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CHILDREN'S LISTENING PERCEPTION AND COGNITIVE PERFORMANCE AT SCHOOL

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ABSTRACT

Classroom acoustics and noise exposure significantly affect students' emotional, cognitive, and academic well-being, especially when they are not mother tongue or they suffer from auditory impairments. This study aims to investigate the specific contribution of the acoustic components on children's auditory and cognitive performance. Before the study, all participants underwent a comprehensive hearing screening to rule out any auditory impairments that could influence the results. Subsequently, children were exposed to two distinct acoustic conditions: a regular classroom with ambient noise and a classroom with artificially induced noise. Performance in both auditory and non-auditory tasks was assessed using a standardized battery of tests administered during the different acoustic conditions. Collected results, such as the number of errors and the response time, were statistically analyzed to compare children's reactions across these conditions, thus providing empirical evidence on the effects of noise on learning processes. The findings of this research can inform educational policies and school building design practice to create more effective and healthier learning spaces.

Keywords: *listening perception, cognitive performance, noise, classroom.*

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1. INTRODUCTION

Exposure to environmental noise has been increasingly recognized as a significant factor influencing children's auditory perception and cognitive development. Recent studies have highlighted that children are more susceptible than adults to the detrimental effects of noise, particularly in tasks involving speech perception and listening comprehension [1]. For instance, research indicates that background noise can severely disrupt children's ability to recall speech information and adversely affect reading skills [2]. Beyond auditory tasks, noise exposure has been linked to impairments in non-auditory cognitive functions such as short-term visual memory and reading comprehension [3]. Classroom environments with high noise levels and reverberation have been associated with poorer performance in verbal tasks among children. Additionally, chronic exposure to environmental noise, such as aircraft noise, has been consistently correlated with lower reading performance in children [3].
The impact of noise extends to attentional processes as well. Studies have shown that exposure to high noise levels can significantly reduce mental workload capacity and diminish both visual and auditory attention in children [1].
Furthermore, the type of noise plays a crucial role in its impact on cognitive performance [4]. Research suggests that while the noise level directly affects annoyance, cognitive performance is more dependent on the nature of the noise. This indicates that certain types of noise may be more disruptive to children's cognitive functions than others. For example Massonniè et al. 2019 [5], found that classroom noise, produced by different noise sources (e.g., different people talking at the same time, external events such as road traffic, as well as local tools and devices)

seems especially likely to capture attention, because it is heterogeneous and irregular. On the other hand speech perception is more influenced by classroom noise than background speech [6].
In this paper performance of children in both auditory and non-auditory tasks was assessed at school using a standardized battery of tests administered during different acoustic conditions. Collected results, were statistically analyzed to compare children's reactions across these conditions, thus providing empirical evidence on the effects of noise on learning processes.

2. METHODOLOGY

2.1 Classrooms acoustic criteria and children sample

An acoustic characterization of 8 classrooms in 4 different primary schools located in the North-East of Italy was carried out. The acoustic measurements were conducted in unoccupied classrooms, following a standard procedure. Three objective parameters, useful to evaluate the classroom acoustic quality, were measured: Reverberation Time (T_{20}), Clarity (C_{50}), and Speech Transmission Index (STI). The T_{20} was measured according to ISO 3382-2 [7] in three different positions for two sound source positions. The omnidirectional dodecahedron source emitted a sweep signal processed by the Odeon Room acoustic software. STI was measured using a a loudspeaker compliant with the requirements of IEC 60268-16 standard [8] signal, positioned in the center of the wall near the teacher's desk. The measurements followed the UNI 11532-2 guidelines [9][10] for the number and position of measurement points, with three positions in line with the talk box and one in the least favorable position. The clarity index C50 was measured at the same microphone positions as the STI, using a talk box source but with a sweep signal, which was then processed by the Odeon Room Acoustic software.
Reverberation time, clarity and Speech transmission Index are reported in Tables 1 and 2 for each classroom.

Table 1: T_{20} [s] in unoccupied room for each class in frequency [Hz].

Classroom	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz
De4A	1.96	1.52	1.53	1.51	1.38	1.16
De4B	1.86	1.60	1.80	1.62	1.49	1.22
DG3A	1.47	1.44	1.17	1.06	0.87	0.72
DG3B	1.05	1.03	0.58	0.49	0.50	0.51
Ma4A	0.84	0.90	1.08	1.19	1.21	0.96
Ma4B	0.83	0.83	0.99	1.03	0.97	0.80
Mo5A	0.57	0.52	0.51	0.45	0.46	0.45
Mo5B	0.65	0.48	0.45	0.52	0.55	0.51

Table 2: C_{50} [dB] and STI for each class in frequency [Hz]

	C_{50} [dB]						
Classroom	**125 Hz**	**250 Hz**	**500 Hz**	**1k Hz**	**2k Hz**	**4k Hz**	**STI**
De4A	-5.9	-4.2	-3.0	-2.1	-0.9	0.3	0.72
De4B	-5.1	-2.2	-2.4	-1.8	-0.3	1.3	0.74
DG3A	0.1	1.2	0.7	1.6	4.6	6.3	0.8
DG3B	2.0	3.0	5.6	7.2	9.1	9.4	0.88
Ma4A	3.2	3.3	1.0	0.6	1.8	3.2	0.79
Ma4B	3.0	4.2	1.5	1.6	2.7	4.5	0.8
Mo5A	3.8	7.8	8.9	8.5	8.9	9.9	0.9
Mo5B	3.6	8.6	10.5	9.3	9.5	10.6	0.9

In each school, two classes of the same grade participated in the experiments, with a total of 122 children subjected to the tests during the typical classroom noise campaigns (Ambient Noise) and 129 children during the induced noise campaigns (Induced Noise).
A summary of the children's characteristics, categorized by grade and campaign type, is presented in Table 3.

Table 3: Number of children participating per campaign type, divided by school grade.

		Ambient Noise		**Induced Noise**	
School grade	**Class**	**Children number**	**Girls [%]**	**Children number**	**Girls [%]**
3rd grade	**DG3A**	19	52.6	20	50.0
	DG3B	20	60.0	19	57.9
4th grade	**MA4A**	10	80.0	16	50.0
	MA4B	12	41.7	10	50.0
	DE4A	15	53.3	18	55.6
	DE4B	15	66.7	16	62.5
5th grade	**MO5A**	15	66.7	15	66.7
	MO5B	16	50.0	15	53.3

All subjects underwent medical hearing screening in order to identify and exclude in the analysis subjects with hearing impairments, At the beginning of the research, informed consent was collected from children's parents for their children to take part in the study. The research was

approved by the Ethics Committees of Iuav University of Venice in agreement with the Department of Neuroscience of the University of Padova (protocol number 92229 dated 08/11/2024).
Before each test session children were trained on each performance test.
At the end of each experimental campaign, children were asked to evaluate subjective cognitive effort due to the tests, using a child oriented five-point scale (1 = "not at all"; 2 = "a little"; 3 = "moderately"; 4 = "very"; 5 = "extremely"), [5, 11]. Cognitive effort was investigated through six questions immediately after each tests campaign. In the case of induced noise one specific question about the noise annoyance was added (Table 4). In the statistic analysis the average vote of questions 1 to 6 has been considered.

Table 4. Cognitive effort questionnaire statement and evaluation scale

Statement
1. Do you feel tired?
2. Do you have headache?
3. Were the games difficult?
4. Was it hard to pay attention?
5. Was it hard to understand words/numbers?
6. Was it hard to remember words/numbers?
7. Have you been bothered by noises?

2.2 Listening perception and cognitive tests

2.2.1 Listening span test

Listening Span Test assess verbal working memory through increased cognitive effort.
Theoretically, the test is based on the pioneering studies of Daneman and Carpenter [12] on working memory, which they describe as an active memory construct capable of maintaining and processing information, playing a crucial role in complex cognitive activities.
This assessment tool derives from the consideration that traditional short -term memory measures, such as digit span, have often appeared insufficient to predict children's performance in logical reasoning and written text comprehension [13]. The clinical tool introduced by Daneman and Carpenter (1980) combines the requirement to process verbal information presented either orally (Listening Span Test) or written form (Reading Span Test) with the need to recall specific fragments. Numerous studies highlight a strong correlation between high performance in verbal working memory tasks, particularly in the Reading Span Test (RST) and proficient written text comprehension and logical reasoning skills, a relationship that has been confirmed across different age groups and educational levels [13]. The contribution of this working memory measure lies primarily in its intrinsic complexity, which closely reflects the complexity of everyday learning tasks in the school setting. Additionally, it provides valuable indicators that reflect the key components of the test.
The clinical tool employed in this study is inspired by P. Palladino's Listening Span Test (2005) [15] and was adapted into a paper-based format for simultaneous administration in the classrooms. Children were instructed to listen to a series of sentences and to evaluate the truthfulness of each statement, by marking the designed true/false boxes. After listening to the entire set of sentences, they were asked to turn the page and transcribe the final word of each of the auditorily presented statements in the appropriate spaces. The first indicator considered was accuracy in evaluating the truthfulness of the statements. This measure, represented by the number of errors, provides insight into the efficiency of verbal processing of the ability and the ability to manage available cognitive resources.
Memory capacity was assessed using a second indicator, namely the total number of words recalled by each child.
By considering the validity and calibration indicators proposed by Palladino (2005), particularly in relation to mean and standard deviation, it was possible to calculate each participants' performance relative to their grade level. Therefore, the standard deviation of the resulting performance compared with the reference performance (medium target) was used as indicator in the statistical analysis.

2.2.2 Digit Span test

The test evaluates short-term verbal memory in children. The digit span is a subcomponent of the BVN-5-11 battery [16], a second-level clinical instrument for neuropsychological assessment in developmental age.
The test involves the immediate serial recall of a string of numbers. In the direct span task, the child is asked to remember the sequence of numbers in the exact order presented by the examiner.
Based on the direct number span test included in BVN-5-11, authors developed a paper-based adaptation suitable for simultaneous administration in a classroom

setting. Children were instructed to listen carefully to prerecorded sequences of numbers and write them in the designated boxes on the protocol sheet, maintaining the correct order as pronounced by the examiner.
The results were analyzed according to the reference standards of the BVN 5-11 battery. Specifically, the raw score and child's age were used to determine the standardized deviation, based on a normative mean of 100 and a standard deviation equal to 15. The distance from the mean, expressed in standard deviation, indicates the gap between the children's performance and the expected performance for their age. By convention, a score that falls at or below two standard deviations from the expected mean is considered clinically significant and may indicate a weakness in the assessed ability. In the statistical analysis the final score is used to investigate the influence of noise on the performance.

2.2.3 Visual-spatial attention test

According to Baddeley (2010) [17], working memory is a cognitive system that enables the temporary storage and manipulation of information, allowing individuals to understand and mentally represent their surroundings, to retain information from their experiences, acquire new knowledge, to solve problems and establish relationships in order to achieve specific goals (Baddeley and Logie, 1999) [18]. The visuospatial component of working memory plays a crucial role in the performance of mathematical tasks, notably number line estimation, counting, and problem solving. Additionally, it contributes to text comprehension (Borella and De Ribaupierre, 2014) [19] and underpins geographical knowledge (Giofrè, Mammarella, and Cornoldi) [20].
To assess visuo-spatial memory capacity in the sequential format, the subcomponent "memory of sequential matrices" of the BVS-Corsi-2 battery, adapted from Giofrè and Cornoldi (2013) [21] was used. Each child, divided into two shifts, was given a tablet displaying a 5x5 of 25 cells. Inside some cells, the symbols X appear in sequence, starting from the minimum number of two. After the presentation, the child was asked to recall and select the cells where Xs had appeared, in the correct order.
The first level consisted of a sequence of two Xs, with the possibility of advancing to more complex levels, up to a maximum of seven Xs, if the child answered two consecutive trials correctly at the previous level.
Before starting the test, the examiners ensured that the children understood the instructions and practiced example. The scoring was recorded automatically by the software, considering means and standard deviations based on the child's reference age, rather than grade level. This decision aligns with the authors' perspective, as there is no evidence to suggest that performance is linked to formal education or level of learning achieved.

Table 5: Summary of the tests performed by children and performance indicator used for the results analysis.

Test type	Cognitive Function	Type of Check	Performance indicator
Listening Span	Verbal working memory	Number of correct true/false responses	Score standard deviation
		Number of correct recalled words	Score standard deviation
Digit Span	Verbal working memory	Number of correct responses	Calculated score
Visual-Spatial attention test	Visual-spatial working memory	Number of correct responses	Calculated score

2.3 Classroom acoustic monitoring during tests

Each pair of classes per school was subjected to the performance tests under the typical noise condition, and, at least two weeks later, under induced noise. During typical noise, tests were performed using the auditory signal was emitted by one speaker located at the teacher's desk, at 65 dBA at one meter from the emitter, In the second case, the signal was fixed at 70 dBA, and two additional speakers at the back of the classroom emitted an induced noise at 65 dBA (measured at one meter distance), The induced noise was a composite sound of the 'classroom noise' type, including stimuli such as passing cars, lawnmowers, unintelligible voices, running water, dog barking, bells, ambulance sirens, etc. Each sound had a duration ranging from 8 seconds (e.g., for coughs) to 30 seconds (e.g., lawnmowers), with 30-second intervals between sounds. They were recorded at a sampling rate of 96000Hz, 24-bit resolution, and stereo channels, and saved in WAV format.
For the Visual spatial short-term memory test (Corsi test), the induced stimulus involved intelligible stories narrated by children. During all campaigns, equivalent levels were measured at the center of the classroom using the Class 1

sound level meter, Nti XL2). The measured values during each experimental campaign are reported in the Table 4.

Table 6: Sound Pressure Level (LAeq) at the center of the classroom during the experimental campaigns.

Classroom	**LAeq [dBA]**	
	Ambient Noise	**Induced Noise**
MA-4A	72.4	69.1
MA-4B	76.2	72.5
DE-4A	72.3	70
DE-4B	70.7	70.7
DG-3A	73.5	74.6
DG-3B	71.3	70.5
MO-5A	63.4	66.6
MO-5B	64.5	62

2.4 Data analysis

The average performance indicators of each panel were correlated with the acoustic conditions of the classrooms. First a correlation analysis was carried out to test whether the sound pressure level is correlated with the investigated listening and cognitive performance. The Pearson coefficient, ρ, was used to this purpose. Then, when the correlation coefficient was higher than 0.25, a regression analysis was performed to represent the relation between the indoor acoustic condition (i.e. the equivalent sound pressure level, LAeq during the test session) and the performance indicator (i.e. the mean indicator of the panel). A significativity level of maximum 5 % was considered to assess the goodness of the model. Statistical analysis has been replicated for both the noise conditions, namely the ambient noise and the induced noise.

3. RESULTS

3.1 Tests carried out in Ambient Noise

Statistical analysis shows the influence of the Equivalent sound pressure level measured during the tests on the results of the Listening Span test, the Visual-Spatial attention, and the Cognitive Effort expressed by subjects. In Table 7 the Pearson coefficient, ρ, the slope, s, the p-value and the coefficient of determination, R^2, of the regressions between the equivalent sound pressure level and the performance indicator for each test are reported. Pearson coefficient was used to assess the strength of the correlation between LAeq and tasks performance and effort. A probability of 95 % was applied to identify those situations in which the cognitive performance and cognitive effort were significantly influenced by noise in the classroom.

Table 7: Statistical analysis: Pearson correlation coefficient, ρ, slopes, s, p-value and coefficient of determination, R^2, of the regressions.

Test type	**ρ**	**s**	**p-value**	**R^2**
Listening Span (T/F)	-0.29	-0.0228	0.007*	0.09
Listening Span (words)	-0.79	-0.2736	0.000*	0.61
Digit Span	0.07	-	-	-
Visual-Spatial attention	-0.91	-0.3608	0.000*	0.82
Cognitive effort	0.29	0.0503	0.000*	0.57

Figures 1a to 1d report the regressions curves between the LAeq measured in each test campaign in ambient noise and the panel average of the performance indicators of each performance test only when a significant influence of the sound pressure level on the indicator was verified with a 95 % of probability.

Regarding listening span test (Figures 1a and 1b), both the indicators are significantly correlated with the sound level, but while the true/false test has a poor coefficient of determination and a small regression slope, the recalled words test has a good coefficient of determination (> 0.6) and a discrete slope thus showing that the noise is more impacting on the verbal long working memory than the verbal short memory.

Regarding the Digit Span test, the influence of noise on the test results is not statistically significant. However, some procedural flaws occurred since children put in action some strategies to overcome memory deficiencies.

The Visual attention task is significantly correlated with the noise level, with a high coefficient of determination and a quite high regression slope. The higher the noise, the lower the average score reached by the panel (Figure 1c).

Finally, the cognitive effort increases with the increasing of the noise with a fair coefficient of determination but a small slope value (Figure 1d).

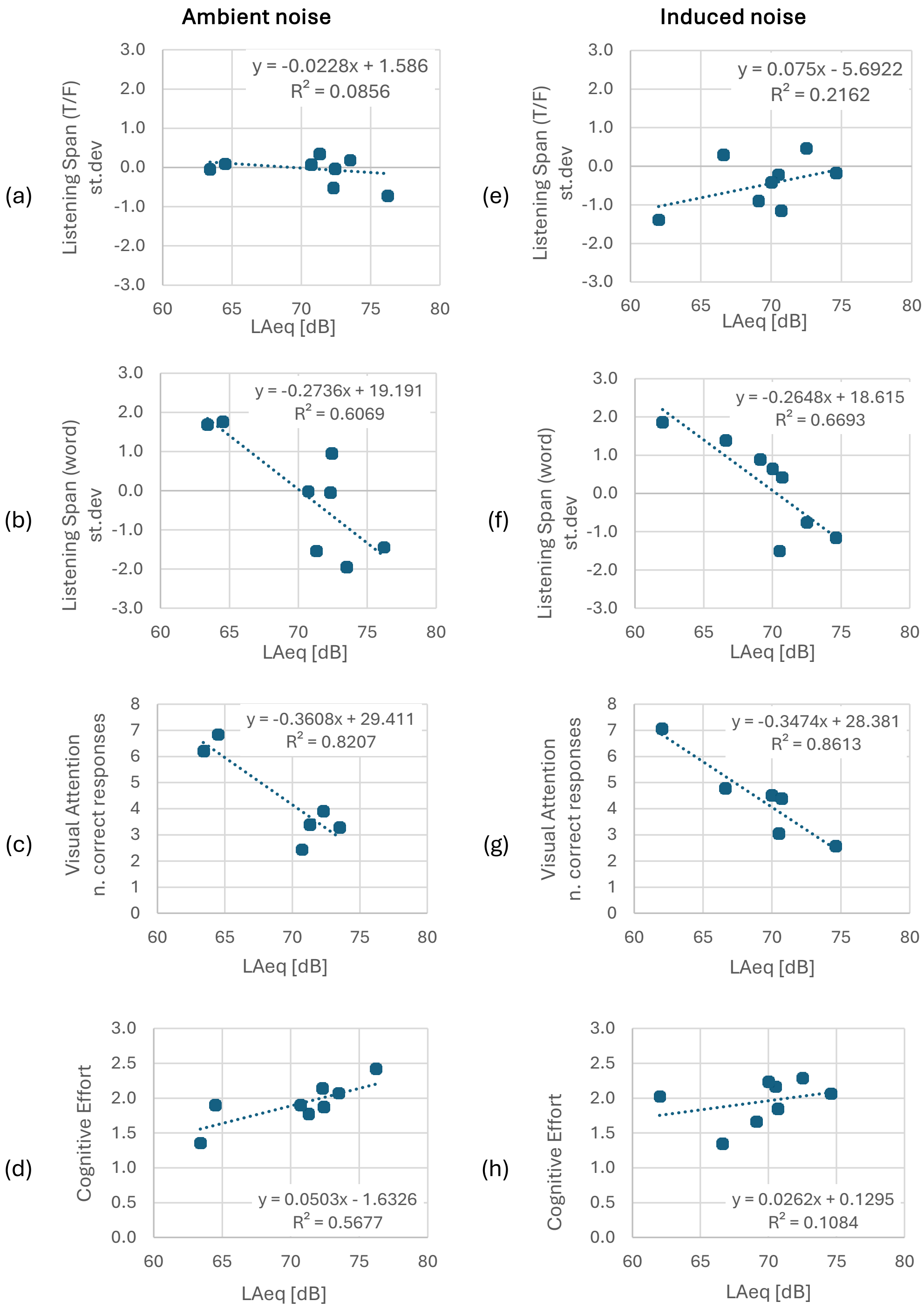

Figure 1: (a, b, e, f) Listening Span test: regressions between the standard deviation and LAeq during the tests; (c, g) Visual attention: regressions between number of correct responses and LAeq during the tests; (d, h) Perceived cognitive effort vs LAeq.

3.2 Tests carried out in Induced Noise

In Table 8 the correlation coefficient, slope, the p-value and the coefficient of determination of the regressions are reported, in order to determine the correlation between the Equivalent sound pressure level and mean cognitive performance and the perceived effort. Statistical analysis shows a significant influence of LAeq measured during the test on all the cognitive tasks, except for Digit Span Test, as seen for the ambient noise analysis.
Figures 1e to 1h report the results of the regression analysis between the LAeq measured in each test campaign in ambient noise and the average of the performance indicators of each performance test are reported only when a significant influence of the sound pressure level on the test result has been verified with a 95 % of probability.
Regarding listening span test (Figures 1e and 1f), both the indicators are significantly correlated with the sound level, but while the true/false test has a poor coefficient of determination and a small regression slope, the recalled words test has a good one (> 0.65) and a discrete slope thus showing that the noise is more impacting on the verbal long working memory than the verbal short memory.
Regarding the Digit Span test, the influence of noise on the test results is not statistically significant.
The Visual attention task is significantly correlated with the noise level, with a high coefficient of determination and a quite high regression slope. The higher the noise, the lower the average score reached by the panel (Figure 1g).
Finally, the cognitive effort expressed by children presents a p-value lower than 0.05 but the R^2 and the slope of the regression curve are very low (Figure 1h).

Table 8: Pearson correlation coefficient, ρ, slopes, s, p-value and coefficient of determination, R^2, of the regressions.

Test type	ρ	s	p-value	R^2
Listening Span (T/F)	0.46	0.075	0.000*	0.22
Listening Span (words)	-0.82	-0.265	0.000*	0.67
Digit Span	0.06	-	-	-
Visual-Spatial attention	0.90	-0.347	0.000*	0.86
Cognitive effort		0.026	0.000*	0.11

4. CONCLUSION

The statistical analysis highlights the influence of both the types of noise on verbal and visual working memory, as well as on the cognitive effort.
However, no significant effect is shown for the Digit Span test. This result could be ascribed to the ability of children in applying strategies to remember the numbers, thus compromising the effectiveness of the test in assessing the influence of the acoustic condition on the cognitive ability.
Moreover, the regression analysis shows a quite high coefficient of determination for the Listening Span Test and the Visual-Spatial Attention test, suggesting a quite strong correlation between noise and ability of children in tasks performing.
The cognitive effort is also significantly influenced by the noise level even though an increment of 10 dB determines a small increment of the perceived effort.
The comparison between the two types of noise, the ambient and the induced ones, shows that their level have similar influence on children performance, despite the differences in the composition.
Further analysis should be done to understand if the distribution of the performance of each panel is similar under the two tested conditions: in particular a pairwise analysis of each panel would contribute to understand the differences in the effects of the two types of noise proposed in this study.

5. ACKNOWLEDGMENTS

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