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The Effect of Noise on Learning Achievement through Students Cognitive Functions: A Stroop Test-Based Mediation Analysis

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ABSTRACT

Environmental noise exposure in schools near airports may negatively impact students' cognitive functioning and academic performance. However, the cognitive mechanisms underlying the relation between noise exposure and learning achievement are still poorly understood. This study aims to explore the direct and indirect associations of environmental noise exposure with learning achievement, with a mediating variable of cognitive function measured by the Stroop Test. This research was done on 120 students of elementary, junior high and vocational high school who lived in the vicinity of Sultan Aji Muhammad Sulaiman Sepinggan Airport, Balikpapan, Indonesia. The data were analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM) with 10.000 bootstrap resamples. The results indicated that environmental noise exposure was negatively associated with cognitive function ($\beta = -0.981$, $p < 0.001$), and cognitive function was positively associated with learning achievement ($\beta = 2.309$, $p < 0.001$). There was a significant and positive direct relationship between noise exposure and learning achievement ($\beta = 1.470$, $p < 0.001$), and a significant and negative indirect relationship through cognitive function ($\beta = -2.266$, $p < 0.001$, 95% CI [−2.729, −1.852]). Overall, the effect was negative and significant ($\beta = -0.796$, $p < 0.001$) suggesting competitive mediation. These findings indicate that cognitive function is an important mediating factor between environmental noise exposure and learning achievement. Our results provide empirical support for a cognitive pathway based on Stroop interference linking airport-related environmental noise and learning outcomes and provide insights for the assessment of environmental conditions and support of cognitive performance in educational contexts.

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1. Introduction

A conducive learning environment is essential for effective education because the physical conditions of school's influence students' ability to learn efficiently, maintain concentration, and participate safely and comfortably in classroom activities (Singkam, 2020). Noise is therefore an important component of the school environment, particularly because unwanted sound can interfere with communication and concentration during learning (Carolina et al., 2021; Prijana et al., 2023; Singkam, 2020).

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Transportation-related and external environmental noise can also penetrate learning spaces and disturb students even when the sound source is located outside the classroom (Hardiani et al., 2022; Merdekawati Noralita Soludale & Bhara, 2024). This issue is especially relevant to schools located near active airports, where aircraft operations can create repeated environmental noise exposure during school hours. In Indonesia, environmental noise is defined as unwanted sound arising from activities or operations at intensity levels and durations that may disturb human health and environmental comfort (Rili & Widyanto et al., 2022; Hardiani et al., 2022; Middelhoff et al., 2022; Singkam, 2020). For school environments, the recommended maximum noise level is 55 dB(A) (Hardiani et al., 2022; Kadir et al., 2024; Rili & Widyanto, 2022). Schools located around Sultan Aji Muhammad Sulaiman Sepinggan Airport in Balikpapan therefore represent an important educational context because students may experience aircraft-related noise as part of their daily learning environment. Such exposure is relevant not only to acoustic comfort but also to the cognitive processes required to maintain attention and perform academic tasks.

The potential effect of noise on learning can be explained through its interference with attention and cognitive inhibition. Classroom noise can impede communication and make it more difficult for students to hear instructional information and maintain concentration (Gharata et al., 2023). Previous evidence indicates that noise levels between 55 and 65 dB can affect the teaching-learning process, particularly by reducing students' ability to hear and concentrate on information delivered by teachers (Afridon et al., 2022). Continuous exposure to high sound pressure levels may further reduce concentration and interfere with cognitive processing (Carolina et al., 2021). Psychologically, noise has also been associated with discomfort, stress, and loss of concentration (Singkam, 2020), while reducing environmental noise has been associated with improved learning concentration among children (Kadir et al., 2024). Consistent with these observations, attention disturbances and reductions in academic performance have been reported among students exposed to external noise (Afridon et al., 2022).

Conceptually, this relationship can be understood as a sequence in which environmental noise competes with task-relevant information for students limited attentional resources. When irrelevant auditory stimuli must be continuously suppressed, students need greater cognitive control to remain focused on instructional tasks. This additional demand may impair inhibitory control, slow information processing, and reduce the efficiency with which students encode and respond to academic information. Consequently, environmental noise may influence learning achievement not only through direct disruption of classroom activities but also indirectly by weakening the cognitive functions that support learning. This mechanism is consistent with evidence showing that higher noise exposure is associated with stronger adverse emotional responses and cognitive impairment, whereas lower noise exposure is associated with better auditory perception, fewer errors, and faster task completion (Greven & Homberg, 2020; Zhang et al., 2024; Zhu et al., 2025).

Learning achievement itself reflects the combined influence of individual and environmental factors. A supportive learning environment contributes to motivation, concentration, health, safety, and academic success Sajadah et al. (2023), and previous research has identified environmental noise as one factor associated with student academic performance (Sajadah et al., 2023). Cognitive function provides a plausible mechanism connecting these environmental conditions with academic outcomes because attention, working memory, processing efficiency, and inhibitory control support students' ability to process information and respond effectively to academic demands. Previous educational research has reported significant associations between cognitive skills and learning outcomes, while cognitive training has been associated with improvements in cognitive and academic performance (Mahmood et al., 2025). Statistical reasoning and related cognitive abilities have likewise been associated with academic performance (Mustafa et al., 2020).

Despite this evidence, an important gap remains. Previous studies have largely established that environmental noise is associated with concentration problems, cognitive disturbance, and poorer educational outcomes, but these relationships are often examined separately. Less attention has been given to whether cognitive function statistically transmits the effect of environmental noise to learning

achievement, particularly when cognitive function is assessed using performance-based Stroop measures. Furthermore, evidence from schools located near airports remains contextually important because students experience repeated transportation-related environmental exposure during regular learning activities. The present study therefore extends previous work by integrating direct environmental noise measurement, Stroop-based cognitive performance, and academic achievement within a single mediation model involving students from elementary, junior high, and vocational high schools near Sultan Aji Muhammad Sulaiman Sepinggan Airport. Direct measurement of school noise and Stroop-based assessment provides an empirical basis for examining the proposed mechanism rather than relying solely on students' perceptions of environmental disturbance (Kadir et al., 2024).

Based on this theoretical framework, environmental noise is expected to reduce cognitive functioning because increased auditory disturbance requires students to allocate greater cognitive resources to filtering irrelevant stimuli. Previous evidence indicates that greater noise exposure is associated with cognitive impairment, whereas more favorable acoustic conditions are associated with fewer errors and faster task completion (Zhang et al., 2024). In the present study, cognitive function is operationalized so that higher scores consistently represent better cognitive performance, including higher Stroop accuracy and faster reaction-time performance.

H1: Environmental noise exposure has a significant negative effect on students' cognitive function. Cognitive function is, in turn, expected to support learning achievement. Students with stronger attention, inhibitory control, and information-processing ability are better positioned to maintain task focus and respond effectively to academic demands. Prior research has demonstrated relationships between cognitive abilities and educational performance (Mahmood et al., 2025; Mustafa et al., 2020).

H2: Cognitive function has a significant positive effect on students' learning achievement. Environmental noise may also influence learning achievement through pathways not completely captured by the measured cognitive construct. Persistent environmental disturbance can disrupt communication, concentration, motivation, and psychological comfort during learning. Related evidence indicates that poorer cognitive and psychological conditions, including burnout and negative emotional responses, may contribute to reduced performance outcomes (Ali et al., 2024; Zhang et al., 2024). Therefore, based on the theoretical expectation that adverse environmental exposure undermines academic performance.

H3: Environmental noise exposure has a significant negative direct effect on students' learning achievement. Finally, the proposed mechanism suggests that environmental noise may affect achievement partly through changes in cognitive functioning. Previous research has demonstrated that psychological and cognitive mechanisms can operate as mediating pathways, including emotional responses to noise as well as academic self-efficacy and student engagement in learning-related relationships (She et al., 2021; Zhang et al., 2024). If noise reduces cognitive functioning and stronger cognitive functioning supports academic achievement, the resulting indirect relationship is expected to be negative.

H4: Cognitive function significantly mediates the relationship between environmental noise exposure and students' learning achievement, such that higher environmental noise is associated with lower learning achievement through reduced cognitive function. Based on these arguments, this study examines the direct effects of environmental noise exposure on cognitive function and learning achievement and evaluates the effect of cognitive function on learning achievement among students attending schools near Sultan Aji Muhammad Sulaiman Sepinggan Airport in Balikpapan. More specifically, the study tests whether Stroop-based cognitive function serves as a mediating mechanism linking airport-related environmental noise exposure to academic achievement. The proposed relationships are evaluated using Partial Least Squares Structural Equation Modeling (PLS-SEM), with bootstrapping used to assess the statistical significance of the direct and indirect effects (Mahmood et al., 2025; Mustafa et al., 2020; She et al., 2021).

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2. Method

2.1. Study Design

This study used a quantitative approach to examine the relationships among environmental noise exposure, cognitive function, and learning achievement among students attending schools located in areas affected by airport-related environmental noise. Data collection was conducted in January 2026. Primary data consisted of environmental noise measurements and Stroop Test performance, while students' academic scores were obtained in collaboration with the participating schools. A total of 120 students were included in the final analysis, comprising 40 elementary school students, 40 junior high school students, and 40 vocational high school students. The demographic and educational characteristics of the participants are summarized in Table 1.

Table 1. Sample Description

Variable	Category	Frequency (n)	Percentage (%)
School	SMKN 1 Balikpapan	40	33.3
	SD Negeri 007 Balikpapan	40	33.3
	SMP Negeri 5 & 10 Balikpapan	40	33.3
Education Level	Elementary School (SD)	40	33.3
	Junior High School (SMP)	40	33.3
	Vocational High School (SMK)	40	33.3
Gender	Male	58	48.3
	Female	62	51.7
Estimated Age	6 – 12 years (Elementary)	40	33.3
	13 – 15 years (Junior High)	40	33.3
	16 – 18 years (Vocational High)	40	33.3
Distance from Sultan Aji Muhammad Sulaiman Sepinggan Airport	< 5 km (Highly Affected)	80	66.7
	5 – 10 km (Moderately Affected)	40	33.3

2.2. Research Subjects and Objects

The study involved active students from elementary, junior high, and vocational high schools in the airport-affected area surrounding Sultan Aji Muhammad Sulaiman (SAMS) Sepinggan Airport in Balikpapan. The participating schools were SD Negeri 007 Balikpapan Selatan, SMP Negeri 10 Balikpapan, SMP Negeri 5 Balikpapan, and SMK Negeri 1 Balikpapan. These locations were selected because previous studies have indicated that schools near airports may experience substantial aircraft noise exposure during learning hours (Baek et al., 2023; Clark et al., 2021). Proportional random sampling was used to ensure representation across educational levels (Sugiyono, 2017). The final sample consisted of 120 students. The research objects were environmental noise exposure, students' cognitive function as assessed using Stroop Test performance, and learning achievement represented by academic scores.

2.3. Data Analysis Techniques

Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 3.2.9. PLS-SEM served as the primary and sole inferential framework for evaluating the proposed measurement and structural relationships. References to separate analyses of multiple linear regression and simple linear regression in the previous version of the manuscript were removed to ensure methodological consistency.

PLS-SEM was selected because it enables simultaneous assessment of measurement relationships and structural paths among latent constructs and is suitable for estimating the explained variance of endogenous constructs (Amiruddin & Baharuddin, 2023; Octavia et al., 2023). The analysis was conducted using SmartPLS software (Ardiansyah & Yenita, 2023; Duryadi, 2024; Situmorang et al., 2023; Subhaktiyasa, 2024).

As a variance-based structural equation modeling approach, PLS-SEM does not require the same distributional assumptions as covariance-based SEM and can accommodate complex structural relationships (Astuti et al., 2022; Sanjaya et al., 2022). Following reconsideration of the conceptual relationship between the constructs and their indicators, the revised measurement model was specified as reflective. The retained indicators were treated as manifestations of their respective underlying constructs. Accordingly, the measurement model was evaluated using criteria appropriate for reflective rather than formative measurement.

The PLS-SEM analysis was conducted sequentially, first assessing the reflective measurement model, then the structural model. The reflective measurement model was evaluated using indicator outer loadings, Cronbach's alpha, rho_A, composite reliability, average variance extracted (AVE), and discriminant validity. Outer loadings of approximately 0.70 or higher were considered desirable. Internal consistency reliability was evaluated using Cronbach's alpha, rho_A, and composite reliability, while AVE values greater than 0.50 were used to assess convergent validity (Hair et al., 2019; Martínez-Navalón et al., 2023). Discriminant validity was examined using the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT) (Fornell & Larcker, 1981; Henseler & Schuberth, 2023). Indicator retention was determined not solely by statistical thresholds but also by each indicator's conceptual role and measurement meaning.

Following measurement-model assessment, the structural model was evaluated using collinearity diagnostics, path coefficients, coefficient of determination (R^2), effect size (f^2), and predictive relevance (Q^2). Predictive relevance was assessed using the blindfolding procedure with an omission distance of seven (D = 7), where Q^2 values greater than zero for the endogenous constructs were interpreted as indicating predictive relevance. Statistical significance of the structural relationships was assessed through nonparametric bootstrapping using 10,000 subsamples, a two-tailed test, a significance level of 0.05, and 95% bias-corrected and accelerated (BCa) confidence intervals. The direction, magnitude, p-value, and confidence interval of each structural coefficient were reported. For directional hypotheses, statistical significance alone was not considered sufficient to support the hypothesis when the estimated coefficient was in the opposite direction to the hypothesized one.

The mediating role of Cognitive Function was assessed using the specific indirect effect of Environmental Noise Exposure on Learning Achievement through Cognitive Function. The bootstrap confidence interval of the specific indirect effect was used as the primary criterion for mediation inference. An indirect effect was considered statistically significant when its 95% bootstrap confidence interval did not contain zero; the corresponding p-value was also reported. Direct, indirect, and total effects were evaluated separately to distinguish the nature of the mediation relationship.

2.4. Research variables

A conceptual path model was developed to examine the direct and indirect relationships among Environmental Noise Exposure, Cognitive Function, and Learning Achievement. All three constructs were specified as reflective measurement models, with the observed indicators representing manifestations of their respective underlying constructs. The operational definitions and indicators of each construct are presented in Table 2.

Environmental Noise Exposure was represented by five sound-level indicators covering equivalent and maximum noise levels and spatial measurements at the front, middle, and back areas of the school environment (Balderrama et al., 2022; Basheer et al., 2022; Mu et al., 2023; Okeoghene Ijabor et al., 2024; Spliethoff et al., 2024; Sugiura et al., 2025; Tufaner, 2020). Noise_Duration_min was retained as a descriptive characteristic of exposure rather than as a reflective indicator because it represents exposure duration rather than noise intensity.

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Table 2. Conceptual Variable

Construct	Reflective indicators and supporting references	Operational interpretation
Environmental Noise Exposure (X)	Noise_Leq_dB (Okeoghene Ijabor et al., 2024; Sugiura et al., 2025; Tufaner, 2020); Noise_Max_dB (Basheer et al., 2022; Sugiura et al., 2025); Noise_Front_dB, Noise_Mid_dB, and Noise_Back_dB (Balderrama et al., 2022; Mu et al., 2023; Spliethoff et al., 2024).	Higher values indicate greater environmental noise intensity.
Cognitive Function (Z)	Stroop_Normal_Correct and Stroop_Noise_Correct (Al-Shargie et al., 2021; D'Angiulli et al., 2023; Fedeli et al., 2022; Nadon et al., 2021; Pratte, 2021); Reverse_Stroop_Normal_RT_ms and Reverse_Stroop_Noise_RT_ms based on the original reaction-time measures (Al-Shargie et al., 2021; D'Angiulli et al., 2023; Hedge et al., 2022; Pratte, 2021).	Higher values consistently indicate better cognitive performance. Reaction-time scores were reverse-coded so that faster responses correspond to higher cognitive-function scores.
Learning Achievement (Y)	Math_Score, Language_Score, and Science_Score (Atalay & Gunduz, 2020; Guerra et al., 2021).	Higher values indicate better academic achievement.

Cognitive Function was assessed using primary Stroop Test measures of accuracy and reaction time under normal and noise conditions (Al-Shargie et al., 2021; D'Angiulli et al., 2023; Fedeli et al., 2022; Hedge et al., 2022; Nadon et al., 2021; Pratte, 2021). Because a higher reaction time represents slower performance, the two reaction-time variables were reverse-coded by multiplying the original values by −1 before inclusion in the reflective measurement model. This procedure aligned the measurement direction so that higher values of all retained Cognitive Function indicators consistently represented better performance. The derived Stroop variables, including Stroop_RT_Noise_Cost, Stroop_Delta_Correct, and Stroop_Percent_Decrease, were retained as supplementary measures for describing changes in cognitive performance between normal and noise conditions but were not simultaneously entered into the reflective block because they were mathematically derived from the primary Stroop measures. Learning Achievement was represented by Mathematics, Language, and Science scores (Atalay & Gunduz, 2020; Guerra et al., 2021). The revised model therefore retained multiple academic indicators rather than reducing learning achievement to a single Mathematics score in Fig. 1.

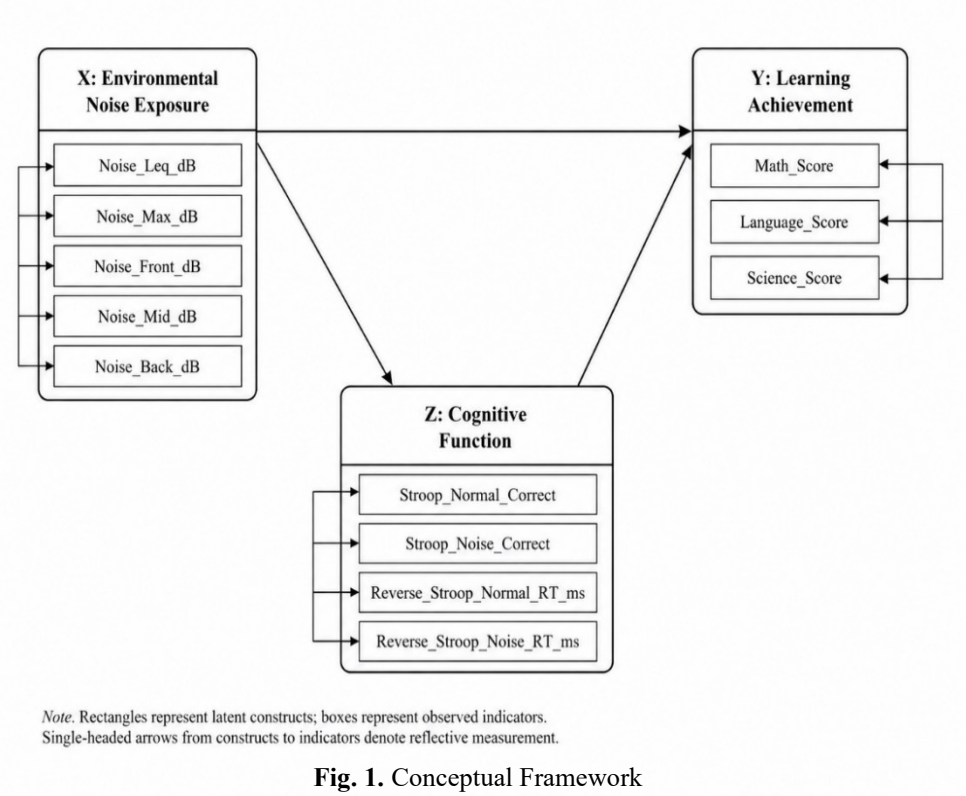


Fig. 1. Conceptual Framework

3. Results and Discussion

3.1. Reflective Measurement Model Assessment

The reflective measurement model was assessed before interpreting the structural relationships. Because the reaction-time indicators of Cognitive Function were reverse-coded, higher scores across all retained cognitive indicators consistently represent better cognitive performance. Therefore, the direction of the structural coefficients can be interpreted directly without assuming that higher Cognitive Function scores represent cognitive impairment. All retained indicators showed high outer loadings. For Environmental Noise Exposure, outer loadings ranged from 0.985 to 0.999. The four Cognitive Function indicators showed loadings ranging from 0.957 to 0.986, while the Learning Achievement indicators showed loadings ranging from 0.992 to 1.000. These results indicate strong indicator reliability in Table 3.

Internal consistency and convergent validity were also high. Cognitive Function produced Cronbach's alpha = 0.980, rho_A = 0.981, composite reliability = 0.985, and AVE = 0.944. Environmental Noise Exposure produced Cronbach's alpha = 0.998, rho_A = 0.998, composite reliability = 0.998, and AVE = 0.992. Learning Achievement produced Cronbach's alpha = 0.995, rho_A = 0.995, composite reliability = 0.996, and AVE = 0.989 in Table 4. Thus, the retained indicators demonstrated strong internal consistency and convergent validity (Hair et al., 2018; Martínez-Navalón et al., 2023).

Nevertheless, discriminant validity requires cautious interpretation. The HTMT values were 0.993 between Environmental Noise Exposure and Cognitive Function, 0.876 between Cognitive Function and Learning Achievement, and 0.798 between Environmental Noise Exposure and Learning Achievement in Table 5. The very high HTMT value between Environmental Noise Exposure and Cognitive Function indicates substantial empirical overlap between these two constructs. The Fornell–Larcker results similarly showed a very strong correlation between Environmental Noise Exposure and Cognitive Function (r = −0.981). Accordingly, although convergent validity and internal consistency were strong, discriminant validity between Environmental Noise Exposure and Cognitive Function was not fully established. This issue is taken into account when interpreting the structural coefficients.

Table 3. Reflective Measurement Model Assessment

Construct	Indicator	Outer Loading
Environmental Noise Exposure	Noise_Leq_dB	0.999
	Noise_Max_dB	0.985
	Noise_Front_dB	0.999
	Noise_Mid_dB	0.999
	Noise_Back_dB	0.998
Cognitive Function	Stroop_Normal_Correct	0.986
	Stroop_Noise_Correct	0.959
	Reverse_Stroop_Normal_RT_ms	0.957
	Reverse_Stroop_Noise_RT_ms	0.986
Learning Achievement	Math_Score	1.000
	Language_Score	0.992
	Science_Score	0.992

Table 4. Construct Reliability and Convergent Validity

Construct	Cronbach's α	rho_A	CR	AVE
Cognitive Function	0.980	0.981	0.985	0.944
Environmental Noise Exposure	0.998	0.998	0.998	0.992
Learning Achievement	0.995	0.995	0.996	0.989

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Table 5. Discriminant Validity – HTMT

Construct pair	HTMT
Environmental Noise Exposure – Cognitive Function	0.993
Cognitive Function – Learning Achievement	0.876
Environmental Noise Exposure – Learning Achievement	0.798

3.2. Structural Model Assessment and Hypothesis Testing

The structural model was assessed after evaluation of the reflective measurement model. Environmental Noise Exposure explained 96.3% of the variance in Cognitive Function ($R^2 = 0.963$) in Table 7, while Environmental Noise Exposure and Cognitive Function jointly explained 83.1% of the variance in Learning Achievement ($R^2 = 0.831$) in Fig. 2. However, the inner VIF values for Environmental Noise Exposure and Cognitive Function as simultaneous predictors of Learning Achievement were both 26.944, indicating substantial collinearity. Therefore, the statistical significance and direction of the structural relationships are reported, while the magnitude of the corresponding path coefficients is interpreted cautiously. Hypothesis testing was conducted using 10,000 bootstrap subsamples, two-tailed testing at $\alpha = 0.05$, and 95% bias-corrected and accelerated (BCa) confidence intervals. Table 6 presents the direct, specific indirect, and total effects separately to avoid duplication and to provide a transparent assessment of the mediation relationship.

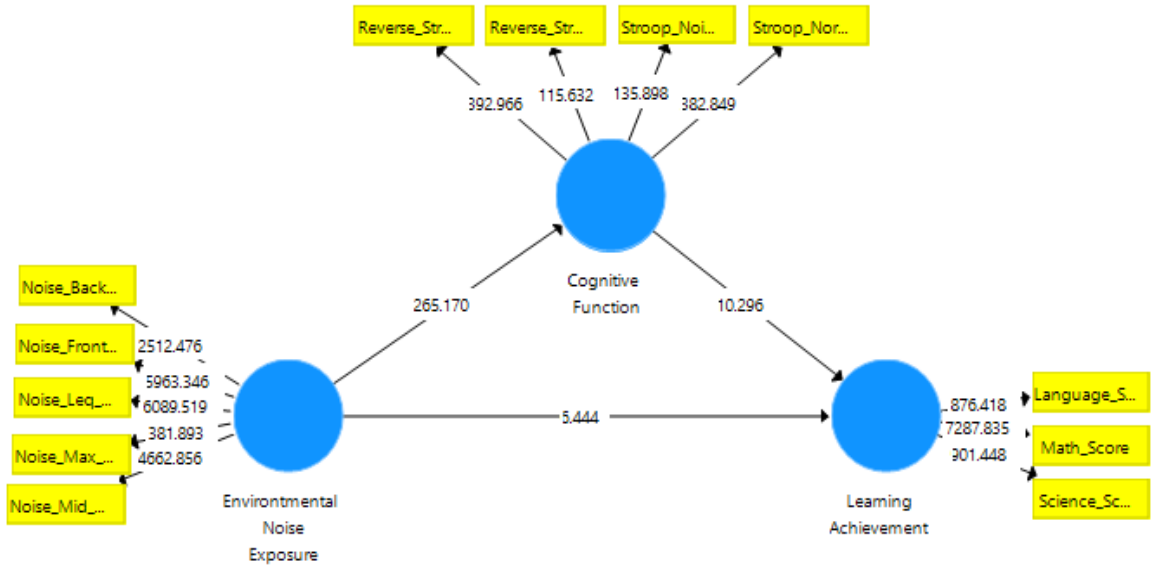


Fig. 2. PLS-SEM Bootstrapping Results

Table 6. Testing for direct and indirect effects

Effect	β	t	p	BCa 95% CI	Decision
H1: Environmental Noise → Cognitive Function	−0.981	263.679	<0.001	[−0.987, −0.972]	Supported
H2: Cognitive Function → Learning Achievement	2.309	10.250	<0.001	[1.891, 2.770]	Supported
H3: Environmental Noise → Learning Achievement, direct effect	1.470	6.412	<0.001	[1.038, 1.934]	Not supported
H4: Noise → Cognitive Function → Learning Achievement	−2.266	10.053	<0.001	[−2.729, −1.852]	Supported
Environmental Noise → Learning Achievement, total effect	−0.796	26.739	<0.001	[−0.845, −0.728]	—

Environmental Noise Exposure had a significant negative effect on Cognitive Function (β = −0.981, p < 0.001, 95% BCa CI [−0.987, −0.972]). Because higher Cognitive Function scores represent better cognitive performance, this result directly indicates that greater environmental noise exposure was associated with poorer cognitive functioning. H1 was therefore supported. Cognitive Function had a significant positive effect on Learning Achievement (β = 2.309, p < 0.001, 95% BCa CI [1.891, 2.770]), supporting H2. The positive direction indicates that better Stroop-based cognitive performance was associated with higher academic achievement. The magnitude of this coefficient should, however, be interpreted cautiously because of the substantial collinearity between Environmental Noise Exposure and Cognitive Function.

The direct effect of Environmental Noise Exposure on Learning Achievement was positive and statistically significant (β = 1.470, p < 0.001, 95% BCa CI [1.038, 1.934]). Because H3 predicted a negative direct effect, statistical significance alone does not constitute support for the hypothesis. Accordingly, H3 was not supported. In contrast, the specific indirect effect of Environmental Noise Exposure on Learning Achievement through Cognitive Function was negative and statistically significant (β = −2.266, p < 0.001, 95% BCa CI [−2.729, −1.852]). Because the bootstrap confidence interval did not contain zero, H4 was supported. The direct and indirect effects were both significant but operated in opposite directions, indicating an inconsistent or competitive mediation pattern.

The total effect of Environmental Noise Exposure on Learning Achievement remained negative and significant (β = −0.796, p < 0.001, 95% BCa CI [−0.845, −0.728]). Thus, although the conditional direct coefficient was positive after Cognitive Function was included in the model, the overall association between environmental noise and learning achievement remained negative.

Table 7. Explanatory and Predictive Relevance of Endogenous Constructs

Endogenous construct	R^2	Adjusted R^2	Q^2
Cognitive Function	0.963	0.963	0.904
Learning Achievement	0.831	0.828	0.816

The blindfolding procedure with an omission distance of seven produced Q^2 values of 0.904 for Cognitive Function and 0.816 for Learning Achievement. Both values were greater than zero, indicating predictive relevance for the two endogenous constructs. These results are interpreted as evidence of predictive relevance within the PLS-SEM model rather than as an assessment of out-of-sample predictive performance.

3.3. Discussion

The negative relationship between Environmental Noise Exposure and Cognitive Function supports the theoretical proposition that repeated environmental noise can interfere with the cognitive resources required to maintain effective task performance. Because the cognitive indicators were oriented so that higher scores represent greater accuracy and faster responses, the negative coefficient can now be interpreted directly: students exposed to higher environmental noise tended to demonstrate poorer Stroop-based cognitive performance.

This relationship can be understood in terms of attentional competition and demands on inhibitory control. In a noisy learning environment, students must simultaneously process instructional information while suppressing irrelevant auditory input. This additional demand may reduce the cognitive resources available for task-relevant processing and impair the efficiency of attentional and inhibitory processes. The finding is consistent with previous evidence linking environmental noise to cognitive impairment and poorer task performance Zhang et al. (2024), as well as studies showing that reducing noise disturbance can improve concentration in educational environments (Kadir et al., 2024). Similar observations have been reported regarding communication and concentration difficulties under excessive noise exposure (Afridon et al., 2022; Carolina et al., 2021).

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The positive association between Cognitive Function and Learning Achievement indicates that students who performed better on Stroop accuracy and response-speed measures also tended to achieve better academic outcomes. This relationship is theoretically plausible because effective learning requires students to sustain attention, inhibit irrelevant information, process instructional material efficiently, and respond accurately to academic demands. Previous studies have similarly linked cognitive abilities and training to academic performance Mahmood et al. (2025), while cognitive and statistical reasoning abilities have been associated with educational achievement in PLS-SEM models (Mustafa et al., 2020).

The estimated path coefficient, however, exceeded 1 and should not be interpreted as a proportional or percentage increase in achievement. Its magnitude is likely influenced by the very strong empirical relationship between Environmental Noise Exposure and Cognitive Function. Accordingly, the substantive interpretation should focus on the positive direction and statistical significance of the relationship rather than on treating the coefficient magnitude as an isolated measure of causal strength. A more complex pattern emerged for the direct relationship between Environmental Noise Exposure and Learning Achievement. Contrary to H3, the conditional direct coefficient became positive after Cognitive Function was included in the structural model. This finding should not be interpreted as evidence that environmental noise improves academic achievement. Instead, it must be considered together with the significant negative indirect effect, the negative total effect, and the high collinearity between Environmental Noise Exposure and Cognitive Function.

The very strong association between noise and cognitive function indicates that both constructs share substantial variance. When Cognitive Function is statistically held constant, the residual component of Environmental Noise Exposure may yield a direct coefficient with a direction that differs from the overall relationship. This pattern is consistent with statistical suppression or inconsistent mediation. The negative total effect ($\beta = -0.796$) therefore provides a more appropriate description of the overall association between noise exposure and academic achievement than the positive conditional direct coefficient alone. This result also demonstrates why direct, indirect, and total effects should not be interpreted interchangeably. The direct coefficient represents the association between noise and achievement conditional on Cognitive Function, whereas the total effect represents their overall modeled relationship before the indirect pathway is separated.

The re-estimated mediation analysis provides stronger evidence for the cognitive mechanism proposed in this study. Environmental Noise Exposure harmed Cognitive Function, while Cognitive Function was positively associated with Learning Achievement. Consequently, their product produced a significant negative indirect effect ($\beta = -2.266$). The 95% BCa confidence interval was entirely below zero, confirming that the indirect effect was statistically distinguishable from zero. Importantly, the current finding differs from the earlier analysis in which the mediation conclusion was ambiguous because the reported p-value and bootstrap confidence interval produced inconsistent decisions. With 10.000 bootstrap subsamples and the aligned reflective measurement specification, the present analysis yielded a consistent result: both the p-value ($p < 0.001$) and confidence interval [−2.729, −1.852] support the indirect effect.

The opposite signs of the significant direct and indirect effects indicate an inconsistent or competitive mediation pattern. Substantively, however, the negative indirect pathway and negative total effect suggest that deterioration in cognitive functioning is an important mechanism linking environmental noise exposure with poorer overall academic outcomes. The result therefore shifts the study's emphasis from viewing cognitive function merely as an associated variable to identifying it as a statistically significant pathway linking environmental noise to learning achievement.

Several limitations should be considered when interpreting these findings. First, the cross-sectional design does not establish temporal or causal ordering among environmental noise exposure, cognitive functioning, and academic achievement. Although mediation was evaluated statistically, longitudinal or experimental designs would be required to more strongly establish the temporal mechanism (Taheri Hossseinabadi et al., 2020).

Second, Environmental Noise Exposure and Cognitive Function showed a very high empirical association, reflected in an HTMT value of 0.993 and substantial structural collinearity. Consequently, the magnitudes of the direct and indirect path coefficients should be interpreted with caution. Future research should examine whether more differentiated indicators of acoustic exposure and cognitive processes can improve empirical separation between these constructs.

Third, the high reliability coefficients of the constructs suggest that several retained indicators may capture highly overlapping information. Further studies could evaluate broader or more heterogeneous indicators of noise exposure, cognitive functioning, and academic achievement. In the present operationalization, noise duration and mathematically derived Stroop change measures were analyzed separately rather than simultaneously included in the reflective measurement blocks.

Finally, the sample consisted of 120 students from schools in the vicinity of a single airport and included different educational levels. Therefore, the findings should not be automatically generalized to all school populations or other environmental noise contexts. Future studies should use larger multi-site samples and consider educational level, age, and other environmental or psychosocial factors that may influence cognitive and academic outcomes.

4. Conclusion

The findings of this study indicate that environmental noise is significantly associated with both cognitive function and learning achievement among students attending schools near airport areas. Higher environmental noise exposure was associated with poorer Stroop-based cognitive performance, while better cognitive function was significantly associated with higher learning achievement. However, the direct effect of environmental noise on learning achievement was positive and statistically significant after cognitive function was included in the model. Because this direction was opposite to the hypothesized negative effect, the direct-effect hypothesis was not supported. Importantly, the total effect of environmental noise on learning achievement remained negative and statistically significant, indicating that greater overall noise exposure was associated with poorer academic outcomes.

The mediation analysis showed that cognitive function significantly mediated the relationship between environmental noise exposure and learning achievement. Environmental noise had a negative effect on cognitive function, and cognitive function had a positive effect on learning achievement, resulting in a significant negative specific indirect effect. The simultaneous presence of a positive direct effect and a negative indirect effect indicates an inconsistent or competitive mediation pattern. Therefore, the positive conditional direct coefficient should not be interpreted as evidence that environmental noise improves academic performance. Rather, the findings suggest that deterioration in cognitive functioning represents an important pathway through which environmental noise may contribute to poorer overall learning achievement. Interpretation of the magnitude of these structural effects should nevertheless remain cautious because of the substantial empirical overlap and collinearity between environmental noise exposure and cognitive function.

These findings emphasize the importance of improving acoustic conditions in schools located in areas exposed to high levels of environmental noise, particularly around airports. Strategies aimed at reducing classroom noise exposure may help preserve students' attentional and inhibitory processes and support more effective learning. Future research should employ longitudinal or experimental designs, larger multi-site samples, and more differentiated measures of environmental noise, cognitive performance, and academic achievement to clarify the temporal and causal mechanisms underlying these relationships.

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