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EVALUATING NOISE-RELATED STRESSORS IN AN ITALIAN SCHOOL: ALIGNING ACOUSTIC ENVIRONMENTS WITH THE NEEDS OF NEURODIVERGENT STUDENTS

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ABSTRACT

Some neurodivergent students may be particularly sensitive to noise in school environments, making acoustic conditions an important factor for their well-being. While sensitivity varies among individuals, certain repetitive or high-intensity sounds can be particularly distressing. One such sound is the ringing of the school bell, which can act as a potential acoustic stressor for some students. This study examines whether school environments accommodate the sensory needs of autistic students by analyzing the impact of school bells. A literature review identified how such auditory signals affect neurodivergent individuals. Based on these findings, real-world school environments were evaluated by measuring the frequency and intensity of school bells. The analysis assessed whether these sound levels exceeded recommended thresholds. The results highlight the acoustic challenges posed by school bells for neurodivergent students and others sensitive to noise, providing insights for more inclusive educational environments.

Keywords: acoustic comfort; inclusive design; school environment; special needs; building acoustics.

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1. INTRODUCTION

Inclusive educational environments must consider the sensory sensitivities of neurodivergent students [1]. While not all neurodivergent students are sensitive to sensory stimuli, some may experience heightened sensitivity to auditory inputs, which can make classrooms challenging spaces for learning and social interaction [2]. Among these environmental factors, acoustic elements play a significant role in shaping the classroom experience. For some neurodivergent students, processing certain sounds can be particularly difficult, making it essential to understand how noise impacts their ability to focus and engage with peers. In fact, sensory sensitivities in many neurodivergent individuals can lead to discomfort and hinder performance, with the classroom environment often being a primary source of stress [3].

Research indicates that noise levels and sound quality in educational settings significantly influence cognitive performance, stress levels, and overall student well-being [4-5]. For neurodivergent students, who may experience sensory hypersensitivity [6-7], loud and repetitive sounds—such as the ringing of a school bell—can be especially distressing. Noises over 50 dB(A) [8] have been shown to compromise cognitive performance, increase anxiety, and reduce concentration, all of which interfere with learning activities. These stressors can have long-lasting effects, making it harder for students to re-engage in classroom activities. Additionally, sensory overload may impede communication and participation in group work.

Despite studies examining the effects of background noise on learning [8-9], limited research has specifically addressed the impact of school bells. Unlike other sudden noises, the school bell is a recurring, intentional signal designed to mark transitions

during the school day. However, its volume, duration, and frequency may create significant challenges for neurodivergent students, especially in environments with high reverberation [10-12]. The predictable nature of the school bell does not mitigate the stress caused by its sharp, intrusive tone. The cumulative effect of these sounds throughout the day can lead to sensory overload, making it difficult for neurodivergent students to remain engaged and focused [13].
This study aims to address this gap by systematically analyzing the acoustic properties of school bells in elementary classrooms. By evaluating factors such as bell placement, environmental absorption, and frequency of exposure, this research seeks to understand the potential stress-inducing properties of school bells.

The findings from this research contribute to a broader understanding of inclusive classroom design and highlight the importance of acoustics in fostering educational equity. By incorporating acoustic considerations into school design, institutions can create environments that support the diverse sensory needs of all students, leading to better engagement, comfort, and academic success. Ultimately, this research emphasizes the need for schools to account for the sensory experiences of neurodivergent students, advocating for environments that promote inclusion and academic achievement.

2. MATERIALS AND METHOD

This section presents the different scenarios that will be simulated, detailing the sound source considered for the analysis. Subsequently, the model calibration process will be described, based on sound pressure level measurements to ensure accuracy and reliability in the simulations.

2.1 Environment and Scenarios

This study considers elementary school classrooms in Northern Italy. To replicate typical classroom conditions during lesson hours, this study first analyzed classrooms in both open-door and closed-door conditions. This approach allowed for an evaluation of how different door positions influence noise propagation and potential stress factors for neurodivergent students with auditory sensitivity:

- Door open: Opening the door introduces additional noise from hallways or adjacent spaces, creating variations in the acoustic environment that may impact students' sensory experiences and concentration.
- Door closed: In this scenario, the classroom is acoustically more isolated from external noise sources, but internal reverberation may still be a significant factor affecting sound clarity and overall noise levels.

Two distinct acoustic conditions were considered:

- Scenario 1: A classroom with no specialized acoustic treatment, where sound reverberates for a longer duration, leading to increased noise levels and reduced speech intelligibility. Such conditions can make it particularly challenging for neurodivergent students with auditory sensitivity to process information clearly, potentially increasing stress and hindering learning.
- Scenario 2: The same classroom, but with the addition of sound-absorbing materials UNI 11532-2 standards [14].

By considering both reverberant and sound-absorbing scenarios, as well as open- and closed-door conditions, these considerations could provide an analysis of how the daily and often adopted conditions of school environment could influence classroom acoustics and impact students' sensory experiences.
To simulate all the scenarios and the room conditions, several simulations were performed to analyze the impact of every small change in the room acoustic. The results of the model calibration for the simulation are shown in Fig. 1.

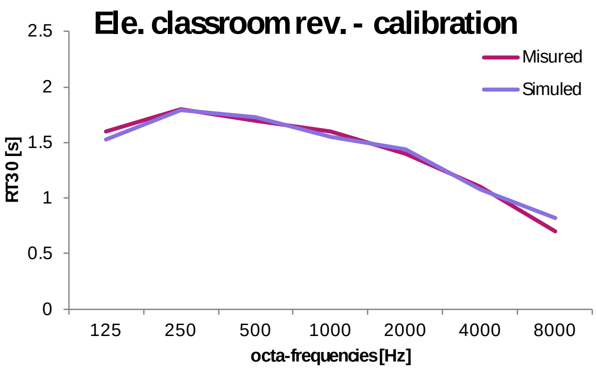

Figure 1. Model calibration for simulation

2.2 Sound Sources

The primary sound source analyzed in this study was the mechanical school bell, a standardized model commonly used in Italian elementary schools. The school bell was chosen as the focal point for this study since it is a recurrent and predictable acoustic event that can impact students' multiple times during the school day.
The bell could often be the source of stress for neurodivergent students, as its sudden and sharp tone can trigger anxiety, disrupt concentration, and create a sense of sensory overload [15]. Understanding its impact in different acoustic environments is key to improving classroom design and supporting neurodivergent students.

2.3 Model Calibration and Sound Pressure Levels

Sound pressure levels of the ringing bell were measured using a sound level meter positioned one meter from the source in a semi-reverberant field (Fig.2). Room reverberation time was assessed following UNI EN ISO 3382 guidelines [16].

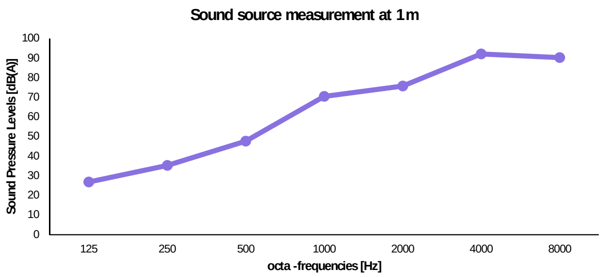

Figure 2. Sound pressure levels of the ringing school bell measured at 1m from the source.

A 3D acoustic simulation model was developed, with sound-absorbing materials implemented in Scenario 2 and without in Scenario 1.
The sound-absorbing properties were assigned using the software's database.

The sound-absorbing material used for the "absorptive" configuration included:

- Polyester fiber covered with an acoustically transparent membrane, placed in square panels of 1.2 m x 1.2 m dimensions.

The certified laboratory sound absorption coefficient is as follows (Fig. 3):

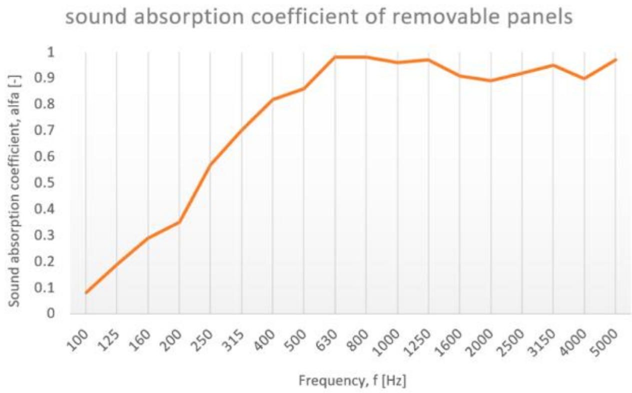

Figure 3. Sound absorption coefficient

3. RESULTS AND DISCUSSION

3.1 Sound Pressure Levels

Fig. 4 shows the variations in sound pressure levels under different conditions (open-door and closed-door) across the two acoustic scenarios (reverberant environment – Scenario 1 and environment with sound-absorbing materials – Scenario 2).
The simulated sound levels of the school bell revealed that its peak intensity exceeded 50 dB(A), surpassing the threshold associated with cognitive stress in learning environments [8]. Furthermore, the school bell exhibited a broad frequency spectrum, with high-frequency components that may be particularly discomforting for neurodivergent individuals with auditory sensitivity.

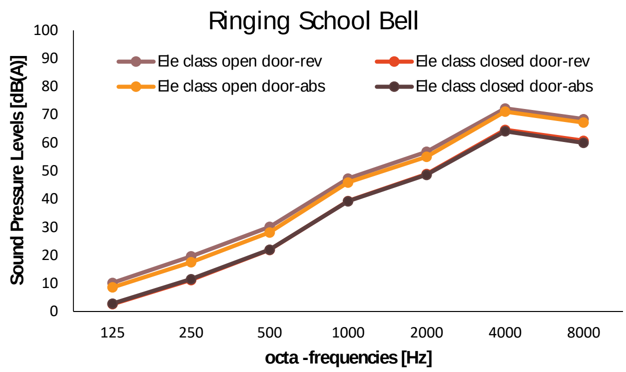

Figure 4. Sound Pressure Levels of the ringing school with opened and closed door in reverberant condition (Scenario 1) and with absorption materials (Scenario 2)

The equivalent noise levels in Tab.1 clearly show that the noise produced by the school bell in Scenario 2, where sound-absorbing materials are applied, is significantly reduced

compared to Scenario 1, where the environment remains reverberant. Specifically, the sound pressure levels in Scenario 2 are consistently 8 dB(A) lower than in Scenario 1, regardless of whether the door is open or closed.
In this specific case, the variation between the open-door and closed-door conditions does not show a significant difference in sound levels, as both scenarios in Scenario 2 result in a sound level of 66 dB(A), compared to the higher values observed in Scenario 1. This indicates that the acoustic treatment in Scenario 2 effectively mitigates the impact of the bell's noise, providing a more favorable auditory environment. However, this reduction is not sufficient to reach the 50 dB(A) threshold identified in the literature [8], which is associated with cognitive stress and potential disruption to learning.

Table 1. Equivalent noise levels for each scenario and each condition of the door (opened/closed)

	Scenario 1 - rev	Scenario 2 - abs
Opened Door	74 dB(A)	66 dB(A)
Closed Door	73 dB(A)	66 dB(A)

3.2 Acoustic Mapping

2D sound pressure level maps were generated to visualize noise distribution in different classroom setups (Fig. 5 – Fig. 8). Results indicated that bell placement and environmental acoustics strongly influenced perceived noise levels. Classrooms with sound-absorbing materials in Scenario 2 demonstrated lower peak values and reduced reverberation, mitigating the disruptive effects of the bell.

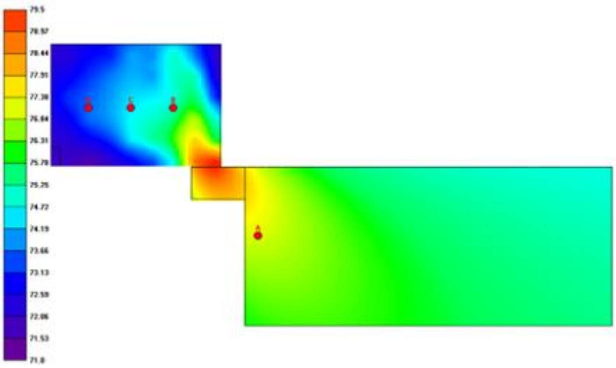

Figure 5. 2D Map of the school ringing propagation in reverberant classroom (Scenario 1) with opened door

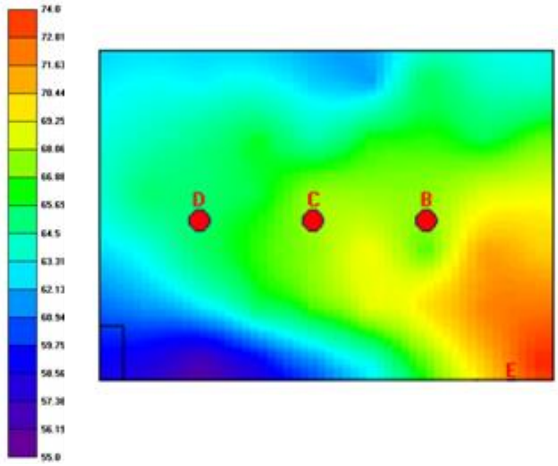

Figure 6. 2D Map of the school ringing propagation in reverberant classroom (Scenario 1) with closed door

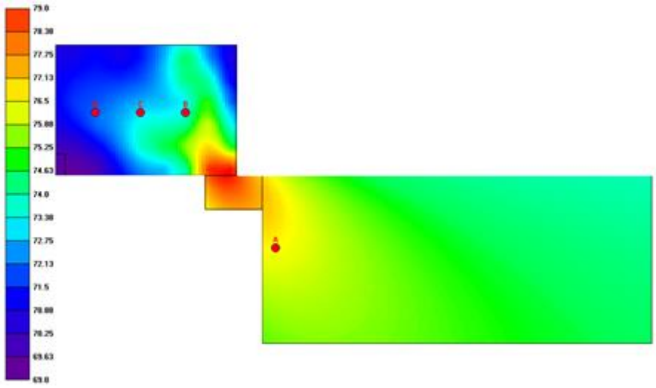

Figure 7. 2D Map of the school ringing propagation in classroom with absorption materials (Scenario 2) with opened door

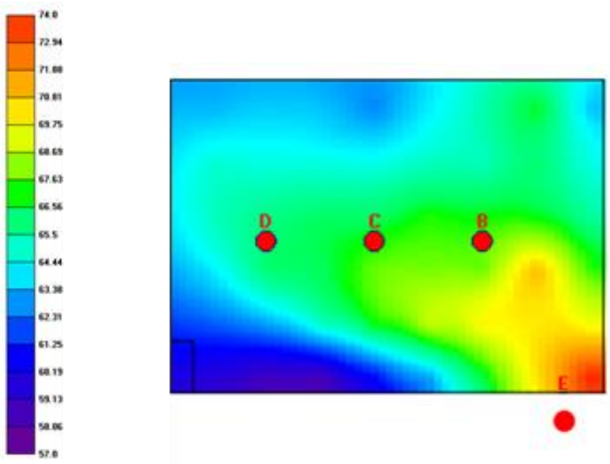

Figure 8. 2D Map of the school ringing propagation in classroom with absorption materials (Scenario 2) with closed door

3.3 Implications for Classroom Design

The findings confirm that the school bell, while necessary for daily operations, is a significant auditory stressor for autistic students. Unlike sudden noises caused by classroom activities, the bell's repetitive nature compounds its impact, leading to heightened anxiety and difficulty in re-engaging with learning tasks [17].

Reverberation plays a crucial role in amplifying the bell's disruptive effects (Tab. 1). In highly reverberant environments (Scenario 1), the prolonged decay of sound could increase discomfort, as neurodivergent individuals may struggle to filter out residual noise. Conversely, classrooms with appropriate acoustic treatments (Scenario 2) exhibited a marked reduction in stress-inducing sound reflections.

Alternative signaling methods present a viable solution to mitigate stress. Research suggests that multimodal signaling—such as combining lower-intensity auditory alerts with visual indicators—can improve response times without overwhelming sensory processing. Schools adopting flexible and customizable notification systems may better accommodate diverse student needs.

Behavioral strategies can further enhance noise management. Providing advance warnings before bell activation allows students time to prepare, reducing the element of surprise. Additionally, school-wide awareness initiatives educating staff and students on sensory sensitivities can foster a more inclusive learning environment.

4. CONCLUSIONS

This study highlights the ringing school bell as a potential stressor in elementary school environments, particularly for autistic students. Adjusting volume levels, optimizing acoustic design, and integrating alternative signaling methods can mitigate its disruptive effects. Future research should explore the long-term impact of modified bell systems on student well-being and academic performance.

Findings suggest practical strategies to mitigate the impact of the school bell on autistic students:

- Volume Reduction: Adjusting the bell's volume to levels below 50 dB(A) may significantly reduce auditory stress[8].
- Alternative Signaling: Using visual cues (e.g., flashing lights) or directional sound sources can provide effective alternatives.
- Bell Placement: Positioning bells away from classrooms with neurodivergent students minimizes exposure.
- Acoustic Treatments: Installing absorptive panels in hallways and near bell sources may dampen excessive noise propagation.

5. AKNOWLEDGEMENT

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