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EFFECTS OF NOISE ON THE COGNITIVE PERFORMANCE OF PRIMARY SCHOOL CHILDREN

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ABSTRACT

The acoustic environments of classrooms are often non-compliant with the existing normative or recommendations. Noisy environments can not only affect children's listening abilities but also lead to a decline in cognitive performance. This study presents preliminary results on how background noise can influence primary school children's cognitive processes. CoEN (Cognitive Effort in Noise) app was developed and used to assess children's cognitive effort using standardized neuropsychological tests. Children attending two primary schools were tested in their classroom environment under two acoustic conditions: quiet and noise. Performance was also correlated with acoustic environmental measures and with a self-report questionnaire on perceived cognitive effort. The preliminary findings only partially support the hypothesis that noise negatively impacts cognitive performance. Noise was found to negatively affect children's performance on attention tasks in the first school, while in the second school, children performed better in noise on both attention and inhibition tasks. Unlike the first school, the second school had a reverberation time that did not meet regulatory standards. These initial findings suggest interesting hypotheses and directions for future research. At the same time, they reveal some weaknesses in the experimental protocol that need to be addressed to further investigate the hypotheses that have emerged.

Keywords: *classroom noise, cognitive performance, acoustic measurements, children*

1. INTRODUCTION

The effects of noise have been widely examined in terms of auditory perception and listening effort.

Listening effort, in particular, can be defined as the attention and cognitive resources necessary to overcome obstacles while performing a listening task. It can be assessed through various methodologies, including self-report, behavioral, and physiological measures [1].

Instead, the impact of noisy environments on cognitive performance and brain activity has often been neglected [2]. However, during the last decade, the non-auditory consequences of noise exposure have been shown to also involve cognition [3]. These effects include annoyance, perceived disturbance, as well as impairments in concentration, productivity, and executive functioning [4].

Given that executive functions (EFs) are higher-order cognitive skills that allow for top-down control and regulation of thought processes and associated actions [5], they are crucial for learning processes. Therefore, exposure to noise could have a ripple effect on learning activities and outcomes. The impact of noise on complex cognitive abilities such as reading, writing, and math can be ascribed to the impairment of underlying subcomponent skills such as working memory (WM), attention, and inhibition, which are essential for these tasks [6].

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In children, in particular, exposure to noise can have lifelong consequences on health and academic outcomes. Children are, in fact, among the most sensitive to noise, not having fully developed cognitive skills and coping strategies to contrast its effects [7]. During the first years of life, children begin to develop the ability to ignore distractions, but their EFs are still not fully developed [8-9]. Their auditory pathway maturation is not yet finished and their phonological processing skills have not yet been fully achieved [10]. As a consequence, children are more sensitive to noise-induced interference than adults, in both auditory and non-auditory tasks [11].
Moreover, a large part of their learning occurs in complex and unfavourable acoustic conditions. Classrooms are almost always noisy environments, due to external noise sources, such as traffic and outdoor play areas, as well as internal noise sources, such as noise from chairs being moved or children talking. Classroom noise may have significant negative effects on children's academic performances [12].
The World Health Organization [13] recommends the following limits for classroom acoustics: 35 dB(A) for background noise and 0.6 s for reverberation time. However, schools and classrooms often fail to meet these acoustic standards [14] and even when attempts are made to improve the environment, they hardly ever mitigate the effects of background noise caused by children's chatter and classroom activities.

The primary objective of this study is to address certain gaps in the existing literature. While numerous studies have highlighted the harmful impacts of noise exposure on classroom performance, there remains no consensus on the type of noise that causes the most disruption to academic tasks [11]. Moreover, past research has primarily focused on the impact of noise on academic skills [15], with only a limited number of studies investigating its effects on cognitive functions [16]. As such, this study aims to investigate the effects of different types of noise on a set of verbal and nonverbal executive functions.
Children's cognitive performance is assessed both in quiet and noise conditions through a set of non-auditory tasks and is evaluated in relation to perceived cognitive effort and classroom acoustic environmental measures.
The following results are the preliminary findings from the data collected up to this point.

2. METHODS

2.1 Participants

Seventy-four fourth graders attending two Italian public primary schools located in the province of Padua were involved in this study.
- School A: two classrooms, 31 children (18 female), mean age 9.2 yrs ± 0.4 yrs
- School B: two classrooms, 43 children (28 female), mean age 9.1 yrs ± 0.4 yrs

None of the children had been diagnosed with cognitive, learning, or sensory disabilities, as reported by the class teacher. The schools share similarities in terms of outdoor noise conditions, as they are situated in similar low-traffic residential areas. In addition, the socioeconomic characteristics of the two areas are comparable.
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 Materials and procedures

2.2.1 Acoustic Measurements

All acoustic measurements were conducted in unoccupied classrooms, following the standards. Reverberation Time (RT) and Speech Transmission Index (STI) were measured, as they are the two objective parameters commonly used to assess the acoustic quality of classrooms. RT was measured in accordance with the normative ISO 3382 [17] at three different positions in each classroom for both sound source locations. The mean values of the six RT measurements were compared with the normative data in the frequency of 250, 500, 1000 and 2000 Hz. In addition, RT values corresponding to a conventional room occupancy of 80% were estimated based on the empty-room RT measurements (following the UNI 11532-2 standard [18]).
The STI measurement was carried out using a talkbox placed on the teacher's desk. These measurements were conducted in unoccupied classrooms during school closures, to determine whether or not the classrooms comply with the normative references.
The initial measurements followed the UNI 11532-2 guidelines for the number and placement of measurement points, which involved selecting three positions in a line at the talkbox, with one point located at a distance of 1 meter and one in the least favorable position. Furthermore, in School B, the measurement protocol included the measurement of the STI index on all desks in the classroom.

During the administration of cognitive tests in the classroom, the equivalent continuous sound level (LAeq,1s) was measured. And finally, the equivalent sound level (SEL) values were calculated for each class under both conditions.

2.2.2 Children's Cognitive Measurements

The cognitive abilities of the children were evaluated using an iOS application called "CoEN - Cognitive Effort in Noise" [19].
The app was developed by a research team from the University of Padua and Venice and uses game-like activities to test verbal WM, visual attention, and cognitive inhibition. CoEN consists of five tasks, including adaptations from standardized neuropsychological tests, such as the Digit Span Test (Forward and Backward), a visual attention test from the WISC-IV (cancellation subtest), a visual attention test from the NEPSY-II (visual search of faces), a Reading Span Test, and the Cognitive Inhibition Task, adapted from Diamond et al. [20].
The Digit Span Test evaluates verbal WM by requiring the child to recall a series of digits in either the same (forward subtest) or reverse order (backward subtest), as they are pronounced by the examiner. In the CoEN version of the test, the digits are presented visually on the screen, with the child typing the series of digits in direct (forward span) or reverse (backward span) order on a keyboard.
The Visual Attention Test (NEPSY-II) is a visual-search task where the child is required to identify target faces from a page (displayed on the tablet screen in CoEN) that also contains distractors. The test is timed and must be completed within three minutes [21].
The Cancellation Test (WISC-IV) is a task similar to the NEPSY-II visual attention test, but it has a shorter duration. The child is required to identify and mark targets (i.e., animals) among various stimuli within a time limit of 45 seconds [22].
The Reading Span Test [23] is used to test the ability to simultaneously hold and manipulate information in WM. It involves presenting children with a series of sentences and then asking them to recall the final word of each sentence.
The inhibition task [20] is used to evaluate the inhibitory control. The test involves displaying a red heart or a flower on either side of the tablet screen. The child must touch the arrow that appears on the same side as the heart (congruent condition) or on the opposite side when a flower appears on the screen (non-congruent condition).
The tests were administered during school hours to all children in the classroom. The children performed the cognitive tests in two assessment sessions of 30 minutes, one in quiet and the other in noise. Reaction time and accuracy in cognitive tasks were recorded through the app.
To minimize any potential learning effects, CoEN was administered with a minimum two-week interval between the two trials. In school A, the order of the task condition was counterbalanced across children. This was not possible in school B due to organizational issues, and both classes performed the tests in quiet during the first trial and in noise during the second trial.
The quiet condition was characterized by the classroom's natural acoustic environment, with noise levels being carefully controlled by instructing the children to remain as quiet as possible. Furthermore, the children were given detailed instructions before the test in order to encourage them to remain quiet while taking the tests.
A multi-talker babbling was used for the noise condition, to study the effects of ambient noise that is similar to the typical background noise in classrooms.
The following signals were introduced into the classroom using a talkbox placed on the teacher's desk:
- School A: multitalker babble noise [24]
- School B: multitalker babble noise plus some transient noises (i.e., door slamming, knocking on the door, ambulance siren sound, etc.)

At the end of the testing session, a self-report questionnaire based on the Bess et al. fatigue scale [25] was administered to the children to assess their cognitive effort during the tasks.

3. RESULTS

3.1 Acoustic measurements

- School A

The reverberation time was measured in both classrooms and the average values obtained were 0.51 and 0.49 seconds, respectively. These values were found to be in accordance with normative standards.
The average STI values were measured in both classes and found to be 0.70 and 0.74, respectively. These values are considered good when compared to the standard scale of values (ISO 9921) [26].

- School B

The average values of the RT measured in both classrooms were found to be 1.55 and 1.36 s, respectively. In this case, both classes have values that exceed the regulatory limit, for each of the analyzed frequencies.
The average STI values for both classes were found to be acceptable when compared to the standard scale of values (ISO 9921), with 0.56 and 0.54, respectively.

The measured RT values in empty classrooms and the estimated optimal RT values, considering 80% occupancy, are summarized in Table 1 for School A and Table 2 for School B.

Table 1 Measured Reverberation Time (RT) values in both classes (RT-1 and RT-2) and tolerance interval for the optimal RT at different frequencies - School A.

	School A				
Freq [Hz]	Optimum RT [s]	Optimum RT (superior) [s]	Optimum RT (inferior) [s]	RT-1 [s]	RT-2 [s]
125	0.53	0.76	0.34	0.58	0.58
250	0.53	0.63	0.42	0.50	0.51
500	0.53	0.63	0.42	0.46	0.44
1000	0.53	0.63	0.42	0.55	0.48
2000	0.53	0.63	0.42	0.52	0.51
4000	0.53	0.63	0.34	0.47	0.45

Table 2 Measured Reverberation Time (RT) values in both classes (RT-1 and RT-2) and tolerance interval for the optimal RT at different frequencies - School B.

	School B				
Freq [Hz]	Optimum RT [s]	Optimum RT (superior) [s]	Optimum RT (inferior) [s]	RT-1 [s]	RT-2 [s]
125	0.52	0.75	0.34	2.25	1.75
250	0.52	0.62	0.42	1.80	1.41
500	0.52	0.62	0.42	1.48	1.39
1000	0.52	0.62	0.42	1.37	1.35
2000	0.52	0.62	0.42	1.30	1.23
4000	0.52	0.62	0.34	1.07	1.05

The calculated values of the equivalent sound level (SEL) are provided below. See Table 3

Table 3 Sound Equivalent Level (SEL) values for each classroom (SEL-1 and SEL-2) in each school, measured in both noisy and quiet conditions.

	School A		School B	
	SEL-1 [dBA]	SEL- 2 [dBA]	SEL-1 [dBA]	SEL- 2 [dBA]
"Quiet"	83.3	77.6	92.4	88.5
"Noise"	92.9	93.4	105.0	101.5

3.2 Children's Cognitive Measurements

Due to technical issues, the inhibition test data could only be analyzed for School B.

- School A

The paired t-test results showed that in the noise condition, children performed significantly worse on the Cancellation Test ($t=1.704$, $p<0.05$) and reported higher levels of cognitive fatigue ($t=-2.408$, $p<0.05$) compared to the quiet condition. See Table 4

Table 4 Children's performance on the CoEN tasks across acoustic conditions - School A

School A (n=31; 18 girls)					
	"Quiet"		"Noise"		
Variable	**Mean**	**SD**	**Mean**	**SD**	***t***
Digit Span Forward (accuracy)	6.04	1.40	6.15	1.89	-0.259
Digit Span Backward (accuracy)	5.27	2.05	5.85	1.29	-1.364
Reading Span (accuracy)	2.00	1.69	2.23	1.97	-0.507
Visual attention (accuracy)	14.69	9.75	11.65	17.41	1.194
Cancellation (accuracy)	26.42	10.71	22.69	10.74	1.704*
Cognitive Effort Self Report	1.73	0.57	2.10	0.69	-2.408*

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

- School B

Data analysis showed significant differences between the quiet and noise conditions in the visual attention ($t=-2.382$, $p<0.05$; $t=-3.426$, $p<0.001$) and inhibition ($t=-3.295$, $p<0.01$) tasks, with better scores observed under the noise condition. See Table 5

Table 5 Children's performance on the CoEN tasks across acoustic conditions - School B

School B (n=43; 28 girls)					
	"Quiet"		"Noise"		
Variable	**Mean**	**SD**	**Mean**	**SD**	***t***
Digit Span Forward (accuracy)	5.65	1.84	5.91	1.58	-0.851
Digit Span Backward (accuracy)	5.29	1.96	5.53	2.12	-0.569
Reading Span (accuracy)	2.03	1.66	2.24	1.71	-0.879
Visual attention (accuracy)	13.16	13.59	18.29	8.73	-2.382*
Cancellation (accuracy)	18.92	15.04	26.87	9.44	-3.426***
Cognitive inhibition – Congruent (accuracy)	18.45	3.60	18.50	3.69	-0.071
Cognitive inhibition – Incongruent (accuracy)	13.92	8.38	18.24	4.08	-3.295**
Cognitive inhibition – Mixed (accuracy)	15.47	4.55	16.45	4.45	-1.593
Cognitive Effort Self Report	1.67	0.46	1.73	0.58	-1.083

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

4. DISCUSSION

The results were only partly in line with the hypothesis that babble noise has negative effects on children's cognitive performance. In the first case (school A), a worsening of the visual attention test and a greater perceived cognitive fatigue by children under noisy conditions were found. Performance in a visual task can be compromised by noise because the attention demands of the visual task are partially redirected from relevant visual information and

reallocated to the auditory signal, resulting in disruption of the task. This result is consistent with prior studies suggesting that babble noise can significantly affect attention in children [27].
Other findings, however, were not in line with those just described. Despite the initial expectation that the noise used in school B, which included transient noises, would be more disruptive for the children, the results showed the opposite effect. Specifically, a significant improvement in performance was observed under noise conditions for both visual attention and inhibition tasks.
This result could be in line with the theory of stochastic resonance, which suggests that the presence of noise in a nonlinear system can enhance the quality of the output signal compared to when no noise is present [28]. This phenomenon can be applied to a range of physiological systems and, for example, noisy (stochastic) stimulation can be associated with an improvement in cognitive functions [29]. The addition of a randomized amount of noise can activate additional cognitive resources and lead to improved attentional performance, particularly in individuals with attention deficits and/or attention deficit hyperactivity disorder (ADHD) [29-30].
It should be noted, however, that when discussing stochastic resonance, white noise or noise with similar characteristics is the most commonly studied form, whereas, in our study, we used babble noise.
The results obtained at the second school might also suggest that contextual factors may have a modulating effect on the impact of noise on cognitive performance.
The reverberation time values were significantly different between the two schools. School A had a sound-absorbing ceiling and showed values that corresponded to the standard, while school B had much higher reverberation times that fell outside the normative range.
Given that a higher reverberation time in a classroom can increase the perceived noise level, a possible hypothesis is that differences in classroom acoustics between the two schools may have contributed to the different responses to noise observed in the study. It is possible that due to regular exposure to poorer acoustic conditions compared to school A, children in school B may have developed more effective compensatory strategies to deal with noise.
This hypothesis is tentative, and its strength remains to be determined. Other factors, such as the type of noise and the baseline cognitive abilities of the children, may have also influenced the results observed. It is plausible that a child's ability in a cognitive task under optimal conditions could influence the type and extent of any disruptive effect that a factor like noise might have on performance.
And, above all, it is important to note that this preliminary study had methodological differences between the two schools that could have impacted their respective results. The main difference was that in school A, the two conditions of quiet and noise were counterbalanced for the two classes, while in school B, both classes always completed the tests first in quiet and then in noise. Although there was a minimum gap of two weeks between each test, it is possible that the children were more familiar with the tasks during the second trial, which could have provided an advantage to the children in both classes of school B during the tests conducted under noisy conditions.
These preliminary findings provide interesting directions for future research.
However, there were some weaknesses in the experimental protocol that need to be addressed and corrected in future evaluations.
In order to further investigate the hypotheses that emerged from these initial findings, it is crucial to establish a clear causal relationship between the effects observed and either noise or room acoustics. One way to achieve this is by always counterbalancing the two acoustic conditions. Additionally, it would be valuable to evaluate the children's baseline cognitive abilities in a noise-free environment and subsequently analyze the impact of noise on groups of children with comparable performance levels.
Furthermore, exploring different types of noise, such as synthesized signals with various physical characteristics, would provide valuable insights into the effects of noise on cognitive performance.

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