25-29 August 2024
inter.noise
NANTES FRANCE

On the effect of indoor acoustic conditions in performing cognitive tests in primary school

Battagliarin Lisa[1], Cappelletti Francesca[2], Romagnoni Piercarlo[3]
University IUAV of Venice, Department of Architecture and Art
Santa Croce 191, 30132 Venice, Italy

Di Bella Antonino[4]
University of Padova, Department of Industrial Engineering
Via Venezia 1, 35121 Padova, Italy

Gheller Flavia[5], Spicciarelli Gaia[6], Arfè Barbara[7]
University of Padova, Department of Developmental Psychology and Socialization
Via Venezia 8, 35121 Padova, Italy

Paccagnella Omar[8]
University of Padova, Department of Statistical Sciences
Via Cesare Battisti 241, 35121 Padova, Italy

ABSTRACT

The quality of the acoustic environment is essential to foster learning as students learn by listening to the teacher. Prolonged exposure to noise during critical learning periods at school can impair development and have a lifelong effect on academic achievement. This is why the problem of noise is of concern in learning environments such as schools. Poor acoustic quality leads to increased cognitive effort that is associated with greater difficulty in processing and remembering information in the short and long term.

Preliminary results from the administration of neuropsychological tests under quiet and noise conditions only partially supported the hypothesis that noise negatively impacts children's cognitive performance. In fact, only in one of the two monitored schools the children's performance was affected by the presence of noise during the execution of the tests. In this paper, new results obtained from the correlation between the acoustic parameters and the children's responses to the cognitive performance are presented to confirm the validity of the hypotheses.

[1] lbattagliarin@iuav.it
[2] francesca.cappelletti@iuav.it
[3] piercarlo.romagnoni@iuav.it
[4] antonino.dibella@unipd.it
[5] flavia.gheller@unipd.it
[6] gaia.spicciarelli@unipd.it
[7] barbara.arfe@unipd.it
[8] omar.paccagnella@unipd.it

1. INTRODUCTION

The impact of noise has been widely explored with regard to hearing and the ability to concentrate, but we often neglect its impact on cognitive functions [1]. Recent research has shown that noise exposure can affect cognition, causing annoyance, perceptual disturbances, and decreasing concentration, productivity, and executive [2].

Impairment of complex cognitive skills, such as reading, writing, and mathematics due to noise, can be attributed to the impairment of basic abilities such as working memory, attention, and inhibition, which are crucial for such tasks [3]. In children, because they have not yet fully developed the cognitive skills and adaptive strategies to counter the effects of noise, noise exposure can have long-term effects on health and school performance [4].
Despite the fact that World Health Organization-recommended limits for classroom acoustics have been established, many schools fail to meet them [5]. Even when efforts are made to improve the environment, it is difficult to reduce the effects of noise caused by student conversations and classroom activities. Therefore, it is essential that during the frontal lecture the classroom ensures clear understanding during the teacher's verbal interaction, while during individual student work it provides a quiet environment that promotes concentration, minimizing as much as possible the noise caused by other students' conversations so that it is not intelligible [6].

The results we had found were partially in line with the hypotheses that babble noise has negative effects on children's cognitive performance [7]. In fact, despite the use of a babble noise with the addition of transient events, which was expected to be more disruptive, improved performance under the noise condition in tests of attention and inhibition was observed [8].

In this study we report the results of a new campaign of administering tests to fourth graders performed in a counterbalancing manner to the noise conditions of the previous measurement campaign in order to confirm or not the hypothesis that the children may have developed more effective compensatory strategies due to their regular exposure to unfavorable noise conditions and in order to resolve the methodological shortcomings present in the previous study.

2. MATERIALS AND METHODS

2.1. Participants

A total of 92 fourth-grade children aged 9-10 years (mean age 9.45, 63.04% female) from four classes (A-D) of a primary school in the province of Padova, Italy, participated in the study.

Children were tested in the same period of two different school years. Two classes, A and B, in school year 2022-2023, and two classes, C and D, in school year 2023-2024). None of the children had been diagnosed with cognitive, learning, or sensory disabilities and all parents signed an informative consent for their children to participate in the study.

The study was approved by the Ethics Committee of the Human Inspired Technology Research Centre – University of Padova (protocol number 2020_92R1).

2.2. Acoustic and environmental measurements

Values of temperature, relative humidity, CO_2 concentrations and illumination are acquired while performing cognitive tests. Similarly, noise levels per second (L_{Aeq1s}) are also acquired using a Class 1 sound level meter.

Acoustic measurements were taken in each classroom under unoccupied conditions to determine Reverberation Time (RT), Speech Transmission Index (STI) and Ambient noise level with closed windows L_{Aeq} and RT and STI measurements are made following the guidance on source placement and microphone positions given in 11532-2 [9] and ISO 3382-2 [10].

2.3. Children's Cognitive measurements

Participants underwent neuro-psychological assessments using the CoEN App [11] to assess the primary cognitive functions: working memory, attention, and inhibition. In Table *1* the main characteristics of the tests administered are reported.

These tasks were performed during school hours, divided into two sessions: one carried out in a quiet environment and the other in the presence of noise. To mitigate the potential for a training effect, the two sessions were carried out at least 2 weeks apart.

The quiet condition simulated the usual acoustic environment of the classroom during individual tasks. The noisy condition replicated the background noise often encountered in classrooms, incorporating multitalker babble noise along with intermittent transient sounds (i.e., door slamming, knocking on the door, ambulance siren sound, etc.). The signal is emitted by a Talkbox positioned at the teacher desk, from which the sound power level in the reverberation chamber was measured by comparison with a reference sound source. This was done by performing 6 measurements at a distance of 50 cm arranged in a circular configuration, following the methodology outlined in ISO 3747 standard [12].

Table 1: List of cognitive tests administered to children and description of Executive functions (Efs) investigating.

Test	**Cognitive function (EFs)**	**Description of EFs**	**Type of check**
Digit Span Test (Forward and Backward)	Verbal working memory	Ability to hold verbal information in mind for short periods and utilize it effectively.	Number of correct responses
Visual Attention Test from NEPSY-II [13] and WISC-IV [14]	Selective attention	Ability to filter incoming information and focus attention solely on what is relevant to the task or goal.	Ratio Right / wrong responses
Cognitive Inhibition Task [15] (Congruent, Incongruent and Mixed)	Inhibition	Ability to control one's impulses, behaviors, or thoughts to adapt to demands.	Number of correct responses

3. RESULTS

3.1. Acoustic and environmental measurements

The classrooms of the school whose results are reported are located in an urban residential setting with low traffic intensity. In fact, from the measurements taken, an unoccupied school in ordinary condition of external traffic noise, an equivalent level, L_{Aeq}<30 dB(A) was observed.

By comparing RT and STI, with the octave band reference values given in UNI 11532-2, it was identified that no classroom meets the requirements of the standard. See Table 2.

Table 3 e Table 4 present the values of Sound Equivalent Level, SEL, calculated from the $L_{Aeq,1s}$ levels acquired during in the test sessions and the average values of the measured environmental parameters. The signal to recreate the noise condition is emitted with a sound power L_W=76.0 dB(A).

Table 2: Volume and values of measured Reverberation Time (RT) and Speech Transmission Index (STI) in classes.

Class	**Volume [m³]**	**RT [s]**	**STI**
A	142	1.55	0.56
B	140	1.36	0.54
C	140	1.55	0.55
D	140	1.54	0,54

Table 3: SEL values across acoustic conditions.

Class	**SEL [dB(A)]**	**SEL [dB(A)]**	**ΔSEL [dB(A)]**
	"Quiet"	"Noise"	
A	92.4	105.0	12.6
B	88.5	101.5	13
C	88.6	102.5	13.9
D	92.8	104.8	12

Table 4: Mean values and standard deviation of Temperature, Relative Humidity, CO_2 concentrations and Illuminance levels across acoustic conditions.

	Temperature [°C]		**Relative Humidity [%]**		**CO_2 concentrations [ppm]**		**Illuminance [lux]**	
Class	"Quiet"	"Noise"	"Quiet"	"Noise"	"Quiet"	"Noise"	"Quiet"	"Noise"
A	18.9 ±0.03	20.0 ±0.12	43.3 ±1.00	36.9 ±0.45	1865 ±197.79	1714 ±122.35	85 ±47.33	251 ±177.22
B	20.0 ±0.06	20.0 ±0.05	56.2 ±0.83	52.1 ±0.40	2479 ±239.16	1895 ±64.42	548 ±1088.40	455 ±191.08
C	15.5 ±0.33	21.0 ±0.54	68.8 ±1.58	67.1 ±1.92	1498 ±226.45	3480 ±229.4	185 ±30.07	303 ±124.10
D	18.1 ±0.43	19.7 ±0.57	71.3 ±1.82	68.6 ±1.87	4296 ±311.79	1498 ±71.1	386 ±272.91	218 ±42.47

3.2. Children's Cognitive measurements

In classes A and B, tasks were administered first in quiet in both classes and then with noise, whereas in classes C and D first in noise and then in quiet.

Observing the mean scores obtained, there was higher performance when administering the tests in the second session. This occurred with noise for classes A and B, and under quiet conditions for classes C and D. The order of test administration, mean value and standard deviation are reported (Table 5).

However, analyzing the results obtained in the tests by including all tested classes (A, B, C, and D) from the t-paired test showed no significant differences between the tests performed in quiet condition and in noise. P-value lower than 5% has been considered to evaluate the statistical significance level on the cognitive performance. See Table 6.

Table 5: Children's performance on the CoEN tasks across acoustic conditions – classes A and B and C and D.

	Classes A-B (n=43; 28 girls)				**Classes C-D (n=49; 24 girls)**			
	"Quiet"		"Noise"		"Quiet"		"Noise"	
Order of test administration	1st		2nd		2nd		1st	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Digit Span Forward	5.65	1.84	5.91	1.58	6.64	1.64	6.32	1.52
Digit Span Backward	5.29	1.96	5.53	2.12	5.98	2.01	6.13	1.81
Visual attention	13.16	13.59	18.29	8.73	18.51	11.81	14.60	8.81
Cancellation	18.92	15.04	26.87	9.44	25.91	8.95	21.43	8.92
Cognitive inhibition – Congruent	18.45	3.60	18.50	3.69	18.74	3.36	19.11	2.92
Cognitive inhibition – Incongruent	13.92	8.38	18.24	4.08	17.81	4.92	16.19	7.27
Cognitive inhibition – Mixed	15.47	4.55	16.45	4.45	17.36	2.90	17.47	2.81

*p<.05; **p<.01; ***p<.001

Table 6: Children's performance on the CoEN tasks across acoustic conditions – all classes

	(n=92; 52 girls)				
	"Quiet"		"Noise"		
Variable	Mean	SD	Mean	SD	*t*
Digit Span Forward	6.16	1.83	6.11	1.55	0.230
Digit Span Backward	5.66	1.99	5.82	1.97	-0.735
Visual attention	15.84	12.93	16.42	9.01	-0.447
Cancellation	22.25	13.09	23.45	9.41	-0.817
Cognitive inhibition – Congruent	18.55	3.48	18.82	3.32	-0.537
Cognitive inhibition – Incongruent	16.46	6.50	17.07	6.18	-0.813
Cognitive inhibition – Mixed	16.66	3.79	17.14	3.49	-1.504

*p<.05; **p<.01; ***p<.001

4. DISCUSSION

From the measured values of temperature, air humidity and illumination in the four classes, it is possible to see that the results are similar in the two acoustic conditions considered, so their effect in cognitive abilities can be neglected. However, by looking at the CO_2 concentrations, although high in each class and in both acoustic test conditions, it is possible to see a counterbalance between the two sessions in all classes.

In classes A and B, where both were tested first in quiet and then in noise, it has been observed that performance improves under noise condition. However, in classes C and D, where both performed first in noise and then in quiet, performance improved in quiet condition. The increased performance in the noise condition for classes A and B and in the quiet condition for classes C and D thus seems to be attributable to the increased familiarity with the tasks during the second session.

Analyzing the results overall by including all classes together, no significant differences emerged in any of the types of tests administered.

Comparing the results of this study with those obtained in the previous research [8], where the same methodology was used, but with the difference that the classrooms in the school analyzed had arrangements for acoustic improvement of the classrooms (RT=0.51s and RT=0.49s), we observe that the findings are consistent with a previous research [16]. In fact, in babble noise sessions, a worsening of the visual attention test and to a higher perception of cognitive fatigue was obtained among children [8].

Since no significant differences in performance between quiet and noise were observed in classes A, B, C and D despite the use of more disruptive noise (babble noise with intermittent transient noises) compared to a babble noise, and considering that the acoustic characteristics of the classrooms do not meet the standards required by regulations, unlike the classrooms analyzed in the previous study where a negative influence was found in the noise condition despite the use of babble noise, this suggests that contextual factors, as an RT outside the limits of compliance required by regulations, could play a role in modulating the impact of noise on cognitive performance. Prolonged exposure to unfavorable acoustic environments might have induced the development of compensatory mechanisms to mitigate noise disturbances.

The study provides interesting insights into the effects of noise on children's cognitive performance. While counter-balancing the acoustic conditions of test administration led to the observation that there were no significant differences between task performance in quiet or noise to task familiarity, it may indicate that the unintelligible nature of the signal may not be so disturbing as to induce a modification in performance.

One of the future prospects of this study will be to perform further analyses on the interindividual variability of the test subjects. Additionally, try to analyze the effects of different types of noise.

ACKNOWLEDGEMENTS

The authors are grateful to teachers and pupils of primary schools “Falcone e Borsellino” in the province of Padova for their collaboration.

This research work was funded by the 2014-2020 PON “Research and Innovation” 2014IT16M2OP005 and by the PRIN 2022 EQUALITY 2022PEL99F project.

REFERENCES

1. M. J. Jafari, R. Khosrowabadi, S. Khodakarim, F. Mohammadian, J. Jafari, and M. Farough, The Effect of Noise Exposure on Cognitive Performance and Brain Activity Patterns. *Public Health Access Macedonian Journal of Medical Sciences*, **7(17)**, 2924–2931, 2019, doi: 10.3889/oamjms.2019.742.
2. M. Basner et al. Auditory and non-auditory effects of noise on health. *Lancet*, **383(9925)**, 1325–1332, 2014, doi: 10.1016/S0140-6736(13)61613-X.
3. H. Jahncke, V. Hongisto, and P. Virjonen. Cognitive performance during irrelevant speech: Effects of speech intelligibility and office-task characteristics. *Applied Acoustics*, **74(3)**, 307–316, 2013, doi: 10.1016/J.APACOUST.2012.08.007.
4. B. M. Shield and J. E. Dockrell. The effects of environmental and classroom noise on the academic attainments of primary school children. *The Journal of the Acoustical Society of America*, **123(1)**, 133-134, 2008, doi: 10.1121/1.2812596.
5. K. Mealings. The effect of classroom acoustic conditions on literacy outcomes for children in primary school: A review. *Building Acoustics*, **29(1)**, 135–156, 2022.
6. D. Zhang, M. Tenpierik, and P. M. Bluyssen. Individual control as a new way to improve classroom acoustics: A simulation-based study. *Applied Acoustics*, **179**, 2021, doi: 10.1016/J.APACOUST.2021.108066.
7. R. A. Fernandes, D. C. G. M. Vidor, and A. A. de Oliveira. The effect of noise on attention and performance in reading and writing tasks. *CoDAS*, **31(4)**, 2019, doi: 10.1590/2317-1782/20182017241.

8. F. Gheller et al.. Effects of noise on the cognitive performance of primary school children. *Proceedings of the 10th Convention of the European Acoustics Association*. 2023, 1603–1610, 2024, doi: 10.61782/FA.2023.0498.
9. UNI. *Caratteristiche acustiche interne di ambienti confinati - Metodi di progettazione e tecniche di valutazione - Parte 2: Settore scolastico*. Standard 11532-2:2020, Ente Italiano di Normazione, 2020.
10. ISO. *Acoustics - Measurement of room acoustic parameters. Part 1: Performance spaces.* Standard 3382-1:2009, International Organization for Standardization, 2009.
11. https://apps.apple.com/no/app/coen/id1565953506
12. ISO. *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering/survey methods for use in situ in a reverberant environment.* Standard 3747:2010, International Organization for Standardization, 2010.
13. M. Korkman, U. Kirk, and S. Kemp. NEPSY-II: Clinical and interpretative manual. Giunti Psychometrics, Firenze, 2018.
14. D. Wechsler, A. Orsini, and L. Pezzuti. WISC-IV Wechsler intelligence scale for children. Florence, Italy: Giunti O.S. Organizzazioni speciali, 2012.
15. Diamond, W. S. Barnett, J. Thomas, and S. Munro. Preschool Program Improves Cognitive Control. *Science*, **318(5855)**, 1387-1388, 2007, doi: 10.1126/SCIENCE.1151148.
16. R. A. Fernandes, D. C. G. M. Vidor, and A. A. de Oliveira. The effect of noise on attention and performance in reading and writing tasks. *CoDAS*, **31(4)**, 2019, doi: 10.1590/2317-1782/20182017241.