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Residential Noise, Cognitive Load, and Mathematics Anxiety in Middle School Mathematics Learning

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Abstract: Environmental conditions may be associated with students' cognitive and affective experiences in mathematics learning. This study examined the relationship between perceived residential environmental noise, cognitive load (CL), and mathematics anxiety (MA) among middle school students. A quantitative cross-sectional design was employed with 109 students in Grades VII–IX at a public Islamic junior secondary school in Kota Serang, Indonesia. Data were collected using an eight-item CL scale, an eight-item MA scale, and a five-category measure of perceived residential environmental noise ranging from very quiet to very noisy. Descriptive statistics, Cronbach's alpha, Spearman's correlation, Kruskal-Wallis tests, Welch's *t*-tests, effect sizes, partial correlation, and spatial visualization were used. The CL and MA scales demonstrated good internal consistency (α = .827 and .821, respectively). Significant differences in CL and MA were found across residential noise categories ($p < .001$). Perceived noise was positively associated with CL ($\rho = .511$, $p < .001$) and MA ($\rho = .604$, $p < .001$). CL and MA were also strongly associated ($r = .760$, $p < .001$), and the relationship remained substantial after controlling for perceived noise ($r_{partial} = .674$, $p < .001$). Students reporting higher-noise environments showed higher CL and MA than those reporting lower-noise environments, with Hedges' g of 1.28 and 1.51, respectively. These findings indicate that perceived residential environmental context is a relevant contextual variable in understanding students' cognitive and affective experiences in mathematics learning. The findings represent associations rather than causal effects of environmental noise.

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INTRODUCTION

Environmental conditions are increasingly recognized as contextual factors that may shape children's cognitive functioning and learning experiences. Noise is particularly relevant because it can interfere with attention, working memory, and other cognitive processes required during learning. A systematic review of 26 studies found that noise exposure can affect children's cognitive and academic performance, although the effects vary according to noise type and cognitive task (Gheller et al., 2023). Similarly, a review of classroom acoustics reported that noise and reverberation can influence children's attention and memory, with many studies showing negative or null effects of poorer acoustic conditions on cognitive processes (Mealings, 2022). More recently, a meta-analysis of studies involving children and adolescents reported a significant negative association between noise exposure and cognitive performance (Fernández-Quezada et al., 2025). Prospective evidence has likewise linked community noise exposure with children's cognitive and behavioral development (Raess et al., 2022), while a population-based cohort study of schoolchildren found associations between road-traffic noise and cognitive development (Foraster et al., 2022). These findings indicate that environmental noise warrants consideration not only as an acoustic issue but also as a contextual factor in children's learning experiences.

However, evidence that environmental noise is associated with children's cognitive functioning does not necessarily explain how students experience the cognitive demands of mathematics learning or how these demands relate to their mathematics-specific emotional responses. This distinction is

important because general cognitive performance, perceived cognitive load, and mathematics anxiety represent related but different aspects of learning. Examining these aspects together may help clarify whether students' perceptions of their residential noise conditions are associated with both the cognitive demands and emotional experiences they report during mathematics learning.

From a learning perspective, one relevant outcome is cognitive load (CL), referring to the mental demands experienced while processing information during learning. Cognitive Load Theory proposes that working memory has limited capacity, making the management of competing cognitive demands important for learning (Sweller, 1988). In mathematics learning, this perspective is particularly relevant because students may need to process and coordinate multiple pieces of information during problem solving. Oktaviyanthi et al. (2024) examined cognitive load in mathematics learning through the formal definition of limit and developed a context-specific cognitive-load scale, illustrating the relevance of cognitive-load measurement in mathematics education. Subjective cognitive-load measures are widely used in educational research, and a systematic meta-analysis found satisfactory internal consistency across commonly used cognitive-load questionnaires while also emphasizing the importance of considering measurement validity (Krieglstein et al., 2022). Environmental noise may be relevant to students' perceived cognitive demands because mathematics learning often requires sustained attention, information processing, and retention of problem-solving steps. Noise-related disruptions to attention and memory provide a plausible contextual rationale for examining this relationship, although they do not establish that residential noise necessarily produces higher cognitive load. Despite existing evidence on noise and general cognitive or academic outcomes, the relationship between perceived residential environmental noise and students' self-reported cognitive load during mathematics learning remains insufficiently understood.

A second relevant outcome is mathematics anxiety (MA), a mathematics-specific emotional response that can involve worry, tension, fear, and other negative reactions during mathematics-related situations. Math anxiety can already be observed among school-aged children and has consequently become an important target of educational and psychological intervention research (Balt et al., 2022). Recent studies emphasize that mathematics anxiety is a distinct construct that should be examined in relation to cognitive as well as affective processes (Cipora et al., 2022). Research has also examined the relationship between mathematics anxiety and mathematical performance, highlighting the role of anxiety in students' mathematics learning (Demedts et al., 2022), while other studies have demonstrated interactions between mathematics anxiety and working memory in mathematical performance (Cuder et al., 2023; Finell et al., 2022), while longitudinal evidence indicates that mathematics anxiety is relevant to students' later educational choices during middle school (Cuder et al., 2024). These findings provide a theoretical basis for considering cognitive load and mathematics anxiety together rather than treating them as entirely separate aspects of mathematics learning. Students who report greater cognitive demands may also experience greater mathematics anxiety, although the direction of this relationship cannot be assumed. Environmental noise may provide an additional contextual dimension for investigating these experiences because noise-related cognitive demands and mathematics-specific emotional responses may both be relevant to students' learning experiences. Nevertheless, relatively little is known about whether students' perceived residential environmental noise is associated simultaneously with cognitive load and mathematics anxiety.

Although previous research has linked environmental noise to children's cognitive functioning, attention, memory, and academic outcomes, much of the available evidence has focused on general cognitive performance, objectively measured noise exposure, or classroom acoustic conditions (Gheller et al., 2023; Mealings, 2022; Fernández-Quezada et al., 2025). Consequently, three related questions remain insufficiently addressed in the context of mathematics education: whether students' perceived residential noise differs in its association with cognitive load and mathematics anxiety across noise categories, whether cognitive load and mathematics anxiety remain associated after accounting for perceived noise, and whether these outcomes differ between students reporting lower-noise and higher-noise residential environments. The present study addresses these questions by examining perceived residential environmental noise, cognitive load (CL), and mathematics anxiety (MA) among middle school students. Rather than treating brain fog as a clinical or independently measured construct, the study uses

the term only as a conceptual framing for cognitive and affective difficulties that may be experienced during mathematics learning. The study extends the existing literature by examining CL and MA simultaneously in relation to students' perceived residential noise, combining descriptive, comparative, and correlational analyses, and using spatial visualization to describe the distribution of observed patterns across residential environmental contexts. The spatial component is descriptive and is not intended to identify statistically defined geographical hotspots. Together, these approaches provide a contextual perspective on students' mathematics-learning experiences without assuming a causal relationship between residential noise and the outcomes investigated.

Accordingly, this study investigates the relationships among perceived residential environmental noise, cognitive load, and mathematics anxiety among middle school students. Specifically, the study addresses four research questions: (1) How do CL and MA differ across perceived residential environmental noise levels? (2) What are the relationships between perceived residential environmental noise and CL and MA? (3) What is the relationship between CL and MA after accounting for perceived residential environmental noise? and (4) How do CL and MA differ between students reporting lower-noise and higher-noise residential environments? In addition, spatial visualization is used to describe the distribution of these observed patterns across residential environmental contexts.

METHOD

Research Design and Setting

This study employed a quantitative cross-sectional design incorporating descriptive, comparative, correlational, and spatial analyses. The study examined the association between students' perceived residential environmental noise and their self-reported cognitive load and mathematics anxiety, and described the spatial distribution of these outcomes across residential environmental contexts. As the study did not manipulate environmental noise or assign participants to exposure conditions, the findings are interpreted as associations rather than causal effects (von Elm et al., 2008). The study was conducted from May to July 2025 at a public Islamic junior secondary school in Kota Serang, Banten, Indonesia, and involved students in Grades VII–IX. The overall research procedure, comprising instrument development and validation, data collection and screening, scoring and data processing, quantitative analysis, spatial visualization, and interpretation of findings, is presented in Figure 1.

Participants and Sampling

A total of 109 students from Grades VII–IX participated in this study at a school located alongside a main road in Kota Serang, Banten, Indonesia. The school was purposively selected because its location was relevant to the study of perceived residential environmental noise and because it served as a pilot research site to generate preliminary findings that could inform subsequent studies. Non-probability sampling was used to recruit participants from the selected school. The findings should be interpreted within this study context, as the use of a single school and non-random sampling limits their generalizability to the broader population of middle school students.

Measures

Data were collected using a structured Google Forms questionnaire comprising three sections: participant characteristics and residential environmental information, an eight-item Cognitive Load (CL) scale, and an eight-item Mathematics Anxiety (MA) scale.

Students reported the perceived sound condition of their residential environment using five ordered categories: very quiet, quiet, moderate, noisy, and very noisy. These categories represented students' subjective perceptions of their residential sound environments rather than sound levels measured in decibels (dB). Because no sound-level meter or repeated decibel measurements were used, the variable was treated as an ordinal measure of perceived residential environmental noise rather than an objective measure of acoustic exposure. Previous research has associated environmental noise with children's cognitive functioning and learning outcomes, although the observed effects vary across noise types and cognitive tasks (Gheller et al., 2023). Research has also examined associations between environmental noise exposure and cognitive and psychological outcomes among schoolchildren (Shukla et al., 2026). These studies provide context for investigating environmental noise but do not establish that

the five categories used in the present study correspond to specific acoustic exposure levels (World Health Organization [WHO], 2018; Guski et al., 2017). The five categories were treated as ordered labels from very quiet to very noisy, without assigning specific decibel ranges or applying external acoustic thresholds. Of the 109 responses, 107 could be classified into one of the five categories. Two responses, recorded as "Sedang, Tenang" ("moderate, quiet"), could not be assigned unambiguously to a single category and were excluded from analyses requiring an ordinal noise classification. Accordingly, the variable represents students' reported perceptions of residential sound conditions and should not be interpreted as a direct measurement of acoustic exposure or evidence that their residential environments exceeded established noise guidelines.

Cognitive Load (CL) was assessed using eight self-report items measuring students' perceived cognitive demands during mathematics learning, including perceived overload, difficulty following explanations, retaining solution steps, and processing mathematics problems. Items were rated on a five-point Likert scale, with higher scores indicating greater perceived cognitive load. The scale was conceptually informed by Cognitive Load Theory, which explains how the limited capacity of working memory constrains learning and problem solving (Sweller, 1988). Subjective ratings of mental effort and cognitive load have been used in learning research, although the interpretation of such ratings depends on the items and measurement procedures employed (Leppink et al., 2013; Paas, 1992). The eight items were summed to obtain a total CL score. The scale demonstrated good internal consistency in the present sample (Cronbach's $\alpha = .827$).

Mathematics Anxiety (MA) was assessed using eight self-report items developed for the present study. The items addressed students' emotional and cognitive responses to mathematics, including nervousness, fear of poor performance, tension, panic, lack of confidence, and discomfort with mathematical symbols. Items were rated on a five-point Likert scale, with higher scores indicating greater mathematics anxiety. The item content was informed by research conceptualizing mathematics anxiety as a mathematics-related emotional response and examining its measurement among secondary-school students (Hill et al., 2016; Yáñez-Marquina & Villardón-Gallego, 2017). The eight items were summed to obtain a total MA score. The scale demonstrated good internal consistency in the present sample (Cronbach's $\alpha = .821$). Because the MA items were developed for this study, the observed internal consistency does not, by itself, establish comprehensive content validity, construct validity, or discriminant validity. In particular, the reliability estimate does not demonstrate that mathematics anxiety has been empirically distinguished from mathematical self-efficacy. The MA total score was therefore interpreted as an indicator of students' self-reported mathematics anxiety, subject to these measurement limitations.

Instrument

Before the substantive analyses, the internal consistency of the CL and MA scales was examined. Cronbach's alpha was calculated for each scale, together with corrected item-total correlations. The results indicated acceptable-to-good internal consistency for both measures (CL, $\alpha = .827$; MA, $\alpha = .821$). These reliability estimates support the use of the total CL and MA scores for subsequent analyses. Content development of the items was informed by the theoretical literature on cognitive load and mathematics anxiety. However, the two scales were developed for the present study rather than being administered as a direct adaptation of a previously validated standardized instrument. Therefore, the reported reliability coefficients provide evidence of internal consistency for this sample but should not be interpreted as evidence that the scales are universally validated measures.

Data Analysis

Data were first screened for completeness, consistency, and coding accuracy, and CL and MA scores were recalculated from their respective eight items. Descriptive statistics (mean, standard deviation, minimum, and maximum) and internal consistency (Cronbach's alpha and corrected item-total correlations) were then examined. Because perceived residential environmental noise was measured on an ordered five-category scale, Spearman's rank-order correlation was used to examine its associations with CL and MA. Differences across noise categories were tested using the Kruskal–Wallis test, followed by pairwise comparisons where appropriate. A predefined comparison between lower-noise (very quiet

and quiet) and higher-noise (noisy and very noisy) environments was additionally examined using Welch's independent-samples t-test, with effect sizes reported to quantify group differences. The association between CL and MA was examined using Pearson's and Spearman's correlations, with partial correlation used to control for perceived residential environmental noise. Statistical significance was set at $\alpha = .05$. Analyses were conducted using IBM SPSS and Python, and graphical visualizations were produced using Matplotlib.

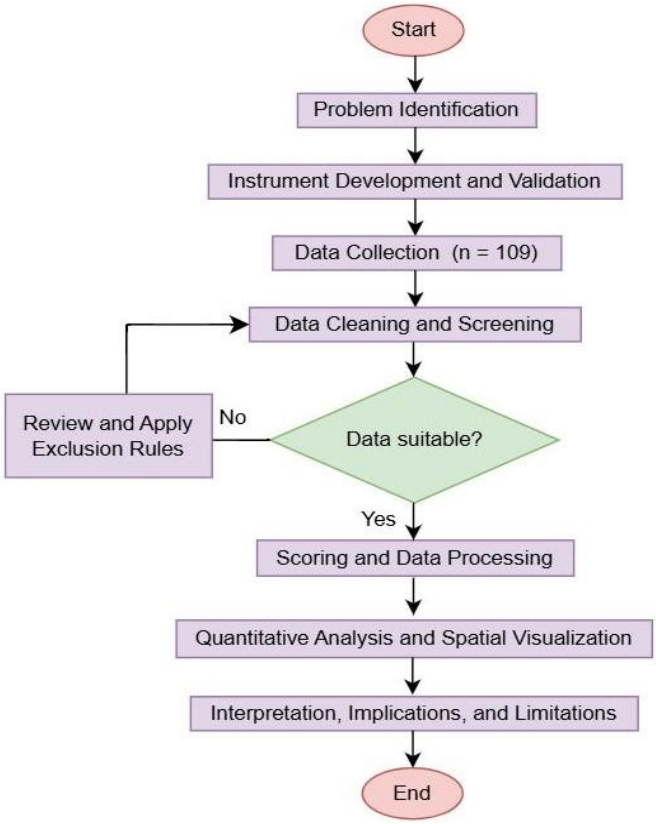


Figure 1. Research Procedure

Spatial Analysis

Spatial visualization was used to describe the distribution of students' cognitive and affective outcomes across residential environmental contexts. The spatial component was treated as a descriptive visualization rather than as a formal spatial-statistical analysis. Residential information was aggregated into environmental categories to avoid displaying individual household locations. The maps therefore represent the spatial distribution of observed cognitive-load and mathematics-anxiety patterns across environmental contexts rather than identifying individual students or estimating statistically defined geographical hotspots. No individual residential coordinates were displayed in the research outputs.

Ethical Considerations

Participation was voluntary, and questionnaire responses were analyzed in aggregated form. Individual residential locations were not displayed in the spatial visualization. Environmental information was reported at the category level to reduce the possibility of identifying individual participants from their residential information. Because the study used a cross-sectional observational design and perceived rather than objectively measured environmental noise, the findings are interpreted as associations. The study does not establish that environmental noise causes increased cognitive load or mathematics anxiety.

RESULT

Descriptive Statistics and Internal Consistency

A total of 109 students from Grades VII–IX participated in the study. Cognitive Load (CL) and

Mathematics Anxiety (MA) scores were calculated by summing the responses to their respective eight Likert-scale items. The resulting CL scores ranged from 13 to 37, with a mean of 25.14 (SD = 5.07), whereas MA scores ranged from 8 to 36, with a mean of 25.70 (SD = 5.58). These results indicate substantial variation in students' self-reported cognitive and affective experiences during mathematics learning.

The internal consistency of both scales was examined using Cronbach's alpha. The CL scale produced an alpha coefficient of .827, while the MA scale produced an alpha coefficient of .821. Corrected item-total correlations were positive across the items in both scales, indicating that the items contributed consistently to their respective total scores. The descriptive statistics and internal consistency coefficients are presented in Table 1.

Table 1. Descriptive Statistics and Internal Consistency of the CL and MA Scales

Measure	Items	M	SD	Min	Max	Cronbach's α
Cognitive Load (CL)	8	25.14	5.07	13	37	.827
Mathematics Anxiety (MA)	8	25.70	5.58	8	36	.821

The results in Table 1 show that the two measures had comparable mean scores, although MA showed slightly greater variability than CL. The reliability coefficients were above .80 for both measures, providing evidence of good internal consistency for the present sample. Accordingly, the subsequent analyses used the continuous CL and MA total scores rather than categorical classifications.

Cognitive Load and Mathematics Anxiety across Perceived Residential Environmental Noise Levels

The distribution of CL and MA scores was examined across the five categories of perceived residential environmental noise: very quiet, quiet, moderate, noisy, and very noisy. These categories represented students' subjective perceptions of their residential sound environments and were not based on objective sound-level measurements in decibels (dB). A total of 107 responses could be classified into these ordered categories. Two responses that contained an ambiguous description combining "moderate" and "quiet" were excluded from the ordinal noise analyses. Accordingly, the analyses reflect differences across self-reported perceptions of residential sound conditions rather than objectively measured differences in noise exposure.

The descriptive pattern shows that both CL and MA tended to increase across the higher categories of perceived residential environmental noise. Students who reported their residential environment as noisy or very noisy generally had higher CL and MA scores than students who reported quiet or very quiet environments. The mean scores for each noise category are presented in Figure 2.

As shown in Figure 2, the mean CL score was 23.29 among students reporting very quiet environments, 22.25 among those reporting quiet environments, 23.85 among those reporting moderate environments, 28.11 among those reporting noisy environments, and 31.11 among those reporting very noisy environments. A similar pattern was observed for MA, with mean scores of 24.86, 21.33, 25.10, 28.19, and 34.00, respectively. The relatively small very-quiet group (n = 7) should be considered when interpreting the corresponding mean scores. Nevertheless, the overall pattern indicates higher CL and MA scores in the noisy and very noisy categories. Because these categories were based on subjective perceptions, students reporting similar acoustic environments may nevertheless have selected different categories depending on their sensitivity to sound, the types of sounds they encountered, or their personal preferences. These factors were not directly measured in the present study.

To examine whether the differences across the five ordered noise categories were statistically significant, separate Kruskal–Wallis tests were conducted for CL and MA. The analysis yielded a significant difference in CL across noise categories, ($H(4) = 34.23$), ($p < .001$). A significant difference was also found for MA, ($H(4) = 46.66$), ($p < .001$). Thus, the distribution of both CL and MA scores differed significantly across the perceived residential environmental noise categories. These results indicate statistically significant differences among the groups defined by perceived residential sound conditions; they do not establish that objectively measured noise intensity differed across groups or that residential noise caused higher cognitive load or mathematics anxiety.

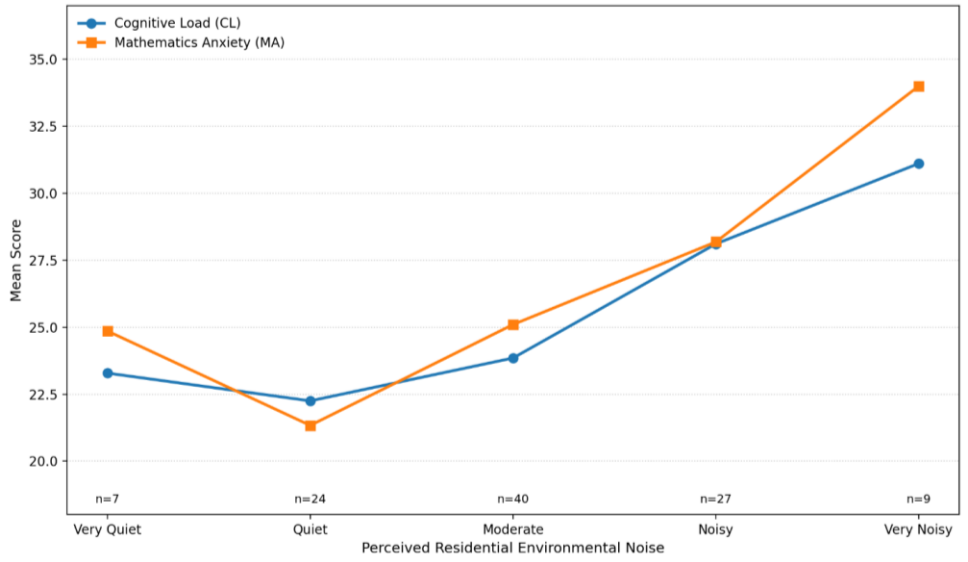


Figure 2. Mean Cognitive Load and Mathematics Anxiety by Noise Level

Associations between Noise, Cognitive Load, and Mathematics Anxiety

The relationship between perceived residential environmental noise and the two psychological measures was examined using Spearman's rank-order correlation because perceived noise was measured using an ordered categorical scale. In addition, the relationship between CL and MA was examined using both Pearson's and Spearman's correlations.

The results are presented in Table 2.

Table 2. Correlations among Noise, Cognitive Load, and Mathematics Anxiety

Variables	Correlation	Coefficient	*p*
Perceived noise – CL	Spearman's ρ	.511	< .001
Perceived noise – MA	Spearman's ρ	.604	< .001
CL – MA	Pearson's *r*	.760	< .001
CL – MA	Spearman's ρ	.746	< .001
CL – MA controlling for perceived noise	Partial *r*	.674	< .001

The results in Table 2 indicate a moderate positive association between perceived residential environmental noise and CL (ρ = .511, $p < .001$). A stronger positive association was observed between perceived noise and MA (ρ = .604, $p < .001$). Thus, students reporting higher levels of perceived residential environmental noise also tended to report higher levels of cognitive load and mathematics anxiety. A strong positive association was also found between CL and MA. Pearson's correlation was $r = .760$ ($p < .001$), while Spearman's correlation was ρ = .746 ($p < .001$). This indicates that students reporting greater cognitive load also tended to report greater mathematics anxiety.

To examine whether the association between CL and MA remained after accounting for perceived residential environmental noise, a partial correlation was calculated. The resulting coefficient was $r = .674$ ($p < .001$). The association therefore remained substantial after controlling for the ordinal noise measure, indicating that the relationship between cognitive load and mathematics anxiety was not explained solely by differences in reported residential environmental noise.

Comparison between Lower-Noise and Higher-Noise Residential Environments

In addition to the analysis across all five noise categories, a predefined comparison was conducted between students reporting lower-noise and higher-noise residential environments. The lower-noise group consisted of students reporting very quiet or quiet environments ($n = 31$), whereas the higher-noise group consisted of students reporting noisy or very noisy environments ($n = 36$). Students in the moderate category were excluded from this specific contrast to maintain a clear separation between the two groups.

Because the two groups differed in size and variability, Welch's independent-samples *t*-test was used. Effect sizes were calculated using Hedges' *g*, and 95% confidence intervals were reported for the mean differences. The results are shown in Table 3.

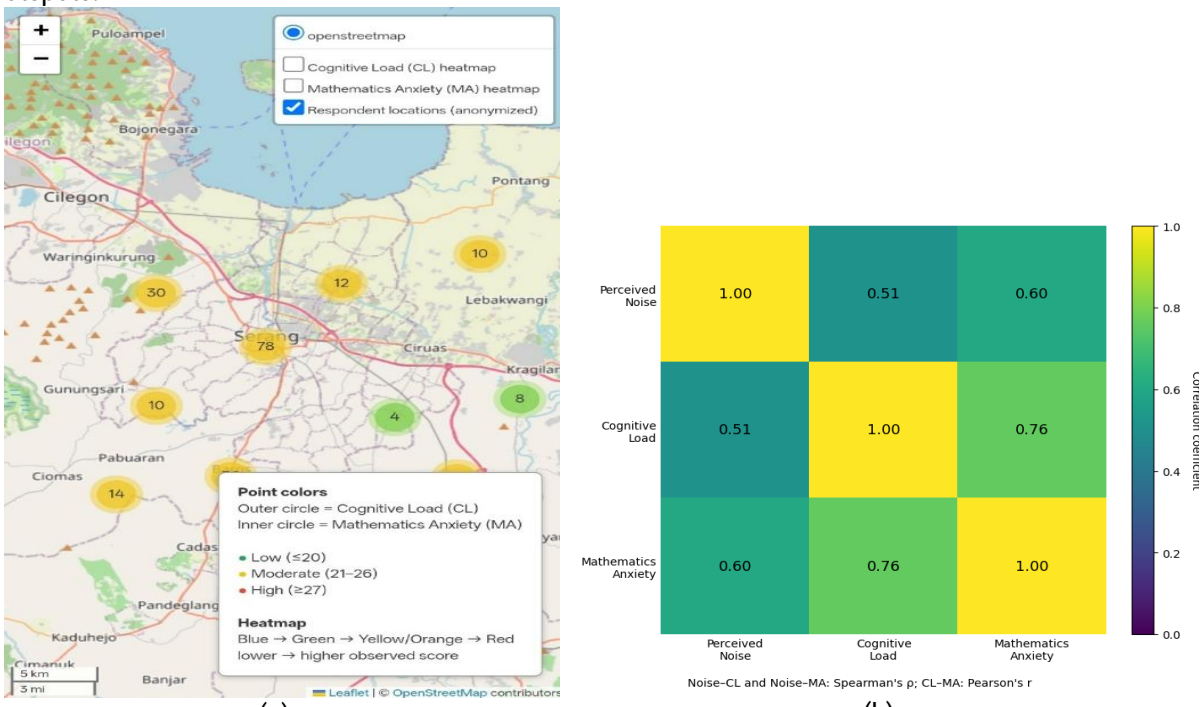
Table 3. Comparison of Cognitive Load and Mathematics Anxiety by Noise Group

Measure	Lower noise M (SD)	Higher noise M (SD)	Mean difference	Welch's *t*	*p*	Hedges' *g*	95% CI of difference
Cognitive Load	22.48 (5.81)	28.86 (3.99)	6.38	5.15	< .001	1.28	[3.89, 8.86]
Mathematics Anxiety	22.13 (5.48)	29.64 (4.35)	7.51	6.14	< .001	1.51	[5.06, 9.96]

The results show that the higher-noise group had a higher mean CL score than the lower-noise group. The mean difference was 6.38 points, and the difference was statistically significant, Welch's t = 5.15, p < .001. The corresponding Hedges' g was 1.28, with a 95% confidence interval for the mean difference ranging from 3.89 to 8.86. A similar pattern was observed for MA. Students in the higher-noise group had a mean MA score of 29.64 compared with 22.13 in the lower-noise group, yielding a mean difference of 7.51 points. This difference was statistically significant, Welch's t = 6.14, p < .001, with Hedges' g = 1.51 and a 95% confidence interval from 5.06 to 9.96. Taken together, the group comparison indicates that students reporting noisy or very noisy residential environments had higher self-reported cognitive load and mathematics anxiety than those reporting very quiet or quiet environments. The standardized differences were large for both outcomes.

Spatial and Correlational Patterns of Cognitive Load and Mathematics Anxiety

The spatial visualization depicts the distribution of students' cognitive load (CL) and mathematics anxiety (MA) across their residential environments (Figure 3a). The visualization provides descriptive geographical context for the observed outcomes, while individual household locations are not displayed as identifiable points. Because the analysis was not designed to test spatial autocorrelation or identify statistically significant geographical clusters, the map should not be interpreted as evidence of spatial hotspots.



(a) (b)

Figure 3. Spatial and Correlational Patterns of CL and MA: (a) Spatial Distribution; (b) Correlation Matrix

The correlation matrix in Figure 3b provides a statistical perspective on the relationships among perceived residential environmental noise, CL, and MA. Perceived noise was positively associated with CL (Spearman's ρ = .511, p < .001) and MA (Spearman's ρ = .604, p < .001). The association with MA was numerically stronger than the association with CL, indicating that students who reported noisier residential environments also tended to report higher mathematics anxiety. CL and MA showed the strongest association among the reported pairs (Pearson's r = .760, p < .001), indicating that students reporting greater cognitive load also tended to report greater mathematics anxiety.

Together, Figure 3 provides complementary descriptive and statistical evidence. The spatial visualization situates the observed outcomes within students' residential environmental contexts, while the correlation matrix quantifies the direction and strength of their associations. These findings are consistent with the broader results showing higher CL and MA among students reporting noisier residential environments. However, the spatial visualization does not establish geographical clustering, and the correlations do not demonstrate that perceived residential noise causes increased cognitive load or mathematics anxiety.

DISCUSSION

Cognitive Load and Mathematics Anxiety across Residential Environmental Noise Levels

The first research question examined how cognitive load (CL) and mathematics anxiety (MA) differed across perceived levels of residential environmental noise. The results showed a general upward trend in both outcomes across the five noise categories: mean CL increased from 22.25 among students reporting quiet environments to 31.11 among those reporting very noisy environments, while mean MA increased from 21.33 to 34.00. The Kruskal-Wallis tests confirmed significant differences across the categories for both CL, $H(4) = 34.23$, $p < .001$, and MA, $H(4) = 46.66$, $p < .001$. This pattern is broadly consistent with recent evidence linking environmental noise with children's cognitive and learning-related outcomes. Gheller et al. (2023), in a systematic review of 26 studies, reported that noise can affect children's cognitive and academic performance, while Fernández-Quezada et al. (2025), in a meta-analysis of eight studies involving children and adolescents, found a significant negative association between noise exposure and cognitive performance. Although these studies primarily addressed cognitive and academic outcomes, the present findings extend this evidence by showing that perceived residential noise was associated with both CL and the mathematics-specific affective experience of MA.

The findings should be interpreted in relation to the nature of the noise measure used in this study. Perceived residential environmental noise was assessed through students' reports rather than objective sound-pressure measurements; therefore, the five categories cannot be interpreted as specific decibel levels. This distinction is relevant because the effects of noise may vary according to noise characteristics, exposure conditions, and cognitive tasks (Gheller et al., 2023). Students experiencing similar acoustic environments may perceive and report noise differently due to differences in sound sensitivity, the types of sounds they encounter, or personal preferences. These factors were not directly measured in this study. Therefore, the categories represent students' perceived residential sound conditions rather than objectively established levels of noise exposure. Accordingly, the present results do not establish that a particular noise intensity produces a particular level of CL or MA. Rather, they indicate that students who perceived their residential environments as noisier also reported greater cognitive and mathematics-related affective demands. The findings should therefore be interpreted as indicating associations between perceived residential environmental noise, CL, and MA. They do not establish a causal relationship. Perceived residential environmental noise may be a relevant contextual variable for understanding students' mathematics learning experiences, while potential causal mechanisms require further investigation through research designs that incorporate objective noise measurements and temporal assessments.

Association between Perceived Residential Noise and Cognitive-Affective Outcomes

The second research question examined the relationship between perceived residential environmental noise and students' cognitive load (CL) and mathematics anxiety (MA). Spearman's correlation showed a moderate positive association between perceived noise and CL ($\rho = .511$, $p < .001$) and a stronger positive association with MA ($\rho = .604$, $p < .001$). Thus, students reporting noisier

residential environments also tended to report greater cognitive demands and mathematics anxiety. The stronger association with MA suggests that environmental context may be related not only to students' perceived mental effort but also to their emotional experiences in mathematics.

This pattern can be interpreted in relation to limited cognitive processing capacity, as proposed by Cognitive Load Theory (Sweller, 1988), while subjective cognitive-load measures require careful interpretation according to their measurement characteristics (Krieglstein et al., 2022). In the present study, the CL scale demonstrated good internal consistency (α = .827), supporting its use for examining perceived cognitive demands in this sample. The relationship with MA is also relevant because mathematics anxiety encompasses cognitive and emotional responses specific to mathematics (Cipora et al., 2022). The stronger association between perceived noise and MA than CL may therefore indicate that residential environmental context is related to both cognitive and affective aspects of mathematics learning. However, because the study was cross-sectional and noise was subjectively reported, these associations should not be interpreted as evidence that residential noise causes higher CL or MA.

Relationship between Cognitive Load and Mathematics Anxiety

The third research question examined the relationship between cognitive load (CL) and mathematics anxiety (MA). A strong positive association was found between CL and MA using both Pearson's correlation (r = .760, p < .001) and Spearman's correlation (ρ = .746, p < .001). The relationship remained substantial after controlling for perceived residential environmental noise ($r$partial = .674, p < .001), indicating that students who reported greater cognitive demands in mathematics also tended to report greater mathematics anxiety beyond differences in perceived residential noise. This pattern is consistent with evidence linking mathematics anxiety with cognitive resources: Pellizzoni et al. (2022) identified an interplay between mathematics anxiety and working memory, while Cuder et al. (2023) and Finell et al. (2022) likewise demonstrated relationships between mathematics anxiety, working memory, and mathematical performance.

The findings suggest that cognitive and affective experiences may be closely connected during mathematics learning. This connection is also relevant from an intervention perspective, as previous research has shown that mathematics anxiety can be addressed through skill-based and therapeutic interventions, although the magnitude of effects varies across intervention approaches (Codding et al., 2023). However, the cross-sectional design does not establish whether greater cognitive load contributes to mathematics anxiety, anxiety increases perceived cognitive load, or both are related to other factors. The partial correlation indicates that the CL-MA association persists after accounting for perceived residential noise, but does not establish a causal mechanism. Accordingly, the findings support considering CL and MA as interconnected dimensions of students' mathematics-learning experiences, while *brain fog* should be retained only as a conceptual framing of this combined cognitive-affective experience rather than as a directly measured clinical, neurological, or psychological condition.

Differences between Lower-Noise and Higher-Noise Residential Environments

The fourth research question compared students reporting lower- and higher-noise residential environments. Students in the higher-noise group reported greater CL (M = 28.86, SD = 3.99) than those in the lower-noise group (M = 22.48, SD = 5.81), with a mean difference of 6.38, t = 5.15, p < .001, and Hedges' g = 1.28. A similar difference was found for MA, with higher scores in the higher-noise group (M = 29.64, SD = 4.35) than in the lower-noise group (M = 22.13, SD = 5.48), a mean difference of 7.51, t = 6.14, p < .001, and Hedges' g = 1.51. Thus, the predefined group comparison confirms the pattern observed across the five noise categories, with higher perceived noise associated with greater cognitive and affective demands in mathematics.

This pattern is consistent with evidence that environmental noise is associated with children's cognitive functioning and learning outcomes. Gheller et al. (2023) found across 26 studies that noise affected children's cognitive performance, with effects varying by noise characteristics and cognitive tasks, while Fernández-Quezada et al. (2025) reported a significant negative association between noise exposure and cognitive performance in children and adolescents. The present findings extend this evidence to mathematics learning by showing differences in both CL and MA between lower- and higher-perceived-noise groups. Because the groups were based on perceived noise and the study was cross-

sectional, the effect sizes describe differences within this sample rather than a causal effect of residential noise. Nevertheless, together with the five-category and correlational analyses, the results identify perceived residential environmental noise as a relevant contextual factor associated with students' cognitive and affective experiences in mathematics.

Limitations, Recommendations, and Implications

Several limitations should be considered when interpreting the findings. First, the cross-sectional design limits causal and temporal interpretations, as the study identifies associations among perceived residential environmental noise, cognitive load (CL), and mathematics anxiety (MA) at a single point in time. Second, residential noise was assessed through students' subjective perceptions rather than objective acoustic measurements; therefore, the five categories represent perceived environmental conditions rather than specific decibel levels, and noise effects may vary according to exposure characteristics and cognitive tasks (Gheller et al., 2023). Students experiencing similar acoustic environments may perceive and report noise differently because of differences in sound sensitivity, the types of sounds encountered, or personal preferences. These factors were not directly measured in this study. Third, CL and MA were measured using self-report scales developed for this study. Although both scales demonstrated good internal consistency (α = .827 and .821, respectively), internal consistency alone does not establish comprehensive construct validity (Krieglstein et al., 2022). Finally, the sample comprised 109 students from a single school recruited through non-probability sampling, limiting the generalizability of the findings beyond the study context. Future research could strengthen the evidence through longitudinal designs, objective and repeated noise measurements, further psychometric validation of the CL and MA scales, and samples from multiple schools and geographic contexts. Combining objective acoustic measurements with students' subjective ratings may help clarify how measured noise exposure relates to perceived residential sound conditions and students' mathematics-learning experiences.

The findings have implications for mathematics education research and practice by highlighting the relevance of contextual, cognitive, and affective factors in understanding students' mathematics-learning experiences. The observed association between perceived residential environmental noise and both cognitive load (CL) and mathematics anxiety (MA) suggests that environmental context may be considered as one contextual variable when examining students' cognitive and affective experiences, without interpreting residential noise as a direct cause of mathematics difficulties. The strong association between CL and MA, which remained substantial after controlling for perceived residential environmental noise, further indicates the value of considering cognitive and affective indicators together rather than relying solely on mathematics achievement to characterize students' learning experiences. This is also relevant to educational practice because meta-analytic evidence indicates that mathematics anxiety can be reduced through educational and psychological interventions, with effects varying across intervention approaches (Sammallahti et al., 2023). However, the present study did not evaluate the effectiveness of any intervention. The spatial visualization also provides a descriptive contextual layer for identifying how observed CL and MA patterns are distributed across residential environmental contexts, although it should not be interpreted as a formal hotspot or spatial-risk analysis. Overall, the findings provide an initial basis for integrating environmental context, cognitive load, and mathematics anxiety in mathematics-education research, while the term *brain fog* should remain a conceptual framing rather than a directly measured clinical or psychological construct.

CONCLUSION

This study highlights the relevance of residential environmental context in understanding students' cognitive and affective experiences in mathematics learning. Rather than viewing cognitive load and mathematics anxiety as isolated characteristics of individual students, the findings indicate that these experiences should also be considered in relation to the environments in which students live and learn. The close relationship between cognitive load and mathematics anxiety further supports an integrated perspective in which cognitive demands and mathematics-related emotional responses are examined together. The study contributes to mathematics education research by examining perceived residential

environmental noise in relation to both cognitive load and mathematics anxiety among middle-school students. The study also demonstrates the value of combining quantitative analysis with contextual spatial visualization to describe patterns in students' mathematics-learning experiences. However, given the cross-sectional design and sample of 109 students from one school, the findings represent associations within a specific context and should not be interpreted as evidence that residential noise causes cognitive load or mathematics anxiety. The concept of brain fog should therefore remain a contextual framing rather than a directly measured psychological or clinical construct. Future research should incorporate objective noise measurements, longitudinal designs, further instrument validation, and samples from multiple schools to examine these relationships more comprehensively.

AI USE STATEMENT

Grammarly Pro and ChatGPT (OpenAI) were used to assist with English-language proofreading, language refinement, and improving the clarity of the manuscript. The authors reviewed the suggested revisions and take full responsibility for the manuscript's content, data analysis, interpretation, and conclusions.

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