Autism and Indoor Sounds

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Loud music. Hunger. Metallic clattering from the kitchen. Strong smells. Bright lights. Conversations reverberate into a discordant blur.

> "Restaurants can be a triggering place for me. Not only do I have to maintain a conversation with the attendants, but I also must deal with the stress of these stimuli. At my favorite Mexican American restaurant, unlike many others where customers only state their order once, we're required to verbally select ingredients at each step, which can be particularly demanding for someone with a disability in communication and interaction. To accommodate customers with hearing or speech disabilities, this restaurant offers an alternative communication method: an order form. Although I do not explicitly fit these criteria, lowering my interaction demands in this adverse environment would benefit me. But do I have the right to use the form? Will attendants question my difficulties if they see me speaking and hearing?
>
> "After this experience, I started to hyperfixate on how I could benefit from proper indoor acoustics and noise control. Could this be a starting point for me to research architectural accessibility for autistic individuals? Surprisingly, it could" (F. Caldas, personal communication).

Such situations, as described by F. Caldas, emphasize the importance of acoustic accessibility in public spaces. Navigating the sensory overload encountered in daily life can pose unique challenges for autistic individuals. In this article, we describe autism and how autistic individuals experience the world of sounds. We then discuss the impact of indoor acoustics on autistic learners and highlight modifications that can improve acoustic accessibility in buildings.

Introduction

What is autism? The answer could depend on who you ask. Indeed, experiences and biases can lead different people to describe autism in different ways. Definitions of autism can, therefore, vary between health professionals, family members, school staff, allies, individuals who are not familiar with autism, and autistic individuals themselves. With time, society may converge toward a universal, neutral definition. For now, however, we, the authors, prefer the following definition: autism is a neurodevelopmental disability that impacts how individuals interact with the world, encompassing sensory experiences, communication patterns, and social behaviors as well as cognitive and motor skills.

Previous research has tried to understand autism by examining its traits, origins, and treatments and pursuing a cure. Unfortunately, studying autism alone can sometimes lead to the perception that autistic individuals are a problem due to their neurological characteristics. Instead, it is also necessary to consider how the environment and nonautistic (also called allistic) individuals interact with autistic persons. As authors, we view disability under the social model where disability is not an individual problem. Instead, it is society's responsibility to reduce the disabling experiences of persons with certain conditions (Oliver, 1990). In recent decades, the understanding of autism has developed to include other external aspects, such as the perception and characteristics of allistic persons, accessibility tools, inclusive education, and the effects of architectural design.

It is not uncommon to hear stories of autistic individuals disclosing their diagnosis publicly. In fact, the increasing number of newly diagnosed autistic adults has been highlighted in different scientific fields, including acoustics. One of the things that makes autism acoustically intriguing is the different auditory experiences

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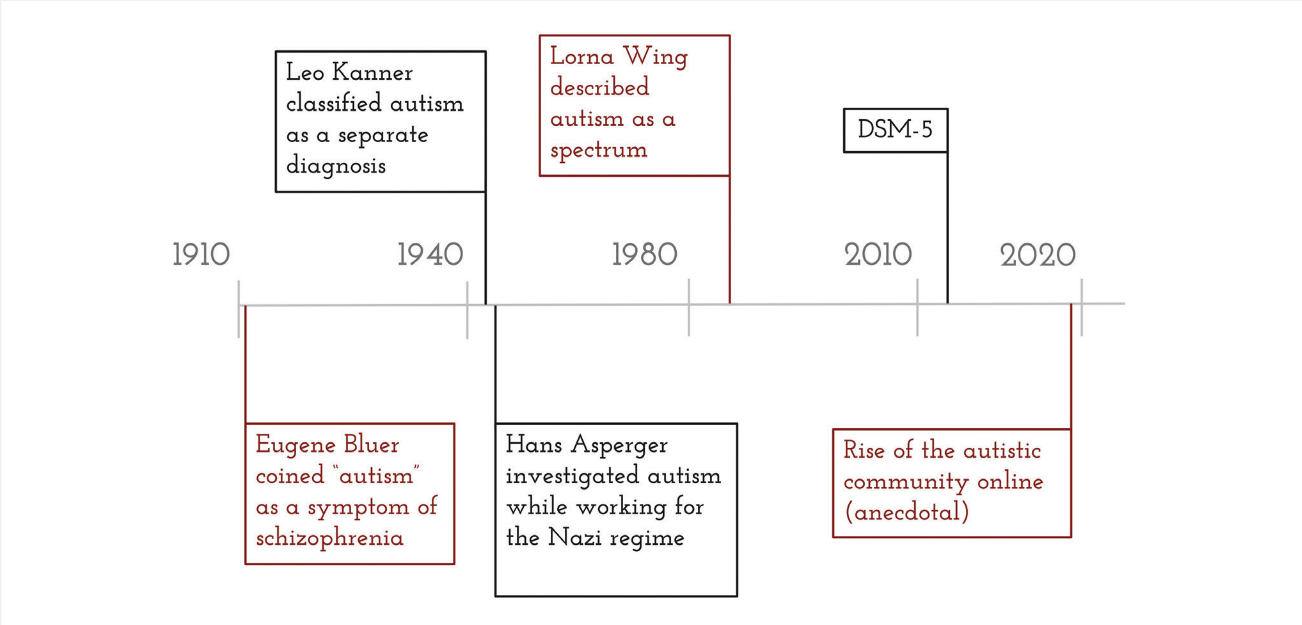


Figure 1. *Highlight of key events in the history of autism diagnosis. DSM-5,* Diagnostic and Statistical Manual of Mental Disorders-5.

reported by neurodivergent individuals (umbrella term for neurological conditions such as autism, attention deficit hyperactivity disorder [ADHD], dyslexia, dyscalculia, and dyspraxia) compared with neurotypical (i.e., nonneurodivergent) individuals. For example, neurodivergent people may perceive sounds as overwhelmingly loud or intense, struggle to filter out background noise, and/or experience discomfort or pain from everyday sounds. Consequently, they will often seek solitude or quiet spaces for relief.

Before diving further into the relationship between the built environment and autistic individuals, we consider the developments related to autism that occurred over the last century. A timeline is presented in **Figure 1**.

History of Autism

The word "autism" was first coined in 1911 by Swiss psychiatrist Eugene Bleuer as a symptom of schizophrenia in children (**Figure 1**). Bleuer coined the term from the word *autós* (meaning "oneself" in Greek) to describe children who became trapped in their own world of hallucinations to avoid contact with the outside world (Evans, 2013). In 1943, the Austrian American psychiatrist Leo Kanner used the term "autistic disturbances of affective contact" to establish autism as a separate diagnosis from schizophrenia. Kanner observed children who "have come into the world with an innate inability to form the usual, biologically provided contact with people" (Kanner, 1943, p. 250). Autism is, therefore, a relatively new diagnosis.

Hans Asperger, a German psychiatrist, also studied autism in the 1940s. Asperger analyzed autistic children who, according to him, exhibited potential for productivity, superior intelligence, and special abilities compared with the average population (Maher, 2021). He distinguished this set of characteristics as a "favorable side" of autism, which existed in some autistic children. Asperger also assumed the presence of genetic components, noting the recurrence of similar traits among family members (discussed in Hippler and Klicpera, 2003) as well as differences in sensory experience (e.g., hypersensitivity) compared with nonautistic children (Blakemore et al., 2006). Although this work may seem positive, Asperger's evaluations were used to separate children perceived as having potential from those deemed expendable (Czech, 2018) under the Nazi regime. Although not a registered member of the Nazi party, Asperger did cooperate with the regime and joined Nazi-affiliated organizations. There is disagreement in the literature regarding the extent to which Asperger was aware that his evaluations were used in the children's euthanasia program.

The societal and scientific view of autism shifted toward the end of the twentieth century, in large part due to the work of psychiatrist Lorna Wing at the Institute of Psychiatry, London, United Kingdom. As a parent of an autistic person, Wing (1988) described autism as a "continuum," or what is now commonly called a spectrum. This conceptualization highlights the set of characteristics that vary in intensity across different autistic individuals. Wing foresaw that this would facilitate the identification of more individuals on the autism spectrum. Consequently, Wing believed that this would empower a deeper understanding among previously undiagnosed individuals, which might lead them to improve the quality of their lives. Alongside Judith Gold, Wing developed what is now known as "Wing's triad," delineating three key diagnostic criteria for autism: deficits in social interaction, communication, and imaginative capacity (Wing, 1988). Wing also described autism as a lifelong condition (Silberman, 2015).

Diversity in the continuum of characteristics within the autistic community is now largely celebrated. In fact, the autistic community has cultivated a vibrant online space to connect with one another and share anecdotal evidence of their experiences. Some autistic individuals may choose to express their knowledge and feelings through social media and discussion in online forums. Such expressions and shared information have proven invaluable to researchers and professionals directly involved with autistic individuals, offering insights that contribute to a more comprehensive understanding of autism.

Still, autism is a dynamic topic subject to ongoing medical and social evolution. Initial research viewed autism as a pathology, but, over time, the term "symptom" has given way to "traits" or "characteristics" (Botha et al., 2022). Similarly, previous research that focused heavily on autism in children has been supplemented by recent works that have expanded the consideration to autism in adults (Parsons, 2015; Robison, 2019). More work is needed in this area.

How Is Autism Formally Diagnosed?

Currently, the Diagnostic and Statistical Manual of Mental Disorders (DSM) is considered the standard reference for formal autism diagnosis in the United States. The DSM delineates a spectrum of characteristics under the autism spectrum disorder (ASD) (American Psychiatric Association, 2013). Despite serving as a foundational resource, medical professionals and researchers have the freedom to interpret the manual as they wish. In the case of medical professionals, a formal diagnosis depends on the physician's interpretation of how autism manifests in a patient. In some cases, this subjective evaluation is a barrier to formally diagnosing adults and, therefore, is one of the arguments in favor of self-diagnosis. This is a controversial topic in the autistic community that we do not discuss here (Sarrett, 2016).

Autism is a disability that is generally characterized by difficulty in communication and social interaction, repetitive behaviors, restricted interests, cognitive rigidity, dichotomous thinking (i.e., rarely seeing nuances or gray areas), and hyposensitivity or hypersensitivity (American Psychiatric Association, 2013). For a time, the differences in sensory experiences between autistic and nonautistic people were ignored, but the differences later became a significant feature in the diagnostic process (Robertson and Baron-Cohen, 2017). Today, the diagnosis is based on the analysis of behaviors and statements provided by the autistic person and/or people in their lives. Although genetic and external factors may contribute to autism, there are no common biological markers in all autistic people.

There is no cure for autism, but there are some therapies and environmental interventions that significantly improve an autistic person's quality of life. Because the autistic community is heterogeneous, it is important to apply these therapies and interventions according to the needs of the individual.

Often, autism is categorized into three different support levels: Level 1 requires support, Level 2 requires substantial support, and Level 3 requires very substantial support. The required level of support is determined according to the intensity of different aspects that manifest in the autistic person (see **Table 1**) (Rudy, 2024). The intensity of each one is subjectively evaluated by a physician to determine the level of support. The level of support an autistic person receives may vary throughout their life and depends on the tools that their environment provides for independence.

Communication skills are commonly viewed to be the primary factor for determining the necessary level of

Table 1. *Some characteristics that vary in intensity*

Aspect	Description
Executive dysfunction	Difficulty in managing time, planning, changing focus from one task to another, or following instructions. It directly impacts learning and maintaining a formal job.
Dependence on others	Requirement of help for daily activities such as maintaining personal hygiene, eating, drinking water, and taking transportation. It relates to executive dysfunction.
Cognitive rigidity	How the person is affected by changes, even if they seem small.
Susceptibility to shutdowns and/or meltdowns	Shutdown = "inertia": disconnection from the environment, reduced ability to communicate, or total lack of communication. Meltdown = explosive crises: disruptive behaviors or risk of harm (to self or to others). Both can be the result of sensory and/or social overload, changes, and frustrations.
Co-occurring conditions	Other neurodivergences, intellectual disability, depression, anxiety, bipolar disorder, or schizophrenia.
Communication skills	General limitation/absence of speech or verbal communication that may vary depending on the context. We make the distinction between "speech" and "verbal communication" because the latter could refer to any type of communication that involves words in a structure (language).

These characteristics are subjectively assessed by a physician to determine the level of support of an autistic person. Level 1 requires support; Level 2 requires substantial support; and Level 3 requires very substantial support.

support, but this is not always true. One example is the misconception that every nonspeaking autistic person requires Level 3 support. On the contrary, some individuals may exhibit low executive dysfunction (see definition in **Table 1**), and demonstrate independence in daily activities and effectively utilize augmentative and alternative communication (AAC). AAC describes a range of communication methods that expand beyond relying only on hearing and speaking. AAC, for example, may include writing, sign language, text-to-voice and voice-to-text converters, graphic symbols, pictograms, and emojis. Many use AAC without even realizing they are doing so.

Indeed, modern technologies like cell phones and tablets play a crucial role in facilitating AAC, breaking down communication barriers for individuals with various disabilities and promoting greater independence. A few examples provided by modern technologies include video editing apps that generate automatic subtitles, artificial voices that read a text, and specific AAC apps that use pictograms to create phrases. Clark (n.d.) presents some examples of AAC applications that can be helpful for nonverbal individuals.

As discussed in the **History of Autism**, the understanding of autism has undergone significant transformation over the years. Historical perspectives on autism often reflected societal biases toward anything deemed abnormal and were even influenced by the prevalent eugenics movement in the twentieth century. Indeed, even today, metrics used to assess the intelligence, communication, and social abilities of autistic individuals can be skewed by this history.

Sensory Sensitivity

Autistic individuals often experience either hypersensitivity or hyposensitivity, two distinct traits that greatly influence their interactions with the world. Hypersensitivity is characterized by an intensified response to various sensory inputs such as light, sound, taste, touch/texture, and/or smell compared with the response of individuals without hypersensitivity. This trait is often associated with heightened anxiety and avoidance in negative situations or constant sensory seeking in positive experiences (Green and Ben-Sasson, 2010). Conversely, hyposensitivity involves an "underresponsiveness" to sensory input, potentially leading to a need for amplified sensory stimuli like louder sounds or brighter lights.

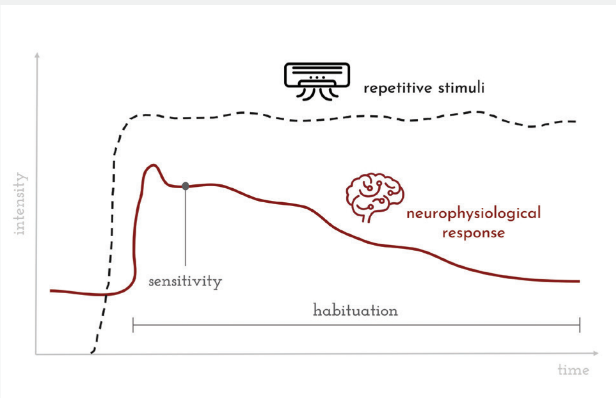
A recent study analyzed the sensitivity (immediate response) and the habituation (response to the same stimuli over a period of time) for autistic and neurotypical persons, with the aim of understanding how auditory hypersensitivity might function (Gandhi et al., 2021). It is usually expected that most people will become accustomed to constant background noises, such as the humming of an air conditioner. Consequently, we would expect an individual's neurophysiological response to decay over time as they become accustomed to the stimuli (see **Figure 2**). This is called habituation. Interestingly, Gandhi et al. (2021) showed that this habituation might not occur in autistic persons.

Measuring Sensory Responses

The galvanic skin response (GSR) is a reliable procedure used to analyze sensory responses in autistic individuals (Schupak et al., 2016). It assesses skin conductance, indicating physiological responses and elevated GSR levels, which serve as indicators of heightened emotional and/or sensory reactivity.

On the other hand, magnetoencephalography (MEG) gauges the electromagnetic activity of neurons and is used to track brain activity (Singh, 2014). GSR and MEG measurements of autistic and neurotypical individuals listening to tone bursts reveal that although the sensitivity does not differ between the two groups, habituation is considerably different. For example, neurotypical participants exhibited some level of habituation to a repetitive sound as their physiological response decreased over time. In contrast, autistic participants do not present a clear tendency for variation, but, on average, the physiological response stays approximately the same during the experiment.

Figure 2. *Simplified functioning of habituation. When exposed to repetitive stimuli (e.g., air conditioner), a person is expected to display a decaying neurophysiological response over time. Sensitivity is the response at an instant of time. Icon of the air conditioner is by ©keenicon via Canva.com. Icon of the brain is by ©satriyo pujo from Triyo Design via Canva.com.*



Thus, from the GSR measurements, one could infer that autistic participants are not habituating to such stimuli. The MEG results also indicated that neurotypical participants appeared to present some habituation, meaning that their neurological responses had a similar tendency and lower values over time. The autistic participants, however, did not present a common tendency within their group. No correlation between age and responses was observed in both groups (autistic and neurotypical) (Gandhi et al., 2021).

This work underscores an important conversation regarding strategies for accommodating autistic individuals in different environments. By continuously monitoring shifts in neurological and physiological arousal, it could be possible to preemptively identify and address possible physical and emotional discomfort through early interventions. This is particularly significant for individuals who require higher communication support, such as nonverbal or nonspeaking/minimally speaking autistic individuals. Still, these continuous monitoring methods need to be further investigated before they can be implemented. This research stands out for including both young adults and children, addressing a gap where most studies have focused on autistic children. Hopefully, more work detailing the experiences of autistic adults will emerge soon.

Finding Relief

Autistic individuals with auditory hypersensitivity can find relief using personal devices such as noise-canceling headphones and stim toys, including items like slime, fidget spinners, bubble pop toys, and chew necklaces (see **Figure 3**). In response to sensory overload or stress, a person might exhibit repetitive movements to achieve a sense of emotional regulation, which is often referred to as self-stimulatory (i.e. stimming) behavior. Stim toys help by channeling this type of reaction into a more controlled and less intrusive outlet, mitigating potentially harmful behaviors. Stimming is a valid form of self-expression that can also appear in joyful situations and, if it is not causing any harm, is not something to be corrected or avoided.

As mentioned in the **History of Autism**, social media can serve as an outlet for autistic persons to share their thoughts and experiences with an online community. In a recent post on Instagram, content creator and

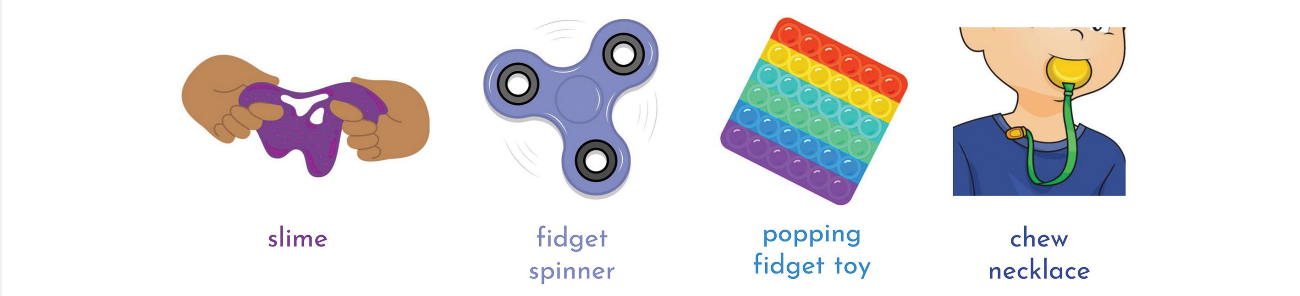


Figure 3. *Examples of stim toys.* ***Left to right****: slime (©InstaStudio via Canva.com), fidget spinner (©igorkrasnoselskyi via Canva.com), popping fidget toy (©diluck via Canva.com), and chew necklace (©BNPDesignStudio via Canva.com).*

researcher Louise Chandler (2023) commented on her experience with reduced auditory habituation and her coping mechanisms as an autistic person. Among her coping mechanisms, Chandler highlighted the use of noise-canceling headphones and stim toys. Once she overcame her fear of judgment from others, Chandler found relief in accessibility aids, especially in situations of discomfort due to sound stimuli. According to Chandler, the sensitivity of autistic persons to sounds is often seen as a phobia rather than pain; therefore, it is something to "be overcome." However, repetitive exposure to such stimuli can increase their stress response.

Auditory Processing Disorder

Another characteristic linked to autism is the auditory processing disorder (APD) (Ocak et al., 2018). APD is, essentially, hearing a sound but not understanding it. The physiological parts of the auditory system are functioning, but the brain may not properly process what is being heard. A person with APD may face barriers to understanding oral instructions, lectures, movies, or TV shows without subtitles, and/or other forms of communication that rely heavily on the auditory system. APD makes it even more difficult to deal with noisy spaces, especially when there is a need to process speech, such as in a classroom. Although some persons with this characteristic may find it hard to understand speech, they may also easily identify instruments in a song (Berke, 2024). Thus, APD describes a range of auditory challenges that may vary from person to person.

Acoustics of Built Environments and Impact on Occupants

The built environment can directly influence the comfort, productivity, and health of its occupants, and acoustics is a key factor in this regard (Altomonte et al., 2020). Despite the recognized importance, guidance on acoustical considerations in the built environment remains less prevalent in building design and code requirements compared with other factors like thermal conditions, indoor air quality, lighting, or electrical systems. An exception to this trend is in the classroom where acoustical guidelines are often explicitly outlined, given their importance toward speech communication (Brill et al., 2018).

Lower signal-to-noise ratio (SNR) conditions correlate with worse speech intelligibility, student performance, and academic achievement as well as a greater listening effort (see references in Wang and Brill, 2021). Studies have also demonstrated that the negative effects of noise are worse for children than for adults, for those with hearing disabilities, and for those who are listening to nonnative-language speakers or who are nonnative listeners.

There are standards and codes that pertain to classroom acoustics. ANSI/ASA S12.60 (2010) established performance guidelines for background noise levels (BNLs) and reverberation time (RT) in unoccupied classrooms. Similarly, Section 808 (Enhanced Acoustics for Classrooms) of the 2017 ICC A117.1 Accessible and Usable Buildings and Facilities Standard (International Code Council, 2017) was recently adapted into the 2021 version of the International Building Code.

There are also examples of standards and codes that pertain to accessibility for individuals with disabilities. The Americans with Disabilities Act (ADA) in the United States, Federal Law Number 10.098 in Brazil, and Approved Document M in England and Wales, United Kingdom, are examples of such regulations. They primarily focus on architectural elements, detailing specific standards for individuals with physical disabilities. These include access to building interiors, dimensions of elevators and ramps, and methods to reduce physical obstacles. However, it is worth noting that regulations regarding indoor acoustics for autistic individuals are not yet widely addressed.

Impact of Acoustical Conditions on Autistic Children in Schools

Kanakri et al. (2017a) examined teachers' viewpoints regarding the academic progress and emotional and behavioral management of their autistic students across various educational levels, spanning students from preschool to high school in a variety of different subjects and settings.

The objective was to assess how noisy classroom environments affect autistic children and whether such conditions contribute to disruptive behavior. Teachers reported their opinions about specific sources of noise that are common in a learning environment. Air-conditioning and echoes were evaluated as having the most negative impact on autistic learners.

Teachers were also asked to name positive and negative acoustic characteristics of school environments. Positive aspects noted in classrooms included spaciousness and separation of different sensory zones with interconnected transition spaces. Metal furniture, echoes, hard floors, and a lack of carpet were reported as negative aspects.

The same research group observed that increased sound levels correlated with the appearance of repetitive behaviors such as repetitive motor movements, repetitive speech/echolalia, ear covering, hitting, loud sounds, and complaining in autistic children (Kanakri et al., 2017b). As mentioned in **Finding Relief**, repetitive behaviors in autistic persons may be indicative of distress. Still, the author emphasized the need for further tests of causal associations in a well-controlled environment. Other sources of discomfort need to be considered, such as social demands.

Impact of Acoustical Conditions on Autistic Adults in Learning Spaces

Rosas-Pérez et al. (2023) examined challenges and strategies related to acoustic conditions in various settings, focusing on perspectives of both formally diagnosed and self-diagnosed autistic adults. Through their responses, participants shared positive and negative experiences about home, work, and indoor/outdoor spaces. Notably, due to the prominence of educational contexts in responses, the study concentrated specifically on schools and universities from the perspectives of students and teachers.

Schools were characterized as "sensory hells," where auditory stimuli, bright lights, and smells were sources of distraction and discomfort. In addition to the discomfort caused by the noise itself, the unpredictability of the stimuli was also identified as an issue. Sensory overload in such environments was reported to lead to fatigue and hindered learning or teaching capabilities. Some participants faced challenges progressing through a university due to inadequate grades or similar difficulties. Those unaware of their autism were sometimes discouraged from acknowledging their difficulties, yet they still felt distinct from their peers and were accused of exaggeration. Knowledge of one's autistic status emerges as a possible way to understand and mitigate stressful situations.

Much has been said in the literature about the overall experience of children in schools, but there is little reported about the experience of autistic teachers. Indeed, insights gleaned from the experiences of

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autistic educators can inform the creation of more accessible spaces for children and adults alike. Rosas-Pérez et al. (2023) found that reverberant rooms and open-plan school configurations were identified as inducing sensory overload in autistic teachers. None of the participants who worked as teachers in schools continued their careers, with noise being one of the determining factors in this decision. The number of years worked prior to departing their teaching roles was not reported. Some participants sought alternative roles in education as consultants or academics.

Modifications to the Built Environment

How can we design the acoustics of the built environment to be more inclusive for autistic people? Through a review of 24 studies that mentioned sound and autism, Black et al. (2022) concluded that the answer involves careful consideration of factors that affect noise levels, such as spatial layout, sound isolation, and reverberation.

First, the layout of the built environment must be thoughtfully planned. Mostafa (2014) developed the ASPECTSS™ framework, which describes key principles in autism-inclusive architectural design. Areas should be spatially sequenced in a logical and predictable manner. Easy-to-access escape spaces should be designed to provide overstimulated users with a neutral environment in which to recuperate. Activity areas should be compartmentalized according to their function and sensory qualities. Transitional spaces can be used to help users adjust their senses to new stimuli in different environments. Transitional, storage, and prefunction spaces can be used to buffer acoustically sensitive rooms from surrounding noise sources.

When considering sound isolation, it is important to ensure that spaces are effectively shielded from external noise sources. External walls (and their openings) must block the transmission of disruptive sounds from the exterior (e.g., traffic, machinery, rain, human activity). Windows are often the weakest link through which sound can leak, but this can be mitigated with multipane window construction with an appropriately airtight and resilient joint sealant. The Sound Transmission Class (STC) and Outdoor-Indoor Transmission Class (OITC) of cavity wall systems can be improved with added mass, resilient layers, and cavity absorption. Partitions should extend to their full height and be sealed to the structure of the roof deck or floor above. Penetrations through sound-isolating partitions should be avoided. Wherever penetrations are unavoidable, they should be packed with insulation and sealed with a resilient joint sealant to minimize the leakage of sound.

Noise levels within the built environment also need to be controlled, not only through sound isolation of nearby activities but also through careful mitigation of in-room noise from equipment, appliances, and building systems. Bathrooms and kitchens are a common concern, given the noise associated with heating, ventilation, air-conditioning (HVAC), and plumbing systems (Mostafa, 2010). Kanakri et al. (2017b) suggested that the average sound levels should be kept at 50 dB or lower to reduce repetitive speech and hitting behavior in children. In some spaces, absorptive finishes, such as carpet, acoustical panels, and ceiling tiles, can be used to reduce the reverberation time and noise level.

These findings are supported by participatory research efforts, which seek to include the perspectives of autistic persons in the design process. For example, McAllister and Sloan (2016) developed a jigsaw activity for students aged 13 to 18 in which they conveyed their likes and dislikes by designing their ideal school layout. Noise was a common concern. Indeed, students suggested layouts that grouped louder programming at a greater distance from their resource base while also providing quieter spaces nearby. Students also suggested eliminating the school bell with a quieter notification system.

Looking Ahead

The exploration of acoustic accessibility for autistic individuals reveals a complex landscape beyond mere hearing. Autistic auditory experiences are diverse and intricate, encompassing challenges such as hypersensitivity and varied responses. Recent research recognizes the correlation between sound levels and behaviors, emphasizing the necessity for acoustical adaptations to minimize potential distress. Reinforcing existing design guidelines, especially in educational settings, becomes vital for ensuring clear communication and minimizing disruptive noises that could affect academic performance. Furthermore, comprehensive architectural design guidelines that take into consideration the diverse sensory needs of neurodivergent populations are needed.

We believe it is important to incorporate the perspectives of neurodivergent individuals into the design process. The participatory research efforts and interviews provide firsthand insights into challenges faced in educational settings, offering valuable suggestions for modifications. This collaborative approach, grounded in empathy and understanding, is pivotal for creating truly inclusive environments that cater to the unique sensory needs of all individuals. In essence, acoustic accessibility for neurodivergent individuals requires a holistic understanding, thoughtful adaptations, and a collaborative design process that places value on lived experiences.

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