International Journal of Otolaryngology and Head & Neck Surgery, 2022, 11, 242-257
https://www.scirp.org/journal/ijohns
ISSN Online: 2168-5460
ISSN Print: 2168-5452

Effects of Environmental Noise on School Performance among Hearing-Impaired Students

Ignace Magloire Kaumbu Nsapu[1], Daniel Okitundu Luwa E-Andjafono[2], Richard Matanda Nzanza[1], Dieudonné Nyembue Tshipukane[1], Israel Kenda Makopa[3], Jérôme Sokolo Gedikondele[1], Christophe Mambueni Thamba[4*]

[1]Faculty of Medicine, Department of ENT, University of Kinshasa, Kinshasa, Democratic Republic of the Congo
[2]Faculty of Medicine, Department of Neurology, University of Kinshasa, Democratic Republic of the Congo
[3]Faculty of Medicine, Department of Neuropsychology, University of Hassan II of Casablanca, Casablanca, Morocco
[4]Diocesan Office of Medical Works (BDOM-KIN), Kinshasa, Democratic Republic of the Congo
Email: *chrisniwx@gmail.com

How to cite this paper: Nsapu, I.M.K., E-Andjafono, D.O.L., Nzanza, R.M., Tshipukane, D.N., Makopa, I.K., Gedikondele, J.S. and Thamba, C.M. (2022) Effects of Environmental Noise on School Performance among Hearing-Impaired Students. *International Journal of Otolaryngology and Head & Neck Surgery*, **11**, 242-257.
https://doi.org/10.4236/ijohns.2022.115026

Received: July 25, 2022
Accepted: August 28, 2022
Published: August 31, 2022

Abstract

Background and Purpose: Our study examined the effect of ambient noise on hearing and school performance in children with hearing loss, and the relationship between hearing loss and cognition. **Method:** A pilot study involving 728 people (aged 11 to 16 years) was conducted in Kinshasa, Democratic Republic of the Congo. All participants completed the ENAFEP test, the SIFTER short scale, pure tone audiometry, and a three-digit test. Teachers and investigators completed a 6-day listening training course. **Results:** Correlation and structural equation modeling indicated that ambient noise and five cognitive domains were associated with hearing in noise, but only unmeasured cognition was associated with hearing loss and poor academic performance. Cognitive compensation significantly reduces communication problems and improves concentration and academic performance. Noise and deafness had significant and moderate effects on academic performance ($r = -0.13$). **Conclusion:** The sample size and relatively high participation rate meant the study was representative. However, the results showed an association between ambient noise, hearing loss and cognition, and reduced school performance. Large-scale randomized interventions for hearing loss and long-term noise exposure studies are needed to measure cognitive outcomes after short- and multi-year noise exposure.

Keywords

Impaired Hearing, Noise, School Performance

1. Introduction

According to the World Health Organization (WHO) and Le Clercq's study hearing is important for the proper development of every child, especially those attending primary school, as it helps in the development of language and speech [1] [2]. The schooling and integration of hearing-impaired children into the classes of so-called normal primary schools dates back to the 1980s worldwide. But accessibility is only achievable under certain conditions. The sound environment in schools is part of these conditions and is a concern for the public authorities and the teacher. A child's deafness in no way hinders his or her ability to learn [3].

Pantomime offers an alternative means of communication. However, several studies indicate that hearing loss has a negative effect on school performance [4] [5]. The topic of school performance of integrated deaf and hard of hearing children has been addressed in the literature and the results are rather mixed [6]. A study by Antia, Jones, Reed and Kreimeyer (2009), conducted over a period of 5 years, showed that 197 deaf and hard of hearing children integrated for at least 2 hours a day scored above or near average; 71% - 79% of these students in mathematics, 48% - 68% in reading and 55% - 77% in language/writing [2] [6] [7] [8] [9]. Studies on the relevant predictive factors of school performance will make it possible to consider strategies for improving listening and learning conditions. Noise pollution has been the subject of several studies following the literature review carried out to date [10] [11].

Pujol found in his earlier studies that noise had a negative impact on academic performance [12] [13] [14]. The mediation of hearing impairments in the correlation of the three factors of the trilogy of elements to be questioned to improve the learning conditions of children in urban areas, which is characterized by the noises of road transport, discotheques, outdoor concerts and leisure, providers of hearing disorders, has been little documented in sub-Saharan Africa.

A preliminary study (Tshimbadi *et al.*) that explores overall the prevalence of deafness in schools describes a rate of 1.4% in a population of 2600 students attending a few primary schools globally located in a noisy environment in the city province of Kinshasa [6]. This epidemiological study was initiated to present a panoramic view of the evolution of school performance under the effect of this hearing disability that affects some students in our primary schools, generally located near noise sources.

Specific aims will be to:

- Assess and quantify the level of noise exposure of 6th primary grade students;
- Assess their hearing impairments;
- Determine their academic performance in mathematics and French.

2. Methods

2.1. Study Type and Population of Interest

2.1.1. Study Type

A cross-sectional and descriptive study for epidemiological purposes in the context of the covid-19 pandemic [15] is taking place over a period of 19 months, from October 2020 to March 2022.

The Lukunga district that served as a framework for the prevalence of hearing loss provided an opportunity for this study.

The participants were made up of schoolchildren aged 11 to 16 in Kinshasa and attending one of the primary schools of the large school complexes bordering the main roads, in grade 6 class during the 2020-2021 school year. Students who have moved from home since the beginning of the last school year were excluded from this study.

2.1.2. Population of Interest

Investigation Units:

- Primary Schools that organize the 6th Primary class in LUKUNGA District;
- The students of the 6th primary class selected and who presented the TENAFEP test whose results are available.

Sampling

Sample size:

Using the approximate number formula needed in simple random sampling with the proportion of the character that one wants to study unknown in the population with desired Margin of Error (d = 1%), at the α threshold of 5%, the sample size will be calculated by the following formula.

$$n = (Z_{\alpha/2})^2 \, p\,(1 - p)/d^2$$

with p = 15% the prevalence of school-based hearing loss worldwide according to WHO, and $Z_{\alpha/2}$ = 1.96 read in the table of the normal distribution.

n = 728 individuals to be retained in our sample.

The draw will be made in two degrees including:

The first degree will be at the school level, drawing 30 schools on the list of all schools in the district per municipality, 3 schools for each of the 10 Provincial Pools of the District of LUKUNGA.

The second stage of drawing will be carried out by simple random sampling (proportion method) in the 30 schools, based on the lists of pupils. All schools included in the school registers of pupils in the 6th primary year of the year 2020-2021, which will constitute the sampling frame to draw 24 and 25 pupils per school (according to the weighting) from the age of 11 to 16 years (normal age group for a child of the 6th primary, which will avoid biases in the interpretation of school results), in order to reach the study sample of 728 students.

Collection in households will be done only for 5 students per school for information related to environmental noise in residences for a total of 40 residences to visit.

The sample is represented by 586 students (out of 728 students) who attend schools where a source of noise has been identified and quantified.

2.1.3. Confounding Factors

The confounding factors were collected through a questionary given to the pupils' parents by the teachers: including socioeconomic status, family composition, the main language of communication in the family and the level of study of the head of the family.

2.2. Audiometric Thresholds, Impedancemetry Measurements and Hearing Tests in Noise

2.2.1. Impedancemetry Using (Zodiac 901 Portable Tympanometry, Interacoustics, Middelfart, Denmak)

Impedancemetry (Zodiac 901 Portable Tympanometer, Interacoustics, Middelfart, Denmak) include tympanometry and acoustic reflex (AR). The tympanometry was performed on variable pressures, ranging from +200 to −400 mm H_2O. Threshold measures of stapedian acoustic reflex using pure sounds (up to 100 dB) at 500, 1000, 2000 and 4000 Hz were made in ipsilateral.

2.2.2. Pure Tone Audiometry

Using a portable audiometer model AD226 (Interacoustics). It included:

- Air conduction: auditory thresholds in air conduction have been determined on the frequencies of 250, 500, 1000, 2000, 4000 and 8000 Hz;
- Mild hearing loss has been defined for an average of 20 - 40 dB to 500, 1000, 2000 and 4000 Hz;
- It is defined as hidden if it was greater than 20 d B on the high frequencies only and for cases with a score < 50% on DTT but with a normal audiogram.

All tests were carried out in a convenient room on school grounds or at the Bondeko Village, Kabambare Centre for the Deaf and Hard of Hearing. Audiometric diagnosis was carried out in air conduction. Tests started at 1000 Hz through the right ear (better ear) with an intensity of 40 dB HL. Thresholds were obtained using the routine method (Houghton-Westlake method), in steps of 10 dB in the descending phase and of 5 dB in the ascending phase.

2.3. Digit Triplet Test (DTT)

The procedure below corresponds to the telephone version of the test.

This is an adaptive procedure where the noise is fixed.

We begin the presentation of the number at −8 dB RSB with a sequence of three digits (between 1 to 9) chosen randomly. The listener must then indicate his 3 answers via a numeric keypad and the triplet is considered correct when all the numbers are well rendered. The speech level is adjusted in steps of −2 dB RSB if the triplet is correct and +2 dB RSB if the triplet is false. A total of 27 triplets are presented in each test.

The result is given by the RSB Average of the last 22 iterations (including the RSB adjusted after the 27th presentation).

2.4. Assessment of Academic Performance and Educational Cognitive Risks

1) Inspired by the Belgian and French education system and also following the protocol adopted by Pujol in Bésançon, since 1968, in the Democratic Republic

of the Congo, the national standardized assessment test, the national primary school leaving test (TENAFEP) has made it possible to evaluate the national curriculum in geography, civic education, health education, anatomy, botany, physics, zoology, French and mathematics, of students at the primary level, in the sixth 6th grade. The ENAFEP test is intended to assess the knowledge acquired in primary school and to guide the student in secondary studies. In August 2021 instead of June, Inspectors from the Ministry of Primary and Secondary Education monitor examinations to prevent frauds and pupils are grouped into pools in compliance with barrier measures. Indeed, the particular circumstances related to the COVID-19 pandemic have forced the Ministry of Primary, Secondary and Technical Education (MEPST) to extend the school year. The French exams consisted of reading, dictations and grammar. The mathematics exams were composed of metric system, geometry, problem solving, multiplication and division. The marking of the examinations is ensured by the teachers of other classes, who do not know the pupils, under the supervision of the inspectors. All results are expressed as a percentage and the overall score in mathematics, French and general culture was used for statistical analyses.

2) The verbal comprehension index and the SIFTER questionnaires in 15 items made it possible to achieve the different scores of cognitive processes for each student.

2.5. Noise Exposure Assessment

According to the provisions of the WHO and the American Institute of Environmental Health, the qualification of the source and level of noise exposure was evaluated by a direct evaluation measurement using the Trotec sound level meter, with the software of the same name in 2017 version. Information on the residence and the exact address of each pupil's residence was collected using the information provided by parents on the standardized questionnaires given by the teachers. Exposure levels were identified and indicated according to 4 indicators based on the equivalent level and the relevant period of day or night, namely: LAeq in dBA; Lden; LNight; LDay. The average in LAeq on the façade of the school and each residence was considered for the analyses.

2.6. Data Processing

According to the National Statistics Institute of the Republic of Congo, socioeconomic status is divided into 4 levels, defined by monthly income: level 1 ordinary and unemployed workers; level 2 middle managers; level 3 = directors; level 4 = business leaders and political leaders.

2.7. Statistical Analysis

The association between quantitative variables was assessed using Pearson's correlation of sound level and academic performance, and the multi-level linear regression models were used.

Variables associated with academic performance with $p \leq 0.2$ in the univariate analysis were then included in the multivariate analysis using a phase-out procedure.

Structural equation modelling was further used to simultaneously test the existence of relationships between hearing loss, performance, cognition and noise in a sequence of several models, described in the results.

Adjustment statistics (RMSEA, CFI, TLI) and standardized regression were reported for each model.

A positive sign means that the probability of the categorical dependent variable (e.g., category 1 for a 0/1 variable) was increased when the value of the predictor increased. A greater amplitude means that this probability is higher.

The threshold considered for statistical significance was a p-value of 0.05. Software was used to perform the analyses using structural equation modelling: ATEC V1.6. and SPSS.

3. Results

Out of 587 (80.19%) schoolchildren were included in this study of 728 schoolchildren for gender, age of schoolchildren, socioeconomic status of parents, prevalence of hearing loss 16%, housing type also analyzed and education level. The mean age was 12.6 years (±2.7, 11 - 16), and 44.5% were female (**Table 1**, **Table 2**). Age of school-age children, socioeconomic status of parents (**Table 1**), residence and education level were also analysed (**Table 1**).

The gender shows that there is a sex ratio of 1.21, the poverty index reflects the socio-economic status of parents (**Table 2**).

Table 1. Characteristics of participants.

Manifest Variables	Auditory Thresholds dB (SD.)		Asym mean/dB (SD)	11 Y	12 Y	13 Y	14 Y	15 Y	16 Y	Total
	1 kHz	4 kHz								
Hidden HL symmetric	17.6 (4.0)	15.3 (2.0)	4.7	n = 13	21	15	13	17	8	87
Hidden HL Asymetric	16.2 (4.9)	14.2 (3.2)	15.5	8	6	5	7	4	5.	36
Symmetric mild HL	26.4 (5.6)	25.7 (4.4)	4.7	7	6	6	3	4	1	26
Asymmetric mild HL	26.5 (6.2)	26.0 (4.5)	22.1	4	2	3	2	4	2	17
Normal Audition	8.3 (4.7)	6.1 (3.8)	3.5	74	101	87	116	112	66	562
Total number of children				102	135	121	142	141	83	728
% Hidden HL				19.7%	19.3	16.5	14.5	14.9	16.9	16.8
% Light HL				10.8	5.6	7.4	3.9	5.7	3.0	6.0

Table 2. Participants in the study sample compared to data on gender and socioeconomic status.

CATEGORIES	Man	Female
Sex %	55.5%	44.5%
Socio-economic status (Poverty index)	−1.1 (2.9)	0.7 (4.2)

Key indicators of noise exposure in student dormitories

Students' exposure levels (Lden) during the morning session ranged from 39.8 decibels to 89.2 decibels, with an average of 56 decibels. During the afternoon session, the sound pressure level fluctuated between 47 dBA and 98 dBA. Residential nighttime exposure levels (Lnight) ranged from 57 dBA to 98 dBA, with an average of 64.2 dBA. The correlation coefficient between home and school exposure was between r = 0.10 and 0.13.

School Performance, Cognitive and Hearing Loss

As shown in Table 1 and Figure 1, there were significant differences in communication and attention between normal-hearing students and hearing-impaired students. However, the differences between conductive hearing loss and sensorineural/hidden hearing loss were significant according to academic performance.

Exposure-Responses between Noise and School Performance

Considering reflexive model (mathematic, French, average score) and recursive model (source, type, level, PTA, DTT, behaviours, attention, memory, communication) measurement models were used according Lden, Lnight, LAeq, and confounders to assess the correlation between noise and school performance.

Figure 1 represents the relation between 4 latent variables, audition, cognition, noise and school performance. 11 manifest variables explain the level for overall measurement.

Model 1 RQMEA = 0.068 (90% CI: 0.066, 0.069) RMSEA probability ≤ 0.05 = 0.000 IAC = 0.805; ITL = 0.0659);

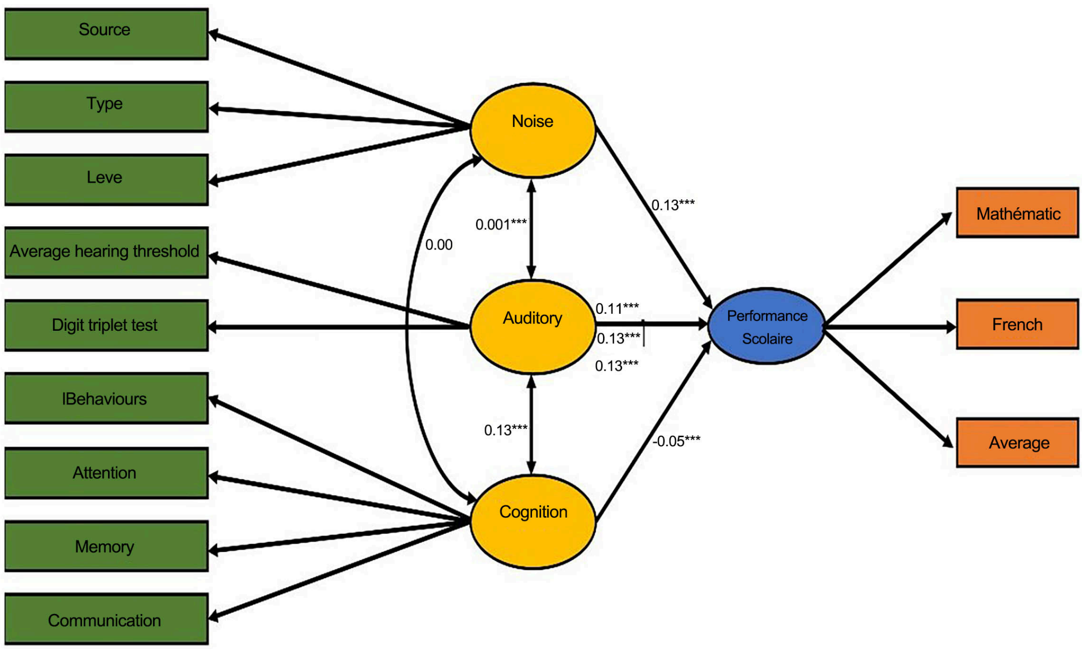

Figure 1. Structural equation models (SEM) of standardized regression coefficients between hearing, cognition, noise, age and socioeconomic status (not shown).

Model 2 RQMEA = 0.038 (90% CI: 0.037, 0.39) Probability RQMEA ≤ 0.05 = 1.000 ITL = 0.884, IAC = 0.946;

Model 3 RQMEA = 0.036 (90% CI = 0.035, 0.037) Probability RQMEA ≤ 0.05 = 1.000 ITL = O.877, IAC = 0.951.

The parameters and the different evaluation indicators of the other models are not displayed.

***p < 0.002, *p < 0.05.

Model 1: hearing-academic performance;

Model 2: hearing-cognition-school performance;

Model 3: hearing-noise-school performance;

Model 4: noise-hearing-school performance;

Model 5: noise-cognition-performance-school performance;

Model 6: hearing-sex, age, SES-performance.

Models with structural equations consisting of a system of equations represented as an oriented graph, the nodes represent the variables as a square or rectangle for the manifest variables and as a rondo or ellipse for the latent variables, the arcs model the causal links.

MODELING

This modeling pursues exploratory rather than confirmatory goals. Scoring models are also listed in the table above. Each manifest variable is associated with a latent variable, and 3 latent variables are correlated with each other. Model1; by including background noise, hearing loss remained significantly associated with lower school performance (**Figure 1**). Fit statistics for the model suggest that the model does not satisfactorily explain changes in school performance. In Model 2, cognitive ability was associated with better academic performance for the same hearing loss (**Figure 1**). The effect of hearing loss on school performance remained significant, suggesting that the effect of hearing loss on school performance was only partially mediated by better cognitive abilities. Environmental noise was associated with poorer school performance and poorer hearing (Model 3), but cognitive performance was less correlated with noise levels (**Figure 1**). The effect of cognition on academic performance was partially mediated by noise, but was still a significant direct effect. In Model 4, noise and hearing loss were significantly associated with poor academic performance (**Figure 1**). The effects of noise and bad behavior were associated with lower academic performance. The effect on cognitive performance was not associated with mathematics academic performance, but was associated with lower noise levels and better academic performance. Fit statistics without the Tucker Lewis Index (TLI) indicate that models 2 through 4 represent the data well. Models 3, 4, and 6 have alternative measures for sensitivity analysis of noise sources and confounders (**Figure 1**).

4. Discussion

This study provides an opportunity to characterize mild, moderate, and hidden hearing loss in children aged 11 to 16 years associated with below-average auditory perception. Furthermore, for cognitive function, it was found that the greater the hearing loss, the greater the negative regression the same in Mathias study. Speech perception in noise using DTT and cognitive performance assessed using SIFTER were also the most impaired skills like in Lieu considering unilateral hearing loss. Overall, the prevalence of mild, moderate, and recessive hearing in children in the study population was 15.9%, supporting the findings of Emilija M Zivkovic Marinkov. This phenomenon gradually negatively affects school performance on ENAFEP tests and SIFTER scores, especially with regard to communication and attention problems; several longitudinal studies have confirmed this relationship [16] [17].

Linear exposure-response relationships were found between school exposure to ambient noise and lower scores on French and math tests. Inverse associations between home exposure to ambient noise, hearing thresholds, and significant boundaries between children's performance were also highlighted in results in French, but not in mathematics, as in Pujol *et al.* study. Few studies have examined the effects of typical exposure to both household and school environmental noise on the academic performance of hearing-impaired children in relation to these noise levels typically encountered in residential areas [16] [18]; to date, no studies have been conducted in Kinshasa any research. To describe school performance, according confounder factors, the studies were also conducted using real-world questionnaires for parents and teachers. Considering the socioeconomic status of parents as a confounding factor and joining Mathias B., this study confirmed the phenomenon on school performance.

As in most cases, we found that it is difficult to determine the exact level at which decline begins and highlights the variability in the tone of body intensity in the relationship between cognitive indicators and academic performance [19] [20].

Participation in this study was high, especially in schools in disadvantaged communities, due to teacher involvement and student support. The population for this study was geographically distributed in the Lukunga Education Zone, thus making it possible to consider children in their plural diversity. Children were not pre-selected on the basis of normal hearing as in previous studies, avoiding pre-selection bias [19] [21], and no children were found to have special needs in terms of hearing loss at the time of enrolment. To add to Pujol and take into account that TENAFEP's assessment tests are based on knowledge acquisition from previous school years, and to ensure that estimated exposures do not reflect current and immediate conditions, only children who had not changed place of residence in the last 2 years.

In addition, sound intensity levels were measured for 14 days during the dry season to avoid contradictory effects of meteorology and other accompanying phenomena. We found that the average overall student percentage in the Lukunga district is comparable to other educational districts in the city of Kinshasa. To avoid situations of fraud and corruption, teachers are told that we only consider results before consultation, as known the consultation can be subjective.

In contrast to this study, according to Pujol, some authors assessed levels and rated children in quiet conditions to ensure that the observed noise effects were due to chronic and non-transient exposure during the test period [19] [20] [21]. Some authors also measured internal or external noise levels during testing in order to adjust noise levels during analysis. A previous study involving adjusting test results for noise levels recorded during exams found no significant effect [17].

Compared to Pujol (using GPS), we used a very similar approach to exposure assessment to provide personal information on noise exposure, and Frédéric Mauny et al physically identified sources of noise pollution in the Lukunga district.

Since public school enrollment does not depend on a student's residential address, it is reasonable to assume that a child who changes residence will not change school. This analysis was carried out to examine school and individual outcomes, especially given the socioeconomic characteristics of the family and the educational level of the parents, which are complemented directly by the child's family. When assessing the auditory and cognitive effects associated with noise exposure, we took into account that students spend most of their evenings at school and at home. The effects of daily exposure to school noise are now well documented. In our research, we confirmed the effects of bar noise and road traffic noise. Household exposure to bar noise has been found to be associated with effects on school performance, considering the TENAFEP.

The studies we reviewed previously only assessed noise exposure in homes and schools near high-intensity sources, with the exception of the study by Pujol *et al.*, which examined road traffic noise exposure in central Besançon. However, the strong correlation between noise levels in bars and church services in homes and schools could explain our results. The current study appears to suggest a link between TENAFEP scores and sacred music, albeit only at one significant level. In our education system in the DRC, students with learning difficulties can stay in school for a year to fill in the gaps and reinforce the skills they have learned.

Recidivism rates were assessed by comparing the participating cohorts of 11- and 13-year-olds with the expected age of children in upper elementary school. Doubling children tended to live in slums, noise exposure had a lower correlation with TENAFEP scores, and age matching led to overfitting. The use of different noise indices in previous studies to quantify children's noise exposure, and the consideration of combined noise sources versus individual noise sources and different times of day, made comparisons between studies difficult (PUJOL).

In this study, we used the "exposed or not" source as a tool in the section entitled "noise exposure in children". On average, noise exposure in dwellings was much higher than reported by Lercher *et al.* (24) but lower than rush hour studies on major European roads [5] [8] [22]. Despite the motorcycle noise, the additional burden of road traffic noise is not highlighted. However, based on some studies on ambient noise, noise exposure in schools does not appear to support an association between noise exposure and poor academic performance [9] [23].

Schoolchildren with hearing loss and in a hostile sound environment face an excessive set of challenges related to multiple disabilities, including cognitive disability. The association between noise pollution and hearing loss even at mild levels or even hidden hearing loss shows cognitive interference on school performance outcomes; of speech and language difficulties, academic results and behavior, in order of importance (according to the results as reported by SIFTER) [24]-[29]. Where cognitive impairment and hearing loss or hearing loss and environmental noise were associated, the result was more cumulative than simply "additive" [30] because the presence of a disability reduces the potential for compensation due to the presence of one or more additional disabilities [31].

Although the prevalence of hearing loss in the general school population is about 0.05% according to some authors [32] and 2% to 17% in this study and other researchers, hearing loss has been reported in the population of students exposed to noise, up to 6% to 8%, the range in which the present study overlaps [25] [27]. Boosting our understanding of the presumed unresolved effect of reduced school performance and hearing loss for children in noisy environments due primarily to music, is an important first step towards identifying strategies and services that can help students with known hearing loss maximize their academic performance and cognitive performance (language communication, in attention and academic results).

The WHO estimates that about 45,000 disability-adjusted life years are lost each year in high-income Western European countries for children aged 7 to 19 due to their exposure to ambient noise. Mechanisms thought to explain the effects of noise on children's cognition include communication difficulties, impaired attention, increased excitement, incompetence to learn, frustration, noise discomfort, and the performance consequences of sleep disturbances [33] [34].

Previous studies have also suggested stress-related psychological responses as a mechanism because 11-year-olds are less equipped in assessing stressors and have less well-developed coping strategies than 16-year-olds [33].

This mechanism may explain the phenomenon observed in this study where the age group of 11 years was found to be more affected in terms of hearing. We also found that areas with high environmental noise levels are socially disadvantaged, and children in socially severely deprived areas scored worse on cognition and TENAFEP tests than children in SES categories 1 and 2. Therefore, measures to assess the socio-economic situation of parents should be taken into account in assessing the associations between noise exposure and health and cognition.

As in the present study, several studies have also shown that exposure to ambient noise has a negative effect on children's school performance and cognitive performance and that children chronically exposed to high-level noise, from road traffic or places of worship and bars at school and at home perform worse on the national standardized TENAFEP tests than children who are not exposed to noise at school [35].

Many studies have examined the exposure-effect links between noise exposure and cognition to identify the level of exposure at which the deleterious effects of noise begin [36] [37].

The RANCH study of children aged 9 to 10 years attending 89 schools located around ambient noise sources showed a linear exposure-effect relationship between noise exposure at a level of 67 dB A at school and a child's reading comprehension and recognition memory after adjusting for a range of socio-economic factors [37] [38].

This average is very close to the one we found around homes. As shown by Mathias B., at an $L_{A\ eq\ day,}$ a 5 dB increase in exposure to high-intensity noise was associated with a 2-month delay in reading age in children in the United Kingdom and a 1-month delay in those in the Netherlands [39]. These linear associations suggest that there is no threshold for effects and that any reduction in noise levels at school should improve cognition, reduce stress and reduce the prevalence of hearing impairment in children.

The WHO Guidelines on Noise in the Community [38] suggest that the background sound pressure level should not exceed L_{Aeq} 35 dB during teaching sessions. We found that the level of noise in school places were above this level. Studies on research and natural experiments have shown that reductions in noise exposure by isolating or closing sources of noise pollution are associated with improvements in cognition and school performance, suggesting that noise reduction may eliminate the deleterious effects of noise on cognition, school performance and hearing [40] [41].

The impact of hearing loss on academic performance can be controlled and addressed with an appropriate overall prevention program, particularly hearing tests for students with poor academic performance [15] [42].

5. Conclusions

This study presents a methodological proposal for implementing a representative indicator of the health hazards of noise pollution in urban areas. This approach has limitations and uncertainties, but has the advantage of providing health information from acoustic data.

Exposure to ambient noise from 39.8 Lden dBA at school and at home was independently associated with decreased performance before and after noise adjustment. The impact of ambient noise on target elements can be estimated by longitudinal studies. For large exposed populations, consideration needs to be given to the extent to which environmental noise and hearing loss affect academic performance and risk of cognitive deafness.

Finally, if we are interested in "true" noise exposure (*i.e.* the amount of noise absorbed in 24 hours), we should be concerned with noise levels and perception of noise while driving, at school, at home and at leisure. Mild hearing loss affects learning. The impact of performance can be controlled and addressed with an appropriate and comprehensive hearing screening program. A hearing test is strongly recommended for every child, especially those who do not perform well in school.

6. Limitations

However, as with previous studies on the effects of ambient noise on children's cognition and academic performance, limitations of this study include a lack of classroom or home acoustic assessments. Another limitation of this study is the lack of adjustment for children's health.

Author Contributions

All authors have contributed, read and agreed to the published version of the manuscript.

Acknowledgements

Many thanks to the team of Dr. Michel Bokolo and the Lukunga Educational Division of the EPS (Elementary and Secondary Education).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Le Clercq, C.M.P., van Ingen, G., Ruytjens, L., Goedegebure, A., Moll, H.A., Raat, H. and van der Schroeff, M.P. (2017) Prevalence of Hearing Loss among Children 9 to 11 Years Old. *JAMA Otolaryngology—Head & Neck Surgery*, **143**, 928-934. https://doi.org/10.1001/jamaoto.2017.1068

[2] Maha, A.S., Asma, A., Najmah, A.M., Nadia, A.M., Lulwah, A.S., Anfal, A.Q. and Susan, A. (2014) The Perceived Effects/Impacts of Auditory Deficiency on the Social and Academic Behavior of Students in Hail, Saudi Arabia. *American Journal of Educational Research*, **2**, 54-65. https://doi.org/10.12691/education-2-1-10

[3] González, C. (2007) Vowels and Consonants: An Introduction to the Sounds of Language (Review). *Language*, **83**, 194-196. https://doi.org/10.1353/lan.2007.0015

[4] Lieu, J.E. (2013) Unilateral Hearing Loss in Children: Speech-Language and School Performance. *B-ENT*, No. 21, 107-115.

[5] Jerrim, J. (2021) National Tests and the Wellbeing of Primary School Pupils: New Evidence from the UK. *Assessment in Education*: *Principles*, *Policy & Practice*, **28**, 507-544. https://doi.org/10.1080/0969594X.2021.1929829

[6] Tshimbadi, K., Tshiswaka, M.J. and Matanda, N.R. (2021) Prevalence of Hearing Impairment among Schoolchildren in Kinshasa, DR. Congo. *African Annals of Medicine*, **4**, 697-701.

[7] Shirin, D.A., Patricia, B.J., Susanne, R. and Kathryn, H.K. (2009) Academic Status

and Progress of Deaf and Hard-of-Hearing Students in General Education Classrooms. *The Journal of Deaf Studies and Deaf Education*, **14**, 293-311. https://doi.org/10.1093/deafed/enp009

[8] Verhulst, F.C. and Van der Ende, J. (2013) ASEBA Manual: Questionnaires for Ages 6 to 18 Years. ASEBA Nederland, Rotterdam. (In Dutch)

[9] Dawes, P. and Bishop, D.V.M. (2007) The SCAN-C in Testing for Auditory Processing Disorder in a Sample of British Children. *International Journal of Audiology*, **46**, 780-786. https://doi.org/10.1080/14992020701545906

[10] Banerjee, D. (2012) Research on Road Traffic Noise and Human Health in India: Review of Literature from 1991 to Current. *Noise Health*, **14**, 113-118.

[11] De Lima Andrade, E., da Cunha e Silva, D.C., de Lima, E.A., de Oliveira, R.A., Zannin, P.H.T. and Martins, A.C.G. (2021) Environmental Noise in Hospitals: A Systematic Review. *Environmental Science and Pollution Research*, **28**, 19629-19642. https://doi.org/10.1007/s11356-021-13211-2

[12] Chere, B. and Kirkham, N. (2021) The Negative Impact of Noise on Adolescents' Executive Function: An Online Study in the Context of Home-Learning during a Pandemic. *Frontiers in Psychology*, **12**, Article ID: 715301. https://doi.org/10.3389/fpsyg.2021.715301

[13] Pujol, S., Levain, J.-P., Houot, H., Petit, R., Berthillier, M., Defrance, J. and Mauny, F. (2013) Association between Ambient Noise Exposure and School Performance of Children Living in an Urban Area: A Cross-Sectional Population-Based Study. *Journal of Urban Health*, **91**, 256-271. https://doi.org/10.1007/s11524-013-9843-6

[14] Foraster, M., Esnaola, M., López-Vicente, M., Rivas, I., Álvarez-Pedrerol, M., Persavento, C., Sebastian-Galles, N., Pujol, J., Dadvand, P. and Sunyer, J. (2022) Exposure to Road Traffic Noise and Cognitive Development in Schoolchildren in Barcelona, Spain: A Population-Based Cohort Study. *PLOS Medicine*, **19**, e1004001. https://doi.org/10.1371/journal.pmed.1004001

[15] Wang, J., le Clercq, C.M.P., Sung, V., Carew, P., Liu, R.S., Mensah, F.K. and Wake, M. (2018) Cross-Sectional Epidemiology of Hearing Loss in Australian Children Aged 11-12 Years Old and 25-Year Secular Trends. *Archives of Disease in Childhood*, **103**, 579. https://doi.org/10.1136/archdischild-2017-313505

[16] Stevenson, J., Kreppner, J., Pimperton, H., Worsfold, S. and Kennedy, C. (2015) Emotional and Behavioural Difficulties in Children and Adolescents with Hearing Impairment: A Systematic Review and Meta-Analysis. *European Child & Adolescent Psychiatry*, **24**, 477-496. https://doi.org/10.1007/s00787-015-0697-1

[17] Ivanova, M.Y., Achenbach, T.M., Rescorla, L.A., Harder, V.S., Ang, R.P., Bilenberg, N. and Verhulst, F.C. (2010) Preschool Psychopathology Reported by Parents in 23 Societies: Testing the Seven-Syndrome Model of the Child Behavior Checklist for Ages 1.5-5. *Journal of the American Academy of Child & Adolescent Psychiatr*y, **49**, 1215-1224. https://doi.org/10.1097/00004583-201012000-00007

[18] Bess, F.H., Dodd-Murphy, J. and Parker, R.A. (1998) Children with Minimal Sensorineural Hearing Loss: Prevalence, Educational Performance, and Functional Status. *Ear and Hearing*, **19**, 339-354. https://doi.org/10.1097/00003446-199810000-00001

[19] Schlauch, R.S. and Carney, E. (2012) The Challenge of Detecting Minimal Hearing Loss in Audiometric Surveys. *American Journal of Audiology*, **21**, 106-119. https://doi.org/10.1044/1059-0889(2012/11-0012)

[20] Khan, S., Edwards, L. and Langdon, D. (2005) The Cognition and Behaviour of Children with Cochlear Implants, Children with Hearing Aids and Their Hearing Peers: A Comparison. *Audiology and Neurotology*, **10**, 117-126.

https://doi.org/10.1159/000083367

[21] Hofman, A., Jaddoe, V.W.V., Mackenbach, J.P., Moll, H.A., Snijders, R.F.M., Steegers, E.A.P. and Buller, H.A. (2004) Growth, Development and Health from Early Fetal Life until Young Adulthood: The Generation R Study. *Paediatric and Perinatal Epidemiology*, **18**, 61-72. https://doi.org/10.1111/j.1365-3016.2003.00521.x

[22] Clark, J.G. (1981) Uses and Abuses of Hearing Loss Classification. *ASHA*, **23**, 493-500.

[23] Kuppler, K., Lewis, M. and Evans, A.K. (2013) A Review of Unilateral Hearing Loss and Academic Performance: Is It Time to Reassess Traditional Dogmata? *International Journal of Pediatric Otorhinolaryngology*, **77**, 617-622. https://doi.org/10.1016/j.ijporl.2013.01.014

[24] Antia, S.D., Jones, P.B., Reed, S. and Kreimeyer, K.H. (2009) Academic Status and Progress of Deaf and Hard-of-Hearing Students in General Education Classrooms. *Journal of Deaf Studies and Deaf Education*, **14**, 293-311. https://doi.org/10.1093/deafed/enp009

[25] Cameto, R., Bergland, F., Knokey, A.-M., Nagle, K.M., Sanford, C., Kalb, S.C., Blackorby, J., Sinclair, B., Riley, D.L. and Ortega, M. (2010) Teacher Perspectives of School-Level Implementation of Alternate Assessments for Students with Significant Cognitive Disabilities. A Report from the National Study on Alternate Assessments (NCSER 2010-3007). SRI International, Menlo Park.

[26] Easterbrooks, S.R. and Beal-Alvarez, J.S. (2012) States' Reading Outcomes of Students Who Are D/Deaf and Hard of Hearing. *American Annals of the Deaf*, **157**, 27-40. https://doi.org/10.1353/aad.2012.1611

[27] Kearns, J.F., Towles-Reeves, E., Kleinert, H.L., Kleinert, J.O.R. and Thomas, M.K.K. (2009) Characteristics of and Implications for Students Participating in Alternate Assessments Based on Alternate Academic Achievement Standards. *The Journal of Special Education*, **45**, 3-14. https://doi.org/10.1177/0022466909344223

[28] Moeller, M.P., Tomblin, J.B., Yoshinaga-Itano, C., Connor, C.M. and Jerger, S. (2007) Current State of Knowledge: Language and Literacy of Children with Hearing Impairment. *Ear & Hearing*, **28**, 740-753. https://doi.org/10.1097/AUD.0b013e318157f07f

[29] Reed, S., Antia, S.D. and Kreimeyer, K.H. (2008) Academic Status of Deaf and Hard-of-Hearing Students in Public Schools: Student, Home, and Service Facilitators and Detractors. *Journal of Deaf Studies and Deaf Education*, **13**, 485-502. https://doi.org/10.1093/deafed/enn006

[30] Wiley, S. and Moeller, M.P. (2007) Red Flags for Disabilities in Children Who Are Deaf/Hard of Hearing. *The ASHA Leader*, **12**, 8-29. https://doi.org/10.1044/leader.FTR3.12012007.8

[31] Knoors, H. and Vervloed, M. (2003). Educational Programming for Deaf Children with Multiple Disabilities. In: Marschark, M. and Spencer, P.E., Eds., *Oxford Handbook of Deaf Studies*, *Language and Education*, Oxford University Press, New York, 82-94.

[32] Vos, T., Flaxman, A.D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M. and Aboyans, V. (2012) Years Lived with Disability (YLDs) for 1160 Sequelae of 289 Diseases and Injuries 1990-2010: A Systematic Analysis for the Global Burden of Disease Study 2010. *The Lancet*, **380**, 2163-2196. https://doi.org/10.1044/leader.FTR3.12012007.8

[33] Boulet, S.L., Boyle, C.A. and Schieve, L.A. (2009) Health Care Use and Health and Functional Impact of Developmental Disabilities among US Children, 1997-2005. *Archives of Pediatrics & Adolescent Medicine*, **163**, 19-26.

https://doi.org/10.1001/archpediatrics.2008.506

[34] Stansfeld, S., Haines, M. and Brown, B. (2000) Noise and Health in the Urban Environment. *Reviews on Environmental Health*, **15**, 43-82. https://doi.org/10.1515/REVEH.2000.15.1-2.43

[35] Evans, G.W. (2006) Child Development and the Physical Environment. *Annual Review of Psychology*, **57**, 423-451. https://doi.org/10.1146/annurev.psych.57.102904.190057

[36] Ana, G.R.E.E., Shendell, D.G., Brown, G.E. and Sridhar, M.K.C. (2009) Assessment of Noise and Associated Health Impacts at Selected Secondary Schools in Ibadan, Nigeria. *Journal of Environmental and Public Health*, **2009**, Article ID: 739502. https://doi.org/10.1155/2009/739502

[37] Stansfeld, S., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E. and Berry, B. (2005) Aircraft and Road Traffic Noise and Children's Cognition and Health: A Cross-National Study. *The Lancet*, **365**, 1942-1949. https://doi.org/10.1016/S0140-6736(05)66660-3

[38] Clark, C., Martin, R., van Kempen, E., Alfred, T., Head, J., Davies, H. W. and Stansfeld, S.A. (2005) Exposure-Effect Relations between Aircraft and Road Traffic Noise Exposure at School and Reading Comprehension. *American Journal of Epidemiology*, **163**, 27-37. https://doi.org/10.1093/aje/kwj001

[39] Berglund, B., Lindvall, T. and Schwela, D.H. (1999) Guidelines for Community Noise. WHO, Geneva. https://doi.org/10.1260/0957456001497535

[40] Baudin, C. (2019) Effects of Exposure to Aircraft Noise on the Health of Airport Residents. Public Health and Epidemiology. University of Lyon, Lyon.

[41] Hygge, S., Evans, G.W. and Bullinger, M. (2002) A Prospective Study of Some Effects of Aircraft Noise on Cognitive Performance in Schoolchildren. *Psychological Science*, **13**, 469-474. https://doi.org/10.1111/1467-9280.00483

[42] Su, B.M. and Chan, D.K. (2017) Prevalence of Hearing Loss in US Children and Adolescents. *JAMA Otolaryngology—Head & Neck Surgery*, **143**, Article No. 920. https://doi.org/10.1001/jamaoto.2017.0953