# COGNITIVE EFFORT IN SCHOOL-AGED CHILDREN

**Chiara Visentin**[1,2*] **Matteo Pellegatti**[1] **Nicola Prodi**[1]

[1] Department of Engineering, University of Ferrara, Ferrara, Italy

[2] Institute for Renewable Energies, Eurac Research, Bolzano, Italy

## ABSTRACT

Sustained cognitive demands from effortful listening may compromise the well-being and learning of school-aged children. It is well-assessed that performing a speech perception task in challenging acoustic conditions (e.g. presence of background noise, too much reverberation) increases the children's effort, due to the need for exploiting additional cognitive resources. However, less is known about the effects of such unfavorable listening conditions on effort concerning tasks that better resemble actual learning activities, and rely on domain-specific skills.

This study aimed to investigate the effect of listening conditions on cognitive effort (behavioral and subjective) in primary school children concerning maths. A total of 121 children aged between 8 and 11 years performed a math facts task in quiet and in the presence of a two-talker noise (signal-to-noise ratio: +1 dB). Individual inhibitory skills and noise sensitivity were also assessed in quiet, on the account that they might influence the effect of the listening conditions on the task.

Results will help in understanding the mechanisms underpinning effort in school-aged children, thus promoting the acoustic design of more inclusive spaces and informing intervention strategies.

**Keywords:** *classroom acoustics, cognition, math, effort*

[1]****Corresponding author***: *chiara.visentin@eurac.edu.*

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## 1. INTRODUCTION

Everyday communication in classrooms takes place in the presence of concurrent noise, mainly generated by the students themselves (e.g., voices, movements), whose dynamical behavior strongly impacts the acoustic quality of the classroom [1]. One of the most challenging conditions for school-aged children is when the teacher's message is masked by informative noise (i.e., a masker composed of a small number of speech streams). The negative impact is due to developmental effects of cognitive abilities, and selective attention in particular [2]. Evidence exists concerning the loss in performance when children perform a speech recognition task [3,4], but less is known about the effect on more cognitively complex tasks, such as mathematics. Given the relevance of the competencies in numeracy for life chances and job opportunities, it seems sensible to investigate the effect of background noise in classrooms on maths performance.

Depending on the level and spectro-temporal features, noise is expected to impact task accuracy (i.e., number of correct answers) and/or listening effort (i.e., allocation of mental resources to overcome obstacles in goal pursuit when carrying out a listening task [5]). The latter can be measured using physiological (e.g., pupillometry), behavioral (e.g., response time), or subjective (e.g., questionnaires) measures, and depends on two interlinked dimensions: cognitive demands (e.g., acoustic condition, individual differences in cognitive abilities) and listener's motivation [6].

The present study investigated whether individual differences in cognitive abilities and noise sensitivity relate to the impact of background noise on a math task, concerning task accuracy and listening effort.

## 2. MATERIALS AND METHODS

The experiment was presented to 121 primary school students (grades 3 to 5, age range: 8-11 years), from 10 classes of three schools in Ferrara (Italy).

The children completed a math task, consisting of three sets of 20 math facts. Math facts are number combinations for addition, subtraction, multiplication, and division that children should know by heart and recall within a few seconds to help them complete higher-order mathematical operations more quickly (e.g., 50+50, 4x7). For each trial of the task, participants listened to the voice of a female talker saying the problem, then three possible answers appeared on their tablets and they were asked to select the right answer. Accuracy and response time (RT) were recorded for each trial.

The math task was completed in two listening conditions, reproduced via headphones: quiet (only target speech, no background noise was added), and two-talker noise presented at a signal-to-noise ratio (SNR) of +1 dB. The listening conditions were obtained by auralization, and simulated the aural environment of a primary school classroom (volume: 256 $m^3$) with a reverberation time (T30) of 0.73 s, complying also in the octave band distribution with the Italian standard on classroom acoustics (UNI 11532-2). For both listening conditions, the speech level was set to 60 dB(A). The order of the listening conditions was counterbalanced across the students of each grade.

At the end of each listening condition, children were asked to rate their perceived effort in completing the task by using a visual analog scale.

In a separate, silent session taking place one week after the experimental task, the children completed a measure of inhibitory control (adaptation of a go/no-go task, presented in the auditory domain) and a questionnaire for the self-rating of the noise sensitivity (reduced version of the Weinstein Noise Sensitivity Scale [7]).

Generalized linear mixed-effects models were used to test changes in the dependent variables across conditions and interactions with children's individual characteristics (inhibitory control, noise sensitivity, grade). The presence of significant differences was further investigated by using pairwise comparisons (Bonferroni correction for multiple comparisons).

## 3. RESULTS

Concerning task accuracy, there was a significant difference between listening conditions ($\chi^2(1)=15.02$, $p <$ 0.001) and grade ($\chi^2(2)=12.75$, $p = 0.002$). In particular, the number of correct responses was higher in quiet (M 0.82, SD 0.17) than in noise (M 0.76, SD 0.19), and for older (grade 5: M 0.89, SD 0.09) compared to younger (grade 3: M 0.73, SD 0.17; grade 4: M 0.77, SD 0.17) students. No significant effect of the other individual characteristics was found.

Concerning RT, included as a behavioral measure of effort, the statistical analysis indicated a significant effect of listening condition ($\chi^2(1)=9.33$, $p = 0.002$), grade ($\chi^2(2)=12.13$, $p = 0.002$), and inhibitory control ($\chi^2(1)=3.84$, $p = 0.046$). Response times were longer in noise (M 2986 ms, SD 737 ms) than in quiet (M 2888 ms, SD 740 ms), and for younger compared to older students (grade 3: M 3282 ms, SD 493 ms; grade 4: M 2955 ms, SD 662 ms; grade 5: M 2639 ms, SD 598 ms). Moreover, RTs were longer for children with better inhibitory control.

Concerning subjectively perceived effort, the same significant effects as for RT were found: listening condition ($\chi^2(1)=14.23$, $p < 0.001$), grade ($\chi^2(2)=16.38$, $p < 0.001$), and inhibitory control ($\chi^2(1)=3.96$, $p = 0.042$). Children perceived more effort in the noisy condition (M 50.4, SD 37.1) compared to quiet (M 40.0, SD 37.3). Younger children (grade 3: M 60.4, SD 40.0; grade 4: M 48.9, SD 36.6) found the task more effortful than older children (grade 5: M 25.5, SD 28.7). Finally, children with better inhibitory control gave higher ratings of effort in both listening conditions.

## 4. DISCUSSION

### 4.1 Effects of noise on task performance

The results showed that the presence of noise has a significant effect on task accuracy and listening effort. The finding aligns with previous research on the effect of noise on math tasks involving mental arithmetic [3,8]. It is worth noticing that evidence exists that also support there is no impact of noise on mathematical performance [9,10], and even a positive impact [11,12]. These differences might be explained by the level of background noise, its phonological/semantic features, and the presence of salient events capable of redirecting the listeners' attention. Differences in the effect of noise might be prompted also by the characteristics of the task, including its difficulty [8] and presentation modality (visual or auditory domain). This manifold scenario indicates that more work needs to be done to understand the impact of noise on math skills, with a specific focus on tasks and noises that children might perform/encounter in everyday situations.

### 4.2 Effects of individual differences

The present findings suggest a significant relationship between our measures of listening effort (response time, perceived effort) and inhibitory control of attention. The relationship did not depend on the listening conditions. In both measures of effort, children with better inhibitory control experienced higher listening effort. Even though the finding might seem counterintuitive, it is possible that only listeners with sufficient resources not engaged in the task (e.g., listeners with a high inhibitory control) can experience an increase in effort during acoustically challenging conditions. Indeed, this view is supported by studies on children of the same age performing a dual task [13] or a passage comprehension task [14].

On the contrary, no significant effect of self-reported noise sensitivity on math performance was found. Even though only a few studies investigated the relationship between noise sensitivity and cognitive performance, the effects seem to depend on the task. For instance, for university students in open-plan environments, it was found that noise sensitivity interacts with the effects of noise on a writing task [15] but not in a collaborative task [16]. Concerning younger students (10-13 years), it was found that higher noise sensitivity was related to increased perceived effort in two-talker noise compared to quiet when performing a sentence comprehension task [17].

### 4.3 Study limitations and future directions

The only cognitive ability included in the study is inhibitory control of attention. Whereas the choice was based on previous literature studies, other executive functions could also impact the effect of listening conditions on the task. Working memory, divided attention, and higher-level executive functions (e.g., planning, reasoning, cognitive flexibility) might provide additional insights into the effects of noise on children's performance.

This study focused on noise interference in math tasks in children who are typically developing. Different results might be obtained for children with special educational needs (e.g., with hearing impairments, L2 learners), whose speech perception is known to be differentially negatively affected by non-adequate acoustic conditions [3]. Future studies could specifically target this population aiming to design inclusive learning environments.

## 5. ACKNOWLEDGMENTS

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