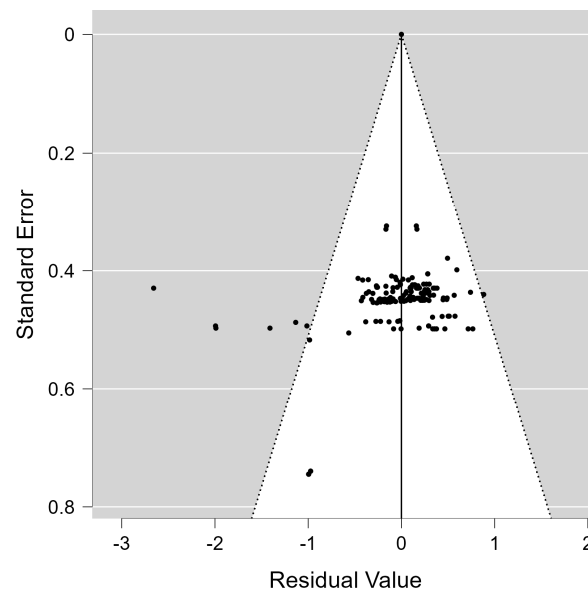


Figure 2. Funnel plot.

To further assess this, Egger's regression test for funnel plot asymmetry was conducted, revealing significant asymmetry ($Z = -4.764, p < 0.001$), suggesting the presence of publication bias. This result indicates that studies proving the significant negative effects of noise on learning may be overrepresented, while studies reporting neutral or positive effects might be underreported in the literature. Given this, the overall effect size of noise on learning could be slightly overestimated.

4. Discussion and Conclusions

The aim of this meta-analysis was to analyze the impact of noise on learning through the academic and/or cognitive performance of non-university students, specifically children and adolescents. To achieve this goal, the following research questions were addressed:

(a) What is the overall effect of noise on the academic or cognitive performance of students? The results, based on 21 studies and 152 effect sizes, show that noise has a significant negative impact on academic and cognitive performance, with a moderate effect size of -0.46 according to Cohen's guidelines. This finding suggests that as noise levels increase, performance decreases. The statistical significance of this effect, supported by a 95% confidence interval that does not include zero, highlights the importance of considering noise as a critical factor in educational settings.

(b) How do characteristics such as noise intensity, noise type, and the age of students influence this effect? The coefficient analysis revealed that the "Children" age category (between 6 and 12 years old) led to highly significant results, with an estimate of -0.350 ($p = 0.007$), indicating that younger students perform significantly worse under noisy conditions. This finding emphasizes the need for effective policies and strategies to mitigate noise in classrooms, especially for younger students, who are particularly vulnerable.

Although classroom noise was not statistically significant, it showed a negative trend, with an estimate of -0.161 ($p = 0.436$), indicating a possible negative relationship between this type of noise and academic performance. Similarly, memory and language functions also showed negative trends, with estimates of -0.127 ($p = 0.461$) and -0.152 ($p = 0.318$), respectively.

It is also worth noting that traffic noise showed a positive estimate of 0.477 ($p = 0.088$), but this result was not statistically significant. This inconsistency may be due to complex interactions with other variables that were not adequately controlled in the included studies.

This study has several limitations. First, despite including multiple studies in this meta-analysis, the high degree of heterogeneity among the studies may have influenced the results. Second, variability in the measurement of noise and academic/cognitive performance across studies may have introduced biases. Differences in noise measurement methods (e.g., objective decibel levels vs. self-reported exposure) and variations in the cognitive and academic processes assessed (e.g., reading comprehension, memory, mathematical reasoning) contribute to this heterogeneity. Similarly, differences in participant characteristics (e.g., age, educational level) may influence the extent to which noise affects learning.

While this meta-analysis provides a general estimate of the effect of noise on learning, the heterogeneity within it suggests that noise does not impact all students and cognitive functions in the same way.

Third, there is evidence of publication bias, as studies reporting significant results are more likely to be published. This may have led to a slight overestimation of the overall effect size.

Fourth, the use of the REML method, while appropriate for estimating random effects, assumes that effect sizes follow a normal distribution and may be sensitive to extreme heterogeneity or moderators. Although the REML method provides a robust variance estimation, these assumptions should be considered when interpreting the results.

Additionally, there were challenges in categorizing age groups, as the age ranges defined in the studies sometimes overlapped, although they were organized in the most useful way possible for analysis.

Lastly, although a meta-analysis aims to generalize results for a broader population, the diversity of the educational contexts and populations studied may limit the universal applicability of these findings.

In conclusion, our findings emphasize the importance of minimizing acoustic distractions to create optimal learning environments for students. This meta-analysis provides strong evidence of the negative impact of noise on academic and cognitive performance, particularly among younger students, who appear more vulnerable to its effects.

However, the variability across studies suggests that the impact of noise is not uniform across all educational settings, as it may depend on factors such as noise type, intensity, and student characteristics. This highlights the need for future research to refine noise exposure assessments, investigate potential moderating variables, and expand the range of studies included to improve the generalizability of these findings.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app15084128/s1>, Figure S1: Forest plot, Table S1: Summary of studies.

Author Contributions: Methodology, G.F. and R.P.; Software, G.F.; Validation, G.F. and R.P.; Formal analysis, G.F.; Investigation, G.F.; Data curation, G.F.; Writing—original draft, G.F.; Writing—review & editing, G.F. and R.P.; Visualization, R.P.; Supervision, R.P.; Project administration, R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Goines, L.; Hagler, L. Noise pollution: A modern plague. *South. Med. J.* **2007**, *100*, 287–294. [[CrossRef](#)] [[PubMed](#)]
2. Akal, D. Noise Induced Workplaces and Noise Related Occupational Risks. *Environ. Ecol. Res.* **2019**, *7*, 259–263. [[CrossRef](#)]
3. Passchier-Vermeer, W.; Passchier, W.F. Noise exposure and public health. *Environ. Health Perspect.* **2000**, *108*, 123–131. [[CrossRef](#)]
4. Szalma, J.L.; Hancock, P.A. Noise effects on human performance: A meta-analytic synthesis. *Psychol. Bull.* **2011**, *137*, 682–707. [[CrossRef](#)] [[PubMed](#)]
5. Clark, C.; Head, J.; Haines, M.; van Kamp, I.; van Kempen, E.; Stansfeld, S.A. A meta-analysis of the association of aircraft noise at school on children’s reading comprehension and psychological health for use in health impact assessment. *J. Environ. Psychol.* **2021**, *76*, 101646. [[CrossRef](#)]
6. Thompson, R.; Smith, R.B.; Bou Karim, Y.; Shen, C.; Drummond, K.; Teng, C.; Toledano, M.B. Noise pollution and human cognition: An updated systematic review and meta-analysis of recent evidence. *Environ. Int.* **2022**, *158*, 106905. [[CrossRef](#)] [[PubMed](#)]
7. Liang, P.; Li, J.; Li, Z.; Wei, J.; Li, J.; Zhang, S.; Xu, S.; Liu, Z.; Wang, J. Effect of low-frequency noise exposure on cognitive function: A systematic review and meta-analysis. *BMC Public Health* **2024**, *24*, 125. [[CrossRef](#)] [[PubMed](#)]
8. Fernández-Quezada, D.; Martínez-Fernández, D.E.; Fuentes, I.; García-Estrada, J.; Luquin, S. The Influence of Noise Exposure on Cognitive Function in Children and Adolescents: A Meta-Analysis. *NeuroSci* **2025**, *6*, 22. [[CrossRef](#)]
9. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.A.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.; Akl, E.A.; Brennan, P.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [[CrossRef](#)] [[PubMed](#)]
10. Shield, B.; Dockrell, J.E. The effects of environmental and classroom noise on the academic attainments of primary school children. *J. Acoust. Soc. Am.* **2008**, *123*, 133–144. [[CrossRef](#)]
11. Bhang, Y.; Yoon, H.; Sung, Y.; Yoo, H.; Sim, H.; Lee, S.; Lee, J.; Lee, J. Comparing Attention and Cognitive Function in School Children across Noise Conditions: A Quasi-Experimental Study. *Psychiatry Investig.* **2018**, *15*, 620–627. [[CrossRef](#)] [[PubMed](#)]
12. Connolly, D.; Dockrell, J.; Shield, B.; Conetta, R.; Mydlarz, A.; Cox, T. The effects of classroom noise on the reading comprehension of adolescents. *J. Acoust. Soc. Am.* **2019**, *145*, 372. [[CrossRef](#)] [[PubMed](#)]
13. Zhang, B.; Navejar, R. Effects of Ambient Noise on the Measurement of Mathematics Achievement for Urban High School Students. *Urban Educ.* **2018**, *53*, 10. [[CrossRef](#)]
14. McCreery, R.W.; Stelmachowicz, P.G. The effects of limited bandwidth and noise on verbal processing time and word recall in normal-hearing children. *Ear Hear.* **2013**, *34*, 585–591. [[CrossRef](#)] [[PubMed](#)]
15. Duarte da Cruz, S.; Silvério, A.; Aceituno Da Costa, L.; Mortari Moret, A.; Pereira Lauris, J.R.; Tangerino de Souza Jacob, R. Evaluating effectiveness of dynamic soundfield system in the classroom. *Noise Health* **2016**, *18*, 42–49. [[CrossRef](#)]
16. Dockrell, J.E.; Shield, B.M. The impact of sound-field systems on learning and attention in elementary school classrooms. *J. Speech Lang. Hear. Res.* **2012**, *55*, 1163–1176. [[CrossRef](#)]
17. Baek, K.; Park, C.; Sakong, J. The Impact of Aircraft Noise on the Cognitive Function of Elementary School Students in Korea. *Noise Health* **2023**, *25*, 83–91. [[CrossRef](#)]
18. Xie, H.; Kang, J.; Tompsett, R. The impacts of environmental noise on the academic achievements of secondary school students in Greater London. *Appl. Acoust.* **2011**, *72*, 551–555. [[CrossRef](#)]
19. Rance, G.; Dowell, R.C.; Tomlin, D. The effect of classroom environment on literacy development. *NPJ Sci. Learn.* **2023**, *8*, 9. [[CrossRef](#)] [[PubMed](#)]
20. Visentin, P.; Pellegatti, P.; Garraffa, M.; Di Domenico, A.; Prodi, N. Be Quiet! Effects of Competing Speakers and Individual Characteristics on Listening Comprehension for Primary School Students. *Int. J. Environ. Res. Public Health* **2023**, *20*, 4822. [[CrossRef](#)]
21. Leist, L.; Breuer, C.; Yadav, M.; Fremerey, S.; Fels, J.; Raake, A.; Lachmann, T.; Schlittmeier, S.J.; Klatte, M. Differential Effects of Task-Irrelevant Monaural and Binaural Classroom Scenarios on Children’s and Adults’ Speech Perception, Listening Comprehension, and Visual-Verbal Short-Term Memory. *Int. J. Environ. Res. Public Health* **2022**, *19*, 15998. [[CrossRef](#)]
22. Vettori, G.; Di Leonardo, L.; Secchi, S.; Astolfi, A.; Bigozzi, L. Primary school children’s verbal working memory performances in classrooms with different acoustic conditions. *Cogn. Dev.* **2022**, *64*, 101256. [[CrossRef](#)]
23. Chere, B.; Kirkham, N. The Negative Impact of Noise on Adolescents’ Executive Function: An Online Study in the Context of Home-Learning During a Pandemic. *Front. Psychol.* **2021**, *12*, 715301. [[CrossRef](#)]
24. Caviola, S.; Visentin, C.; Borella, E.; Mammarella, I.C.; Prodi, N. Out of the noise: Effects of sound environment on maths performance in middle-school students. *J. Environ. Psychol.* **2021**, *73*, 101552. [[CrossRef](#)]
25. Brill, L.; Wang, L.M. Higher Sound Levels in K-12 Classrooms Correlate to Lower Math Achievement Scores. *Front. Built Environ.* **2021**, *7*, 688395. [[CrossRef](#)]

26. Griffin, A.M.; Poissant, S.F.; Freyman, R.L. Auditory Comprehension in School-Aged Children with Normal Hearing and with Unilateral Hearing Loss. *Lang. Speech Hear. Serv. Sch.* **2020**, *51*, 29–41. [[CrossRef](#)]
27. Valente, D.L.; Plevinsky, H.M.; Franco, J.M.; Heinrichs-Graham, E.C.; Lewis, D.E. Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children. *J. Acoust. Soc. Am.* **2012**, *131*, 232–246. [[CrossRef](#)]
28. Ljung, R.; Sorqvist, P.; Hygge, S. Effects of road traffic noise and irrelevant speech on children's reading and mathematical performance. *Noise Health* **2009**, *11*, 194–198. [[CrossRef](#)]
29. Haines, M.M.; Stansfeld, S.A.; Job, R.F.; Berglund, B.; Head, J. A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition. *Int. J. Epidemiol.* **2001**, *30*, 839–845. [[CrossRef](#)]
30. Zhang, L.; Ma, H. The effects of environmental noise on children's cognitive performance and annoyance. *Appl. Acoust.* **2022**, *198*, 108995. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.