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How Classroom Acoustic Conditions May Impact Autistic Students: A Review

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ABSTRACT

Data about the prevalence of autism worldwide diverge across different censuses. However, with the growing availability of diagnostic assessments, the number of diagnosed autistic persons has been increasing over the years and, with that, also the need for accommodations. One differentiating characteristic of autistic persons compared to those who are not is a hypo- or hypersensitive response to any sensory input, usually referred to as sensory processing disorder. Here we focus on auditory hypersensitivity. In room acoustics, and more specifically in the field of classroom acoustics, it is known that the design of indoor spaces affects speech intelligibility and comprehension for persons regardless of their neurological condition, which is essential in learning environments. For autistic persons, high levels of reverberation and background noise may lead to a sensory overload. This situation could be ameliorated with the use of assistive technology or adequate acoustic design. In this paper we present a literature review regarding the impacts of room acoustics on autistic persons, how it can be used as an accessibility tool, and propose ideas for work to be done to better identify and resolve acoustic issues for autistic persons in classrooms.

1. INTRODUCTION

Data from the Centers of Disease Control and Prevention (CDC) estimate that 1% of the world population is on the autism spectrum. With the growing availability of diagnostic assessments, this number has been increasing over the years. One common characteristic in autistic persons is a sensory processing that differs from non-autistic persons [1]. Usually referred to as sensory processing

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disorder, this trait is described as a hypo- or hypersensitive response to any sensory input such as lights, sounds, smells, touch and tastes. Here we focus on auditory hypersensitivity.

Recent technological advancements, such as noise canceling devices for personal use, may find use as accessibility aids, providing a better life quality to autistic persons. However, few research has been done to design more inclusive equipment or spaces to autistic persons. In room acoustics, and more specifically in the field of classroom acoustics, it is known that the architecture of indoor spaces affects speech intelligibility for persons regardless of their neurological condition, which is essential in learning environments [2]. Furthermore, high levels of reverberation and background noise may lead to a sensory overload in a person with auditory hypersensitivity, which may not only have a negative impact in learning, but may ultimately lead to a meltdown/shutdown.

Designing spaces for autistic individuals must take into consideration more nuances than for an non-autistic individual. Details such as indirect lightning could make a great impact [3]. The use of clean direct signs and instructions are also necessary, since too much information might be confusing. Any modification in the learning space, if not warned, could cause distress on an autistic individual that does not respond well to changes. These are just a few examples. The auditory characteristics of a space go on the same path. Although a well designed acoustical environment is beneficial for any person, the needs of an autistic individual may require more attention and adaptations.

The goal of this paper is to review recent works about room acoustics requirements for autistic individuals as a first step in our goal to formulate design guidelines towards more inclusive classrooms, taking into special consideration students with auditory hypersensitivity.

2. NON-ABLEIST LANGUAGE

Ableism is defined as a set of ideas and beliefs that perpetuates discrimination against persons with disabilities [4]. Language is one of the key elements in promoting or combating those ideas, particularly in science. Since autism has a long history of dehumanization in research [5], partly due to inaccurate views on autistic traits and partly due to the choice of words to describe autistic individuals, researchers should be wary about their choice of words in their written and spoken works.

Autism is an ongoing topic of research with several misunderstandings in the past, not only by lack of comprehension surrounding the topic and means to investigate it, but mainly due to a stigmatized image of autistic persons and the fact that their voices have not been amplified in scientific works until recently [6]. With new findings and perspectives, some terms, ideas and/or conclusions presented in this article may not be suitable in the future.

Below, we lay out the main aspects (extracted from [6]) we followed in this manuscript to avoid ableist language:

- We prefer an identity-first language ("autistic person") instead of person-first language ("person with autism").
- We refer to autism as a neurological condition and disability instead of a disorder or illness.
- We use "trait", "characteristic" or "feature" instead of "symptom".
- Neurodiversity is an umbrella term for neurological conditions such as autism, Attention Deficit Hyperactivity Disorder (ADHD) and Learning Disabilities (Dyslexia, Dyscalculia, Dyspraxia). In this text neurodivergent is used for individuals with either of those conditions. Neurotypical is used for individuals who are not neurodivergent.
- The terms non-autistic or allistic are used for individuals who are not autistic.

3. AUTISM

First introduced in 1943 [7], autism is a neurodevelopmental disability that influences the way a person processes the world [8]. This is perceived as an impairment in social communication and social interaction along with repetitive patterns of behavior, interests or activities. Some autistic persons show those characteristics from early age. Others may present only when social demands become higher or even learn how to mask their traits throughout their lives [9]. Diagnostic criteria have been changing over the years and also the diagnostic assessments availability. Recently, we see an increase in awareness about autism and, with that, an increase in interest about a formal diagnosis if there is a belief that an individual might fit the criteria. The prevalence, however, varies and some data do not reflect the reality, particularly in developing countries where interventions regarding autism still lack support and under-diagnose is speculated [9].

The exact cause of autism is still unknown. However, both genetic and external components are suggested by researchers [10]. Regardless of the origins, it is worth noting that no cure exists for autism and that some therapies and environmental interventions could significantly improve the life quality of an autistic person. These treatments and adaptations are individualized and catered to the needs of each autistic person, since autism manifests in very different ways. The manifestation also varies across genders [11] and cultural backgrounds [12]. Nevertheless, it is possible to draw some common characteristics found in autism, such as: difficulties in socializing and communicating, repetitive behaviors, binary thinking, focused interests, cognitive rigidity, hypo- or hypersensitivity to one or more sensory input, and others.

The autistic community is significantly diverse and, for that reason, it is difficult for researchers to define biological hallmarks of autism with certainty. No set pattern of changes is present in every autistic person [13]. Nowadays, diagnostic criteria are defined by analyzing behaviors and not physiological characteristics. Some studies suggest volumetric alterations in parts of the brain [14]. Others rely on the connectivity theory, which states that the way some parts of the brain of autistic persons are connected differs from non-autistic persons [15].

One common trait that used to be neglected is a distinct sensory perception when compared to non-autistic persons, which now is a core feature in diagnostic assessments [16, 17]. The so-called “atypical sensory experience” [16] acts on every sensory input: taste, smell, audition, touch and vision. An autistic person might have hypo- or hypersensitivity to any of those inputs, or neither. Hypersensitivity could be linked to increased anxiety and avoidance in autistic individuals when the sensory experience is negative [18] and sensory-seeking activities when it is positive [19], while under-responsivity could lead to the need for an exaggerated sensory input, i.e. loud sounds and bright lights.

Despite the general public viewing autism in a negative manner, autistic individuals do not see it as either good or bad, but rather neutral [5]. The stigma and lack of support are the aspects that are actually viewed as negative by the autistic community, which could lead to a deteriorating mental state [8]. Autism is seen as part of one’s identity and not as an illness [5]. Therefore, it is not something to be cured or corrected, as suggested by the medical model of disabilities, which believes that the disability itself is the problem and places a dichotomy between “healthy” and “unhealthy”, “able” and “disable” [6]. Instead, the focus should be on how to make positive changes in the environment to enable the active participation of persons with different disabilities. This is what the social model states [6] and could be interpreted as society allowing disabling experiences for individuals with certain conditions, autism being one example.

4. AUDITORY HYPERSENSITIVITY

Sensory Over-Responsivity (SOR) is defined as a sensory overload in individuals with hypersensitivity. This is not specific to autism and has been observed in allistic neurodivergent persons as well [20]. Sensory input may cause positive or negative impacts in any individual. For example, a person without SOR might listen to an unpleasant sound and, depending on its characteristics, this can either be ignored or cause some discomfort. For individuals with SOR, however, the threshold for tolerating the sensory input is much lower. Sounds that are generally ignored or bearable for neurotypical individuals could cause a great amount of stress in the other group.

Research work about SOR and autism have analyzed the effects of sensory overload on the behavior of autistic individuals [21]. Some reactions such as *"self-injurious behavior, withdrawal, uncooperative behavior, aggression, disruptive behavior, and destruction of property"* ([21], page 2182) might be indicative of distress caused by an unbearable sensory input, which could negatively impact their life quality and ability to socialize or accomplish daily activities.

There is little information about the exact way sensory differences manifest in autistic individuals. Previous studies have suggested that the instantaneous sensory sensitivity is not where the differences lie [22]. However, a closer look at the sensory responses to a repetitive stimuli over time in both neurodivergent and neurotypical individuals is necessary. In the next subsection, we discuss the findings of a study that analyze such responses.

4.1. Auditory Habituation

A recent study has analyzed the sensitivity, i.e. the instantaneous response, and the habituation, i.e. the response over a period of time, for both autistic and non-autistic persons in the auditory domain [22]. The evaluation is made with the use of both galvanic skin response (GSR) and magneto-encephalography (MEG) methods. GSR is a gold-standard method to analyze sensory responses in autistic persons [23] and measures the skin-conductance, i.e., a physiological response. High levels of GSR are an indicator of emotional arousal. MEG, on the other hand, measures the neuronal electromagnetic activity, i.e., a neurophysiological response. Although the sensitivity does not differ in both groups, the habituation is largely different, with autistic persons presenting less habituation than non-autistic persons. This means that the second group has a decreasing sensory response and is able to ignore sounds over time while the first group has varying sensory responses that, in average, did not alter with time and, therefore, may have more difficulty in noisy spaces.

The experimental procedure is described as follows: "*While sitting comfortably in a quiet room, participants listened to a periodic sequence of short tone bursts (250 Hz, 73 dB, onset 116 ms, inter-stimulus interval of one second). The sequence consisted of a 2-min-long period of silence, followed by 240 to 300 tone bursts presented at a rate of 1 Hz (for all subjects, data were analyzed for the first 240 tones). GSR and MEG recording sessions were conducted separately, with non-overlapping groups of participants*" ([22], page 2220). The measurements through GSR were made with 26 volunteers: 13 autistic individuals (27.1 +- 5.9 years, age range 18.9-36 years, 5 females) and 13 neurotypical individuals (28.9 +- 5.1 years, age range 18.9-35.9 years, 5 females). The MEG evaluation had 24 volunteers: 12 autistic individuals (15.12 +- 5.6 years, age range 8-27 years, all male) and 12 neurotypical individuals (14.75 +- 5.9 years, age range 7-27 years, 2 females).

It is not specified whether neurotypical individuals were considered as any allistic individual or individuals who are not neurodivergent. We assume the latter. What stands out on the profile of the volunteers is the age range. Since much of the research to date focus only on autistic children and ignore adults, in the future we expect to find more work on the experience of autistic adults, such as this one. The gender diversity, however, could improve. Autism is usually associated with male individuals, which leads persons to assume that female individuals are not likely to be autistic. The under-diagnosis of girls and women is probably due to the lack of understanding about the autistic traits on female individuals rather than male individuals being more prone to autism [11]. If we take into consideration the expressive number of trans persons—binary or non-binary— who are also autistic [24], the conversation surrounding gender is even more nuanced.

The plots in Figure 1 show the GSR measurements for, respectively, neurotypical and autistic individuals. The curve on the left (blue) indicates that neurotypical participants display habituation due to a repetitive sound which is seen as a decrease of the GSR amplitude. Autistic participants, however, do not present a clear variation trend in the same amplitude which, on average, is unchanged over time. The MEG results were divided into early responses (average of every participant for the first 50 trials) and late responses (average of every participant for the last 50 trials). There were 300 trials in total. A clear difference is noted between the two groups. While the first 50 trials for neurotypical participants have significantly higher z-scores than the last 50 trials, the respective values for autistic participants do not show significant changes. Therefore, we are able to conclude that neurotypical individuals exhibit a steady habituation due to a continuous auditory stimuli. The authors did not have a definite explanation for the lower z-score values in the autistic participants. The hypothesis of noisier signals in autistic participants was considered. Figures 3A and 3B from the supplementary material in [22] show, respectively, the MEG responses of all the neurotypical and autistic participants. The first group has responses with a similar format. The second group, however, has a more inconsistent response. Through the MEG broad age range, the authors did not obtain a significant correlation between age and evoked responses.

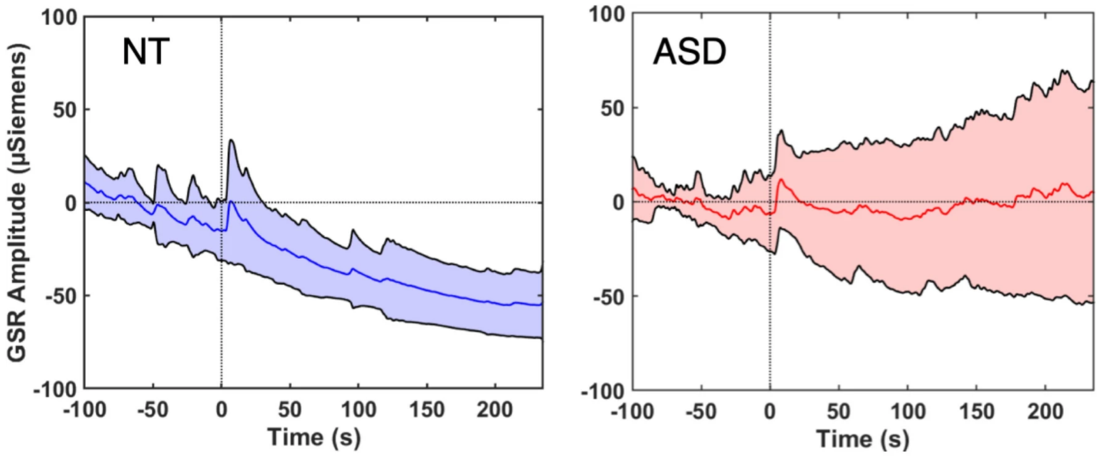

Figure 1: Average GSR traces (and standard deviations) of habituation profiles for neurotypical and autistic participants (Source: [22], page 2221).

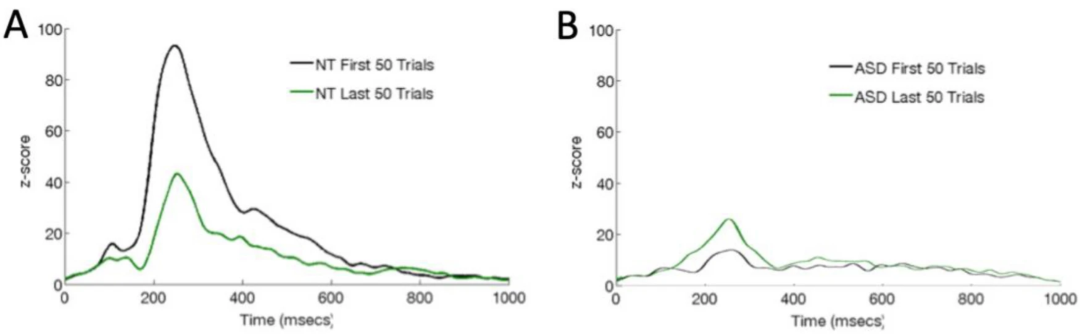

Figure 2: Group average MEG responses for neurotypical and autistic participants (Source: [22], page 2223).

The research conducted by Gandhi et. al. encourages a highly important discussion surrounding strategies to best accommodate autistic individuals in different settings. If we were able to monitor physiological arousal, further distress could be preventable with early intervention, such as reducing demands of the autistic person and moving them away from the stimuli. This would be particularly necessary for autistic persons who require greater support for communication, e.g. nonspeaking or nonverbal individuals. The measurement of habituation is also an interesting possibility in the design of accessible spaces, which we will discuss in Section 6. The findings, however, need further investigation before practical use, regarding both the robustness and generality of the method.

5. CLASSROOM ACOUSTICS

Current guidelines for the design of acoustic conditions in classrooms may be found in assorted countries around the world, including the United States, the United Kingdom, Italy, and Brazil [25, 26, 27, 28]. Many of these provide guidelines for maximum sound levels in unoccupied classrooms due to noise sources resulting from the building layout or site location, with the aim of producing appropriate signal-to-noise ratios. Some also present maximum reverberation times for learning spaces and sound isolation requirements between spaces. ANSI S12.60 in particular [25] was developed in response to the Americans with Disabilities Act passed in 1990 in the United States, to ensure that classroom acoustics allowed for good aural communication for those with hearing disabilities. It sets the maximum allowable unoccupied background noise level to be 35 dBA for most classrooms, in order to achieve signal-to-noise ratios (SNR) of at least 15 to 20 dB throughout the classroom. Researchers have noted that a SNR of 20 dB or more can further serve younger students and those who learn in a language other than their native language, as the greater clarity of speech above noise levels improves the speech comprehension of these groups [2].

To date, the classroom acoustic guidelines in use around the world have not considered specifically the needs of autistic students or others with auditory hypersensitivity or different degrees of auditory habituation. How might the acoustic conditions in learning spaces be designed or set so as to accommodate and optimize the learning experience for autistic persons? The next sections review some recent work related to this topic. The authors note that it is unlikely that classroom acoustic guidelines should set maximum background noise levels to be even lower than 35 dBA. One reason is that auditory hypersensitivity may be heightened when the background noise level is very low; another is that maintaining lower background noise levels in spaces results in the need for greater sound isolation between learning spaces and surrounding environments, which is often not economically feasible.

6. CLASSROOM ACOUSTICS DESIGN AND AUTISM

In the health field, auditory hypersensitivity is a well known autistic trait from reports of clinicians and, most importantly, autistic individuals. The second group has been reinforcing the need for accommodations whether by the use of personal devices or by adaptations made in the environment. Although this is not a new topic in the acoustics field, we believe there is still a lack of discussion about the importance of acoustic technology for persons with auditory hypersensitivity. In the section, we review some previous research on the topic in school environments. Unfortunately the literature available is sparse and further research is still necessary.

It is worth noting that the research papers reviewed below focus on the perspective of persons analyzing autistic individuals. In other words, the findings were based on behaviors observed by others. We emphasize the need for research that values mainly the perspective of autistic individuals. However, as mentioned before, some behaviors may be indicative that a person is in distress and the perspective of an observer is still valid—particularly in cases in which autistic individuals are not able to have functional communication, e.g. young children.

6.1. Influence of Noise on Autistic Students

The study conducted by Kanakri et. al. evaluates the perspective of teachers on the academic performance and emotional and behavioral regulation of autistic students. The specific grade levels are "*preschool (17%), pre-kindergarten (3%), kindergarten (7%), lower elementary (10%), upper elementary (6%), middle school (17%), and high school (2%), with 38% of teachers teaching multiple grade levels. The most common types of classrooms reported by teachers were general education (48%), special education (8%), and specific subject or service classes (56%). Teachers reported spending an average of 30.28h with their students each week (SD = 8.41). Most teachers reported* *having between one and ten students in their class. Teachers reported working with children with autism an average of 106.48 (SD = 84.72) months*" ([19], page 89). 74 teachers participated in this research.

The purpose was to analyze the impact of noisy classrooms on the autistic children and whether they are linked to disruptive behaviors. Reverberation time was not evaluated. A 5-point Likert Scale was adopted for teachers to rate the negative impacts caused by different sources. The results are shown in Table 1.

Table 1: Negative impacts of different sources according to teachers (N = 74). Extracted from [19], page 90.

Source of noise	**Teacher Ratings (%)**				
	1	2	3	4	5
Air conditioner	47.3	50.0	2.7	0.0	0.0
Echoes	48.6	45.9	1.4	2.7	1.4
Other children	2.7	5.4	23.0	13.5	55.4
Other classrooms	0.0	0.0	13.5	59.5	27.0
Traffic	0.0	0.0	59.5	24.3	16.2

1 = most negative, 5 = least negative

Teachers were also asked to name positive and negative acoustical aspects of school spaces. In the classroom, the positive acoustical aspects and the respective percentage of teachers are: large spaces (19%), transitional space (7.6%) and multi-zoning (13.9%). As for the negative acoustical aspects: no carpets (15.2%), metal furniture (9.5%), echos (13.5%) and hard floors (13.5%). The other spaces evaluated by teachers were: corridor, art room library, music room and PE room. The relevance of design modifications was rated as well by teachers. On the Table 2, there are the percentages of each modification according to teachers.

The authors stated that there is still a gap in literature on how to build autistic-friendly acoustical environments. Negative changes in behavior are noticed by teachers and caregivers, which could be influenced by spatial features of classrooms and ameliorated with future research and guidelines for proper design. Due to the subjective nature of this survey, there are some limitations, especially regarding the teacher's ability to evaluate the students.

6.2. Classroom Acoustical Design and Repetitive Behaviors

A more extensive research conducted by the same group [29] starts with the hypothesis that increasing noise levels in a classroom are correlated with repetitive behaviors in autistic children. Four classrooms were evaluated in two different schools for autistic children (two classrooms in each school). 20 children (four females) participated in School 1 and 22 children (one female) participated in School 2. All children were of ages ranging from 6 to 9 years old. The observations were made through the use of a video recording system, which allows for a more accurate analysis. After a 12h pilot test, 64h of data from each classroom were recorded on a 6-week period of observations. A total of seven behaviors were counted every 30s: repetitive movements, repetitive speech, covering the ears, hitting response, loud sounds, blinking eyes and complaining. A measurement of the sound

Table 2: Importance of design modifications according to teachers (N = 74) in which 5 = strongly agree, 4 = somewhat agree, 3 = neither agree or disagree, 2 = somewhat disagree, 1 = strongly disagree. Extracted from [19], page 91.

Design Modifications	**Teacher Ratings (%)**				
	5	4	3	2	1
Wood tables and chairs	1.4	31.5	52.1	12.3	2.7
Carpet	34.7	34.7	22.2	4.2	4.2
Thick walls	45.2	42.4	5.5	4.1	2.7
Wood panels	2.7	16.4	75.3	4.1	1.4

pressure level was obtained every 10s on the occupied classrooms—levels ranged from 40.3 dB to 96.7 dB. At the end of each day of observation, teachers answered a questionnaire regarding their opinions about the classroom environment.

Table 3: Correlations Between dB Levels and the Seven Observed Behaviors, 40-90dB. From [29], page 861.

Behavior	**School 1** (n = 268)	**School 2** (n = 222)	**Both schools** (N = 490)
Repetitive motor movement	.24***	.37***	.30***
Repetitive speech	.39***	.41***	.31***
Cover ears	.37***	−.13	.24***
Hitting	.11	.49***	.18***
Produce loud sound	.15*	.54***	.31***
Blink eyes	.10	−.02	.05
Complain	.12*	.31***	.16***

*$p < .05$. **$p < .01$. ***$p < .001$.

All the correlations between sound pressure levels and repetitive behaviors are shown on Table 3. Given the low p-value (< 0.001) for most behaviors in both schools, it is possible to infer there is a positive correlation between increasing noise levels and frequency of repetitive behaviors. The research corroborates previous studies that suggest a link between these two variables [30]. The authors highlight the importance to test causal association in future works using a well controlled environment. Other sources of discomfort should be considered in this context such as social demands and teaching approaches.

The results from [19] and [29] show the influence of acoustical characteristics on autistic individuals and provide a basis for future research. Teachers do notice how the environment affects autistic students, and a positive correlation between repetitive behaviors and noise levels was found later with more extensive work. It would be interesting to see a similar study that evaluates the effect of changes in acoustical features of school spaces using the design modifications in Table 2.

7. FINAL CONSIDERATIONS

Research works on how to accommodate students with auditory hypersensitivity are limited. However, a rise in the number of diagnosed autistic individuals may attract more interest in the review of current acoustical guidelines of classrooms taking into consideration neurodivergent students. In the future we expect to provide tools to best accommodate these individuals in the auditory domain of a classroom. The influence of reverberation time on the response of autistic persons is a variable to also be included in future work, since there is little information about it. Both noise level and reverberation could be evaluated with the use of an objective measurement such as GSR or MEG and a subjective input from autistic volunteers. Individuals with auditory hypersensitivity may also benefit from acoustical technologies such as active noise canceling or active sound enhancing devices for personal use or other solutions that mitigate noise pollution. These are a few examples that could provide better life quality for the general population and should also be seen as accessibility tools for individuals with auditory hypersensitivity.

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