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Hearing Loss and Academic Performance in Kinshasa School Close to a Source of Noise

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Abstract

Context: Cognitive learning disabilities and hearing loss, a sensory impairment that is very common at all ages, are risk factors for declining academic performance. They are due to several causes, particularly ambient noise. However, there are very few studies on this aspect in low-income countries, such as ours. **Aim:** To assess the association between environmental noise, hearing loss and school performance among young primary school children in an educational district in Kinshasa. **Methods:** A cross-sectional descriptive study on data obtained from a representative survey at the scale of an urban municipality between 2019 and 2021. Two hundred thirty eight children aged 10 to 15 years, eligible for the National Primary School Leaving test, TENAFEP, and a dichotomized measurement of hearing status found or not during an ENT examination, were included. Cognition was assessed using the Screening Instrument For Targeting Educational Risk (SIFTER) score and TENAFEP results, as a dedicated measure. **Results:** Hearing loss was associated with cognitive impairment (correlation coefficient r was 0.611) and decreased academic performance with an odds ratio (OR): 2.48 (90% CI 1.22 - 5.06) and R^2: 0.511. Hearing loss was associated with a decline in school performance (r: 0.412), with 8% increase in risk and R^2: 0.380 - 0.558, compared to people with able hearing. Hearing loss and cognitive decline (r: 0.611) mediated the association between frequent engagement in leisure activities, noise exposure and academic performance for all samples and the subsample of boys (R^2: 0.380). **Conclusion:** Hearing loss associated with environmental noise is a predictor of cognitive decline and academic performance. Involvement in leisure activities mediated association among boys rather than girls, hence the need to consider prospective longitudinal studies and the implementation of holistic deafness prevention and sound sanitation programs in schools.

Keywords

Hearing Loss, Environmental Noise, Cognitive Function, Student

1. Introduction

School performance reflects the intelligence quotient. It is also influenced by the environmental sound conditions in children's homes and on the facades of their schools. Noise pollution is a factor that causes deafness. Hearing loss is very common in primary school children, with a prevalence of 6% worldwide [1] [2]. The causes of deafness in children can be hereditary, congenital or acquired (due to infectious or traumatic origin). Drug-induced ototoxicity has developed as a corollary to the explosion of the pharmaceutical industry.

Acute and chronic sound trauma is now recognized as a source of hidden [3] and symptomatic hearing loss.

Over the last 5 decades, environmental noise in urban areas has been developed at the expense of urbanization and exponential industrialization at the global level. Sites intended for schools, formerly located outside the hubbub of road traffic and leisure music, are now bathed in this adjoining discomfort on a large scale [4].

Several previous empirical studies have shown that the environmental noise in schools is the cause of certain sensorineural hearing loss [5] [6]. Since 2012, researchers from the Kresge Hearing Research Institute in Michigan and Charles Libermann's team in the United States of America have shown that the decline in speech intelligibility in a noisy environment is due, among other things, to hidden deafness [7].

To date, very few studies have included these cases in the prevalence of deafness in schools. Indeed, conventional audiograms of hearing thresholds by pure tone audiometry (PTA) are not available to detect this type of hearing loss [8]. The explanation of this problem has already been documented in high-income countries. In the DRC, there is no systematic screening program for deafness in schools to assess this phenomenon in a young population.

This study aims to assess the association between hearing loss and academic performance in young students, and whether exposure to environmental noise would mediate this association. In this study, we also consider young students attending a primary school in a county of an educational district in Kinshasa.

We therefore proposed to look for cases of deafness and to determine their correlation with the decline in school performance in a school close to a dominant source of noise pollution and located in one of the municipalities of the VPK.

2. Methods

This is a cross-sectional and comparative study that crosses the period from September 2019 to December 2021 stigmatized by the COVID-19 pandemic. This study took place in primary schools within the Saint Pierre school complex in the commune of Kinshasa, in the VPK where a sound source was identified, quantified and qualified after characterization.

This complex was randomly selected from among those with a population > 1000 students, the exposure level greater than 55 dB A, considered as the maximum limit of the average tolerated exposure level in a school environment and located along major highways [9]. In a survey of the ambient noise level in Lukunga district, an average of 55 dBA was found [4].

All students enrolled in sixth grade and eligible for the TENAFEP test were selected from our sample.

We have previously requested and obtained the authorization of the ethics committee of the School of Public Health (ESP) of the University of Kinshasa (UNIKIN).

2.1. Hearing Measurements

2.1.1. Pure Tone Audiometry (PTA)

In our study, hearing was assessed using pure tone audiometry (PTA). Hearing thresholds specific to each ear without a hearing aid were measured in the range of 500 to 8000 Hz. Higher decibel thresholds indicated poorer hearing. The basic investigation concerned deafness, as defined by the hearing threshold on 4 frequencies in the better ear, representing the average threshold at 500, 1000, 2000 and 4000 Hz. The choice of the best mean hearing threshold of the ear was consistent with previous epidemiological studies [10] [11] of age-related hearing loss. The threshold on the 8000 Hz frequency was evaluated to explore hidden deafness.

Hearing loss was defined by the globally used clinical and research mean threshold of a PTA greater than 25 dB *HL*. Traditionally, normal hearing is defined as an average hearing threshold of 25 dB *HL* or less. In an analysis with more sensitivity, we defined minimal deafness as a hearing threshold greater than 15 dB *HL*. In this study, we defined subclinical hearing loss as a hearing threshold of 1 to 25 dB.

2.1.2. Digit Triplet Test (*DTT*)

The procedure below corresponds to the telephone version of the *DTT*.

This is an adaptive procedure where the noise is fixed.

The presentation of digits at −8 dB SNR begins with a sequence of three digits (from 1 to 9) chosen at random. The listener must then indicate his 3 answers via a numeric keypad and the triplet is considered correct when all the digits are correctly reproduced. 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 was given by the average of the SNR of the last 22 iterations (including the adjusted SNR after the 27th presentation).

2.2. Noise Measurement

For noise measurement, via a sound level meter connected to a laptop that collects the information via Trotec 400 software that stores it and this data is exported to a database.

2.3. Data Collection

Data on the student's address, age, and information on noise around the school and residence of those students who have lived at least two years at that address found on the day of collection or study.

The data collected included:

a) Environmental noise around the school and around the home where the respondent (Student) lived, represented in dB A as a numerical variable for one hour/day and then classified according to source and type, as a qualitative variable.

b) Academic performance in the primary school leaving examination test (TENAFEP), collected as a percentage as a numerical variable converted into a qualitative variable by grouping the percentage according to "success ≥ 50% or failure < 50%".

c) The psychological state of the student, collected as a qualitative variable, via the Verbal Comprehension Index (LCI) for the Subtests: (similarity, vocabulary and comprehension).

d) Cognitive ability through TENAFEP results and *S.I.F.T.E.R* score.

e) Examination (ATL and *DTT* examination) of the hearing status by an ENT doctor.

f) Information on environmental noise is collected by 5 doctors, at the school and around 35 homes, during 17 days of visits to the homes where the pupils reside.

2.4. Data Processing

Data processing included data sorting, quality control, and final processing.

The first quality control was carried out in the field by investigators, doctors and public health experts who checked whether the inclusion and non-inclusion criteria were met and whether the responses were complete and correctly scored. During collection, the data sent was evaluated as soon as it was received by supervisors.

The final data processing consisted of dividing the data into different categories and coding them. For closed-ended questions, categories were created in the questionnaires. They referred to the possible options. On the other hand, for open-ended questions, the categories were created during the codification.

2.4.1. Quantitative Data Processing

Quantitative data were collected:

1) For noise measurement, by a sound level meter connected to a laptop and the information was collected via Trotec 400 software, stored and exported to a database.

Sound Pressure Level

(a) The dB scale is a logarithmic scale for measuring the sound pressure level. A double increase in sound energy (e.g., two identical jackhammers instead of one) will result in an increase in sound pressure level of 3 dB. A tenfold increase in sound energy (10 jackhammers) will result in an increase in the sound pressure level of 10 dB, which is perceived to be about twice as loud.

(b) L_{max}: The highest sound pressure level for a given period.

(c) L_{eq}: Average sound pressure level over a certain period of time. If filter A is used for frequency weighting, the average level is called L_{Aeq}. The filter and time period used for the average are often indicated as an index, for example, L_{Aeq8h}, $L_{Aeq23-7h}$, or L_{night}.

(d) L_{DEN}: L_{DEN}(Level-Day-Evening-Night), also referred to as DENL, is the filtered average sound pressure level A, measured over a 24-hour period, with a penalty of 10 dB added for the night (23:00-07:00 or 22:00-06:00, respectively), and a penalty of 5 dB added to the evening period (19:00-23:00 or 18:00-22:00, respectively), and no penalties added to the average level during the day (07:00-19:00 or 06:00-18:00, respectively). The L_{DN} measurement is similar to the L_{DEN} measurement, but omits the 5 dB penalty during the evening period. Penalties are introduced to indicate people's additional sensitivity to noise during the night and evening. Both, L_{DEN} and L_{DN} are based on A-weighted sound pressure levels, although this factor is not usually given as an index.

2) The student's cognitive ability was assessed using the results of the TENAFEP percentage and the standardized SIFTER questionnaire completed by the student's teacher in ordinal data from 3 to 15 and these quantitative data were then coded.

3) Data on the students' hearing were collected during an ENT examination according to the average hearing threshold (SAM) in dB HL or dB RSB and then encoded in a database for statistical processing with SPSS version 21.0 software.

2.4.2. Qualitative Data Processing

Qualitative data were collected through interviews with the various student leaders (parents and teachers). Doctors trained in the use of the collection tool processed the data and centralized explanations on the subject, using a grid as a guide.

Quality control of the completion of the questionnaires was carried out by the coordination team composed of the principal investigator and the auxiliary investigators. The observation note was annexed to each questionnaire for the purpose of taking it into account.

2.5. Statistical Analyses

A multivariate logistic regression model to calculate odds ratios for associations between hearing loss and various factors. The model included demographic characteristics; known risk factors; and associations between hearing loss and noise sources.

Adjustments were made for potential confounders (known risk factors for deafness), including age, sex, household income, second-hand smoke, any history of ear infection or rhino sinusitis, and family history of deafness.

Multivariate logistic regression also explored the association between noise exposure and hearing loss, adjusted for age, sex, household income, smoking, alcohol consumption, any history of ear infection or rhino sinusitis, and any family history of deafness. It was used to study associations between low academic achievement and hearing status after adjusting for education, gender and income of the head of household.

Structural equation modelling was used to analyze the relationships between latent variables: noise, hearing loss, cognitive capacity and school performance.

All statistical analyses were carried out using IBM SPSS 2021 software with the possibility of export to dedicated software for structural modelling. Statistical significance was defined as *a double-sided p* value < 0.05.

3. Results

Two hundred thirty eight pupils regularly enrolled in the 6th grade were registered for the present study. There was a loss of 7.75% of the expected and calculated sample due to COVID period.

Table 1. Analysis of the prevalence of hearing loss.

Variables	Categories	Hearing Screening		*p*-value
		Deaf n (%)	Hearing Norms n (%)	
Reported hearing loss	Yes	24 (12.5)	176 (87.5)	0.002**
	No	14 (34.2)	24 (65.8)	
Exam Type	*DTT*	14 (31.1)	31 (68.9)	0.004**
	ATL	24 (12.4)	169 (87.6)	
Tubal dysfunction	Bilateral	5 (45.5)	6 (54.5)	0.006**
	Right Ear	5 (21.7)	18 (78.3)	
	Left Ear	4 (33.3)	8 (66.7)	
	Normal	24 (12.5)	168 (87.5)	
Residential environment	Poor environment	22 (16.7)	110 (83.3)	0.859
	Rich environment	16 (15.1)	90 (84.9)	
Sex	Masculine	18 (16.2)	93 (83.8)	0.922
	Feminine	20 (15.7)	107 (84.3)	
Age range (years)	Child (11 - 13)	32 (19.6)	131 (80.4)	0.035*
	Teen (14 - 16)	6 (8)	69 (92)	
Otoscopy	Amended	13 (30.6)	43 (69.4)	0.0004***
	Normal	19 (10.8)	157 (89.2)	
Deafness Type	Hidden	2 (9.5)	19 (90.5)	0.129
	Moderate	7 (31.8)	15 (68.2)	
	Minimal	9 (11.4)	70 (88.6)	
	Light	20 (17.2)	96 (82.8)	
Socio-economic status	Classes 1 - 2	14 (11.8)	105 (88.2)	0.142
	Classes 3 - 4	10 (20.8)	38 (79.2)	

* *Statistical significance.*

Table 1 shows that the prevalence of hearing loss was 16% (11.7 - 21.4%), while 26.1% of children (20.7 - 32.2%) had impaired otoscopy, 16% (11.7 - 21.4%) had parent-reported hearing difficulties, and 18.9% (14.3 - 24.6%) reported ear pain.

The mean age of participants was 12.76 ± 2.81 years and 53.4% were girls. There was a significant difference between hearing screening results and self-reported signs, self-reported hearing loss and hidden hearing loss, age group, and otoscopy outcome. The subclass analyses presented in Table 1 significantly identified certain risk factors for deafness, such as age, among others.

3.1. Academic Performance

Table 1 and Figure 1 highlight the relation between the performance of students and their hearing status according to their place of residence. Students from wealthy urban areas perform better results than those from poor backgrounds, and the difference is significant at the 5% threshold. In rich urban areas (SES 1.2) more than 50% of pupils have more than 60%, in contrast to poor areas where half have less. Indeed, in the wealthy urban environment, infrastructures and equipment, less noisy and allowing better learning, are located there (electricity, library, internet, transport, etc.).

However, in poor and noisy environments students are sometimes very far from school, and these students have to travel miles to get to school. All these factors contribute to poor academic performance. Data on the level of noise in poor and wealthy urban areas are not reported here.

3.2. Noise Level

3.2.1. School Facades and Homes

Environmental noise sources detected in schools and homes.

The data presented in Table 2 describe how, during a single visit to the schools included in this study, we found that noise from bars and road traffic was the main source of noise pollution, with the exception of rear facades, where we found that the main sources of noise were music from places of religious worship, nightclubs and bars nearby. Most respondents reported being exposed to noise in their homes, especially students living in poor neighborhoods (88%).

The percentages of participants who reported being affected by noise in other spaces or circumstances (recreation, play) were 76% and 64%, respectively.

3.2.2. Environmental Noise Level Measured in Schools

Table 2 and Figure 1 display and analyze the ratio of noise levels recorded at different coordinates in the courtyards of the schools surveyed within the school complex. Average noise levels recorded in the schoolyard ranged from 68.3 dB A <*L*> to 84.7 dB A outdoors on playgrounds and between 69.5 dB A and 76.1 dB A inside classrooms.

These ranges were above the WHO recommended noise level of 55 dB A for community (school) learning environments.

Table 2. Environmental noise sources and intensity.

School	Noise level (dBA)	Home
Street vendor	45	Refrigerator
Conversation in an office	60	Dishwasher
Canteen/Restaurant/Alarm clock 70 dBA	70	Canteen/Restaurant/Alarm clock
Desk Set/	75	Vacuum cleaner
Hand Saw	85	Motorcycle
Machine Workshop	87	Circular Saw/Gas Mower
Ambulance/Driver	95	Pneumatic Screwdriver/Electric Generator/MP3 Player/ Religious Worship
Accelerating a Truck	110	
Hammer Blow/Stadium of Games		Playground
Motorcycle horn	120	Outdoor Concert/Rock/ Evangelism Campaign
Jackhammer/	130	Auto Racing
Dynamite/	140	Bicycle horn
Tire puncture	150	
Quarry stone/Firecracker	160 - 170	Firecracker Shot

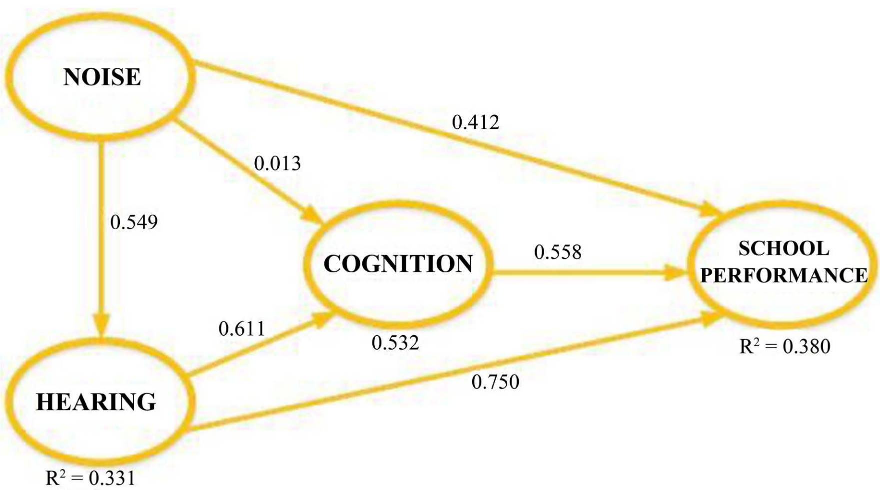

Figure 1. Modeling by structural equations with latent variables: noise, hearing, cognition and school performance, according to a contextualized scale.

MODEL 1: RMSEA = 0.068 (90% CI: 0.066; 0069)

Probability RMSEA $\leq 0.05 = 0.000$

CFI = 0.805

TLI = 0.659

MODEL 2: RMSEA = 0.038 (90% CI: 0.037; 0.09)
RMSEA Probability ≤ 0.05 = 1.000
CFI = 0.946
TLI = 0.884
MODEL 3: RMSEA = 0.036 (90% CI: 0.035; 0.037)
RMSEA Probability ≤ 0.05 = 1.000
CFI = 0.951
TLI = 0.877
MODEL 4: RMSEA = 0.031 (90% CI: 0.035; 0.037)
Probability RMSEA ≤ 0.05 = 1.000
CFI = 0.951
TLI = 0.877
Notes:
RMSEA = Root Mean Square Error of Approximation
CFI = Comparative Fit Index
TLI = Tucker Lewis Index

In one of the classrooms, the highest average noise level was recorded, 86.1 dB A for noise inside the classrooms; the average measurement in this school was 84.7 dB A for outdoor playground noise.

On the other hand, the lowest average noise level recorded was 68.3 dB A for classroom (indoor) noise; the average measurement in this school was 74.4 dB A for indoor playground noise. The noise levels measured were issued from reported and identified external sources, as well as those produced by students.

3.3. Modeling

Structural equation modelling (**Figure 1**) is based on the measurement model represented by 14 manifest variables or items and 4 latent variables, 3 of which are independent (noise, cognition and hearing) and 1 dependent variable, school performance. The different correlation coefficients calculated expressed relationships between these variables. The coefficients of determinant given by the R^2 parameter suggest that these effects are moderately to strongly elevated overall.

Although the associations were significant, the different sizes of the noise effect on decreased hearing ability compared to the French tests (TENAFEP) results were all moderate. The average size of the effect of noise on the results of end-of-cycle examinations (TENAFEP) was higher, but still moderate. Students with known hearing loss performed lower in math. A chi-square independence test showed a significant association between the category of students with multiple problems (e.g. noise exposure) and auditory status compared to those with normal hearing ($p < 0.001$). The effect size indicated a moderate association between noise and hearing status. The students with known cognitive decline are more strongly associated with higher "deafness".

4. Discussion

According to the literature consulted on codification, pure tone audiometry is the first crucial moment in an investigation of auditory function. In the present study, a dedicated tool was used to assess the hearing threshold of students using the *DTT* in order to better assess hearing in noise and in strict compliance with barrier measures against COVD-19.

Prendergast finds that *DTT* has a sensitivity of 80% and a specificity of 92% compared to ATL. Sixty percent of children were assessed using this tool. 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 at even mild levels shows cognitive interference with school performance outcomes; speech and language difficulty, academic performance and behaviour, in order of importance (according to results as reported by *SIFTER*) [12]-[17]. When cognitive impairment and hearing loss or hearing loss and environmental noise were associated, the outcome was "cumulative rather than merely additive" [18] because the presence of a disability reduces the potential for compensation due to the presence of one or more additional disabilities [19] [20].

Boosting our understanding of the presumed and as yet unclear effect of poor academic 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 and cognitive performance (language communication, attention and academic performance).

The WHO estimates that about 45,000 cognitively adjusted life years are lost each year in high-income Western European countries for children aged 7 to 19 years, due to their exposure to ambient noise. Mechanisms hypothesized to explain the effects of noise on children's cognition include communication difficulties, impaired attention, increased arousal, incompetence in learning, frustration, noise annoyance, and the consequences of sleep disturbances on cognitive performance [21] [22]. Previous studies have also suggested stress-related psychological responses as a mechanism because 11-year-olds are less equipped to assess stressors and have less well-developed coping strategies than 16-year-olds [21].

This mechanism may explain the phenomenon observed in this study where the 11-year-old age group was found to be more affected auditorily [23]-[25]. We also found that areas with high levels of environmental noise are socially disadvantaged, and children in highly socially deprived areas performed worse on cognition and TENAFEP tests than children in SES categories 1 and 2. Therefore, measures to assess the socio-economic status of parents should be taken into account in the assessment of associations between noise exposure and cognition. As in this study, several studies have also shown that exposure to ambient noise has a negative effect on children's academic performance and cognitive scores. In addition, children who are chronically exposed to high-level noise, from road traffic or places of worship and bars at school and at home [26] [27].

At a day's L, a 5 dB increase in exposure to loud 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 [28]. 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 loss in children. The WHO Community Noise Guidelines [27] define that the background sound pressure level should not exceed LAeq 35 dB during teaching sessions. Research studies and natural experiments have shown that reductions in noise exposure by isolating or compartmentalizing sources of noise nuisance are associated with improvements in cognitive abilities and academic performance, suggesting that noise reduction can eliminate noise exposure [29].

Noise is the leading preventable cause of hearing loss. Noise-induced hearing loss can be caused by a single exposure to a loud sound (such as gunshots), or by chronic steady-state exposure with sound pressure levels above LAeqN 75 - 85 dB according to historical references [30]. The new references have completely changed the way we see things. The pathological feature of noise-induced hearing loss is primarily the loss of auditory sensory cells in the cochlea. Hearing loss leading to the inability to understand speech in everyday situations can have a serious social effect. It can also affect cognitive performance and decrease attention to tasks. Noise-induced hearing loss is a public health problem, as the results of this study can show. The 2010 WHO [31] estimated that 1.3 billion people are affected by hearing loss and researchers ranked hearing loss as the 13th largest provider (19.9 million years, 2.6% of the total) to years lived globally with a disability. The age-adjusted prevalence is similar in Asia. The situation of children in sub-Saharan Africa presents a more dramatic problem. The WHO estimates that 10% of the world's population is exposed to sound pressure levels that could potentially cause noise-induced hearing loss.

Limitations

There were not enough participants to generalize the results of this study to the general population. The limited number of participants could be due to the method of delivery of the questionnaire and the limited duration of the research project.

Conflicts of Interest

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

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