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EFFECT OF SOUNDS ON COGNITION: A COMPARISON BETWEEN CLASSROOM AND LABORATORY

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Abstract

Research on the impact of environmental quality on cognitive performance is frequently conducted in laboratory settings. However, findings can differ significantly from those obtained in real-world environments. This study compares outcomes from two experiments, involving students aged 11 to 14 years. The former experiment was conducted inside a students' classroom, while the latter in a laboratory environment. Both experiments investigated the effect of sound stimuli on calculation abilities. Two main effects emerged. First, children performed better in the laboratory probably thanks to a reduction in distractions compared to the regular classroom setting. This was further facilitated by working in smaller groups and by the fact that the laboratory experiment was consistently conducted after the classroom experiment. Secondly, the effects of the sound stimuli depended on the setting, likely due to an interaction with undetected personal characteristics. Overall, the findings show discrepancies between the two settings highlighting the limited ecological validity of the laboratory and illustrating the importance of minimising lab-field differences when investigating this particular age group.

Keywords: *Students, Lab-Dilemma, Acoustics, Calculation*

1. Introduction

The literature demonstrates how Indoor Environmental Quality (IEQ) affects students' performance within the classroom. While conducting experiments directly in the classroom represents the choice with the highest ecological validity, it is not always feasible, particularly when specific environmental parameters, such as those related to thermo-hygrometric conditions or air quality, require strict control. In such instances laboratories are the typical alternative, with efforts made to recreate an environment as similar as possible to the real-world setting. Nevertheless, a discrepancy regarding human behaviour will always exist between the real-world setting and the laboratory; this phenomenon is termed the "lab-dilemma" [1], [2]. This behavioural discrepancy arises from the inherent impossibility of reproducing every element of the real environment within a laboratory setting. For instance, in the case of school classrooms, factors such as noise from corridors or adjacent rooms, as well as specific lighting conditions, are difficult to recreate and affect results in a way which is difficult to predict. Furthermore, in the case of children in classrooms, variations in occupancy numbers, such as working in small groups or individually, can lead to peculiar behaviour and performance outcomes between laboratory and field conditions. For example, Ref. [3] identified that working individually leads to improved memory skills in students due to a reduced number of distractions compared to the classroom environment.

Despite the interest shown in the literature, few studies have investigated how the effect of environmental parameters, especially acoustic ones, changes between the classroom and the laboratory for school-aged students. Therefore, this study aims to answer the following research question:

- Does a laboratory environment change the effect of sound stimuli on calculation for school-age children, compared to a classroom setting?

This paper will compare the results obtained from two experiments conducted with the same group of participants: one in the classroom [4] and one in the laboratory [5].

2. Methods

2.1 Participants and locations

A total of 229 students (aged 11–14 years; M = 12.8, SD = 1.4; 47% female) participated in the field experiment, which was conducted within their classrooms. Five schools in the Province of Bolzano, Italy, took part in the study.

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A total of 197 students from the same cohort participated in the laboratory experiment. This experiment was carried out in the Façade System Interaction Lab of Eurac Research (Façade System Interactions Lab - Eurac Research) [6], [7]. This facility was selected for its capability to modify façade configurations to simulate a classroom windowed façade as closely as possible, as well as for the feasibility of controlling indoor thermo-hygrometric parameters and air quality via the HVAC system. In both experiments the participation was on a voluntary basis, and legal guardians of the students signed an informed consent. In the present work, only students participating in both experiments were included (n = 118).

2.2 Measurements

Students completed an arithmetic task using tablets via the online platform Gorilla.sc [8]. Participants were required to determine whether a series of arithmetic equations were true or false. In total, students responded to 24 equations per experimental condition. Accuracy and response time of each equation were recorded during the experiment. The order of the experimental blocks was counterbalanced across participants. The experiment in the classroom setting started in November 2022 and ended in January 2023, while the laboratory experiment was conducted in May 2023.

2.3 Testing conditions

During the arithmetic task, students were exposed to four auditory conditions, namely mechanical ventilation noise, playground noise (children playing in the school courtyard), birdsongs and quiet (classroom/laboratory background noise). All sound stimuli, except quiet, were recorded using binaural techniques and reproduced via headphones at a sound pressure level of 47 dBA. Participants in the laboratory experiment were divided into two groups. Group 1 performed the task under good air quality (CO_2 800 ppm), while Group 2 under poor air quality (CO_2 2000 ppm).

2.4 Data Analysis

In the present work, the data-cleaning and analysis procedures applied in Refs. [4], [5] are not reported for the sake of brevity; readers are referred to the respective publications for a complete description of the cleaning criteria. The statistical analysis of the data collected indicated that the air quality did not influence the students' performance; therefore, its effect [5] was not considered in this work. Statistical analyses will be reported with reference to response time only, as results of studies [4], [5] showed that the acoustic condition did not influence the accuracy outcomes. As a first step, the results of the two experiments were compared based on descriptive statistics (Fig. 1). This comparison suggested shorter response times in the laboratory setting and a different pattern of listening condition effects across locations. Specifically, in the classroom setting, shorter response times were observed in the playground condition and longer times in the mechanical ventilation condition, whereas the opposite pattern was observed in the laboratory. Then, this trend was verified by fitting a Generalised Linear Mixed-effect Model to the data, in which response time was investigated as a function of the listening condition, test setting (Classroom; Laboratory), and their interaction. Participants were included in the model as a random effect. This initial model was then extended by including the available personal factors of the students, such as noise sensitivity and gender, as additional interaction terms, in order to explore whether they could further explain the observed variation in the effects of the listening conditions across test settings but did not converge. Finally, the participants were divided into two groups based on their performance in the quiet condition. This was based on the hypothesis that a differing trend between the two settings indicates the presence of personal characteristics that could modify the affective response across the different settings. The difference between the median response times in the classroom and laboratory settings was calculated for each participant. Students with a difference lower than the overall median were assigned to Group A, whereas the remaining participants were assigned to Group B. A generalised linear mixed model was then developed, incorporating test setting, auditory condition except quiet, Group, and their corresponding two-way and three-way interactions.

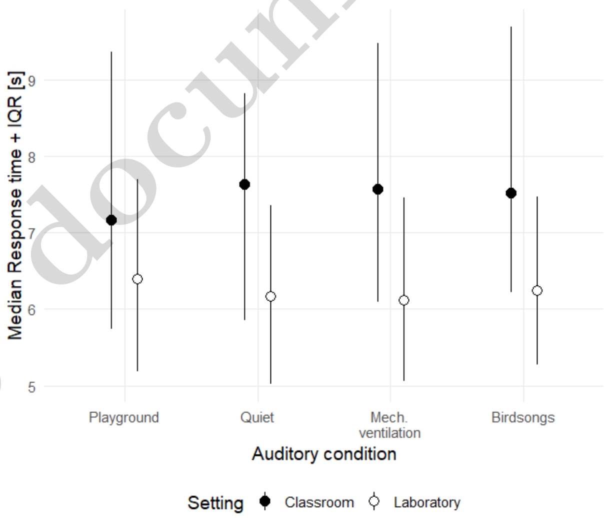

Figure 1. Comparison of the results of the classroom and laboratory experiment for each acoustic condition (Playground, Quiet, Mechanical Ventilation, Birdsongs). Dots represents median values across participants and bars the interquartile range.

3. Results

The initial model run revealed a significant main effect of the setting ($\chi^2(1) = 577.88$, $p < 0.001$) and a significant interaction between the auditory conditions and the setting ($\chi^2(3) = 17.07$, $p < 0.001$). Post-hoc pairwise comparisons, adjusted using the Benjamini–Hochberg correction for multiple comparisons, were performed to probe this interaction. Effect sizes were calculated only for significant comparisons as Cohen's d. Within the classroom setting, the analysis revealed a significant difference between the playground and mechanical ventilation conditions, with students demonstrating faster response times in the former ($z = 3.28$, $p = 0.003$, $d = 0.11$). Furthermore, students were significantly faster in the laboratory than in the classroom across all listening conditions (all ps < 0.001). The statistical details for the comparisons between settings under fixed auditory conditions are summarised in Table 1. Notably, an inversion in the trend of how auditory conditions affected response times was observed: the playground condition led to the fastest responses in the classroom setting, whereas it resulted in the slowest responses in the laboratory.

Table 1. Results of the comparison of the settings for each Auditory condition. For each condition, response time was shorter in the laboratory setting

Auditory condition	z	p. value	Cohen' d
Quiet	13.03	< 0.001	0.434
Playground	8.96	< 0.001	0.312
Mechanical Ventilation	14.86	< 0.001	0.505
Birdsongs	11.20	< 0.001	0.378

Concerning the second analysis, the model revealed a significant effect specifically for the three-way interaction ($\chi2(2) = 11.38$, $p = 0.003$). Consequently, new models were constructed for each subgroup; for each subgroup, Generalised Linear Mixed-effect Models were fitted, in which response time was analysed as a function of acoustic condition, setting (laboratory, classroom), and their two-way interaction. For Group A, the model revealed an interaction effect between the setting and the acoustic condition. Specifically, the results indicated that in the classroom setting, students had faster response times in both the playground and birdsong conditions compared to mechanical ventilation. As regards the laboratory, opposite results were identified. Students were slower in the playground condition compared to mechanical ventilation. The comparison at fixed acoustic conditions highlighted faster responses in laboratory for the playground and birdsongs. For Group B, only the main effect of setting was significant with faster responses in the laboratory compared to the classroom. A graphical summary of the result trends for Groups A and B is provided in Figure 2.

4. Discussion

Two primary effects emerged from the analysis: children performed better in the laboratory setting, and two distinct groups (Group A and Group B) were identified as having divergent trends across acoustical conditions. The enhanced laboratory performance can likely be attributed to reduced distractions due to working in smaller groups [3]. Specifically, smaller group sizes minimise distractions caused by peers finishing tasks earlier, as fewer individuals move around and visually disrupt the participant. Furthermore, ambient noise levels under these conditions were significantly lower. Moreover, since students participated in the laboratory experiment after the classroom session, a potential learning effect cannot be ruled out.

Regarding the second finding, children were divided into two groups based on their performance in the quiet condition, under the premise that personal traits might influence sound perception relative to the setting and thereby affect overall performance. The results supported this categorisation: Group A showed varying effects of sound stimuli depending on the setting, whereas Group B demonstrated no significant differences within the same location, but only between different locations. While this study merely identified the effect of a hypothetical personal trait associated with these performance patterns, the nature of this effect suggests it may depend on how the trait modulates students' baseline arousal across settings. Indeed, sound stimuli have the potential to alter arousal levels, and the relationship between performance and arousal typically follows an inverted U-shape [9]. Consequently, variations in baseline arousal could interact with both the environmental context and the auditory stimuli. This interaction could position the combined arousal state either closer to or further from the optimal peak described by the Yerkes–Dodson law, thereby leading to enhanced performance at the peak, or performance decrements the further arousal deviates from it. Nevertheless, this remains a speculative interpretation, given that direct measurements of physiological arousal were not conducted in the present study. Consequently, the initial baseline arousal level results in differing performance outcomes. These findings appear to fully align with the well-known lab-dilemma [1], as the environment seems to interact with personal traits, thereby altering results when moving from real-world to laboratory settings.

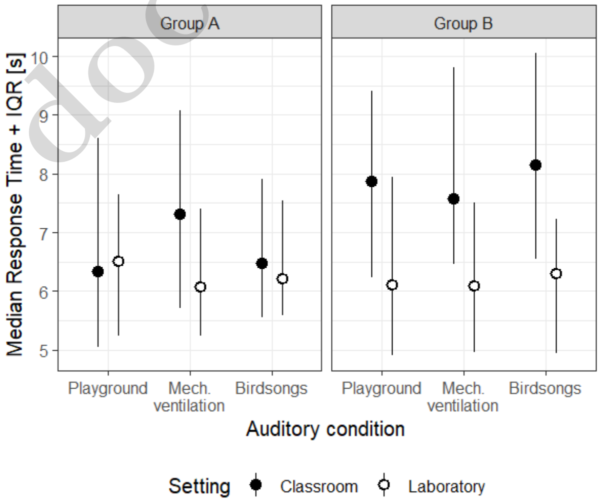

Figure 2. Comparison of the results of the classroom and laboratory experiment for the two groups (A and B) and for each acoustic condition (Playground, Quiet, Mechanical Ventilation, Birdsongs). Dots represent median values across participants and bars the interquartile range.

5. Conclusion

This study evaluated outcomes by comparing an *in-situ* classroom (field) experiment with a laboratory trial. The findings revealed that responses were consistently faster in the laboratory, owing to a reduction in distractions which likely improved overall performance. Additionally, personal traits, which typically influence performance independently, might even interact with the physical setting, further modifying students' responses to sound stimuli. Future laboratory studies should pay particular attention to the personal characteristics of students to validate this hypothesis, whilst also striving to make laboratory environments as realistic as possible to effectively mimic real-world settings.

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