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Acoustically sensitive school environments for sensory discrimination disorders in children and adolescents with autism

Ambientes escolares acusticamente sensíveis aos transtornos de discriminação sensorial de crianças e adolescentes com autismo

Entornos escolares acústicamente sensibles para trastornos del procesamiento sensorial en niños y adolescentes con autismo

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Abstract

The purpose of this research is to examine how the acoustics of educational environments can contribute to the neurodevelopment and academic progress of children and adolescents with autism spectrum disorder (ASD). This research is relevant because it examines how the auditory stimuli within school buildings affect the sensory processing and behavior of individuals with autism. The study is justified by the increasing number of children diagnosed with autism each year, both in Brazil and worldwide. By using a correlational method, the relationships between sensory discrimination disorders (SDD) and the behavior of individuals with autism are explored through literature reviews. The study used a tool known as the map of applied behavior analysis (MABA), which uses a sensory mapping device. The application of this tool revealed that auditory sensory stimuli have the most significant negative impact on students with ASD, either triggering or inhibiting stereotyped behaviors. The classroom and cafeteria were identified as the environments most negatively impacted by their acoustics. Therefore, the creation of acoustically sensitive environments for students with ASD can stimulate neurodevelopment and academic progress by providing greater comfort.

Keywords: Human Comfort; School Architecture; Neurodevelopment; Sensory Discrimination Disorders (TDS); Autism Spectrum Disorder (ASD).

Resumo

O objetivo da pesquisa é verificar como a acústica dos ambientes de ensino pode contribuir para o neurodesenvolvimento e a progressão acadêmica de crianças e adolescentes com transtorno do espectro autista (TEA). Esta investigação é pertinente, pois permite verificar como os estímulos sonoros do edifício escolar impactam o processamento sensorial e o comportamento do autista. O estudo justifica-se, pois a cada ano cresce o número de crianças diagnosticadas com autismo, no Brasil e no mundo. A partir do método correlacional, são estudadas as relações entre os transtornos de discriminação sensorial (TDS) e o comportamento dos autistas, mediante a realização de revisões bibliográficas. Neste estudo, empregou-se a ferramenta chamada mapa da análise do comportamento aplicada (MABA), por meio do dispositivo de mapeamento sensorial. Com a sua aplicação, foi possível identificar que os estímulos sensoriais sonoros são os que mais impactam negativamente o educando com TEA, induzindo ou inibindo comportamentos estereotipados, sendo a sala de aula e o refeitório os ambientes que mais influenciam negativamente devido à sua acústica. Assim, a criação de ambientes acústicos sensíveis aos educandos com TEA é capaz de estimular o neurodesenvolvimento e a progressão acadêmica, proporcionando conforto humano a eles.

Palavras-chave: Conforto Humano; Arquitetura Escolar; Neurodesenvolvimento; Transtornos de Discriminação Sensorial (TDS); Transtorno do Espectro Autista (TEA).

Resumen

El propósito de esta investigación es examinar cómo la acústica de los entornos educativos puede contribuir al neurodesarrollo y al progreso académico de niños y adolescentes con trastorno del espectro autista (TEA). Esta investigación es relevante porque analiza cómo los estímulos auditivos dentro de los edificios escolares afectan el procesamiento sensorial y el comportamiento de las personas con autismo. El estudio se justifica por el creciente número de niños diagnosticados con autismo cada año, tanto en Brasil como en todo el mundo. Utilizando un método correlacional, se exploran las relaciones entre los trastornos de discriminación sensorial (TDS) y el comportamiento de las personas con autismo a través de revisiones de literatura. El estudio utilizó una herramienta conocida como el mapa de análisis de comportamiento aplicado (MABA), que emplea un dispositivo de mapeo sensorial. La aplicación de esta herramienta reveló que los estímulos sensoriales auditivos tienen el impacto negativo más significativo en los estudiantes con TEA, ya que pueden desencadenar o inhibir comportamientos estereotipados. El aula y la cafetería fueron identificados como los entornos más afectados negativamente por su acústica. Por lo tanto, la creación de entornos acústicamente sensibles para los estudiantes con TEA puede estimular el neurodesarrollo y el progreso académico al proporcionar mayor comodidad.

Palabras clave: Confort Humano; Arquitectura Escolar; Neurodesarrollo; Trastornos

Introduction

The design of school architecture must consider the needs of the users of the built environment, in addition to compliance with laws, building codes, and regulations. Schools designed to accommodate students with autism spectrum disorder (ASD) should also consider the specific sensory processing needs of these individuals in order to create more appropriate spatial solutions and provide environmental and psychological comfort for this population.

This analysis aims to explore how educational building design can contribute to the neurodevelopment and academic progress of children and adolescents with ASD by making learning environments acoustically comfortable for them.

This work is relevant and warranted because, according to a Centers for Disease Control and Prevention (CDC) report published in March 2023 with data from 2020, one in 36 children in the United States will be diagnosed with ASD. Autism

occurs across all racial, ethnic, and socioeconomic groups and is 4.3 times more common in boys than in girls (Maenner, M. J.; et al., 2023). If this prevalence of 2.8% in the U.S. population is applied to Brazil in 2023, the country would have approximately 5.95 million people with autism. However, there are still no official prevalence figures for autism in Brazil (Paiva Jr., 2023).

The age range of individuals with autism considered in this study, which will influence the acoustic design recommendations, is defined as the target population of Early Childhood Education, with children aged 0 to 5 years, and Elementary Education, including both early and later years, with students aged 6 to 14 years. This focus is because the early years of life are critical for the neural development of children (Brazil, 2020).

This research conducted a systematic literature review of national and international studies in psychology, education, neurodevelopment, and neuroarchitecture. These studies examine sensory discrimination disorders (SDDs) in individuals with autism and the relationship between the built environment and their neurodevelopment. In addition, sensory mapping, a tool from the map of applied behavior analysis (MABA), was used.

Thus, the studies highlight specific criteria and aspects of architectural acoustics that are essential for creating environments sensitive to the auditory needs of individuals with autism. The database created emphasizes that improving the physical structure of the school and the quality of education provided to students with ASD contributes to their human comfort and academic progress.

Methodology: The Map of Applied Behavior Analysis (MABA)

This study is an experiential research investigation focusing on the analytical tool used to examine the relationship between individuals with autism and the built environment. The experiential approach explores how a person experiences a place, how each place influences human behavior, and how human presence imparts meaning and significance to each environment. In this way, the study aims to uncover insights and meanings from the interactions within these spaces (Rheingantz et al., 2009).

The MABA is an experiential research tool that integrates the behavior map and applied behavior analysis (ABA). This tool allows for an accurate understanding of how the built environment can impact the behavior of students with ASD. The specific component of MABA used in this study is called Sensory Mapping, an adaptation of a tool known as visual mapping (Silva, 2022).

> Visual mapping is a tool for identifying users' perceptions of a particular environment, focusing on factors such as location,

> appropriateness, territorial boundaries, inadequacies of existing situations, excessive or inappropriate furniture, and barriers, among others (Rheingantz et al., 2009, p. 50).

According to Silva (2022), sensory mapping aims to conduct the investigation proposed by visual mapping, considering visual comfort, tactile comfort, gustatory comfort, olfactory comfort, and auditory comfort. This tool aims to determine how the sensory processing of individuals with ASD may be affected by the sensory stimuli present in the physical environment.

The student with autism spectrum disorder (ASD)

Autism is derived from the Greek word "autós," meaning "self." Psychiatry uses this term to describe human behaviors that are self-centered and focused inward (Orrú, 2016).

According to the American Psychiatric Association (APA, 2014), ASD is classified within the group of Neurodevelopmental Disorders, as outlined in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5).

The psychoanalyst Kanner (1943) describes autism as a developmental disorder and identifies hypersensitivity to sensory stimuli as a characteristic that distinguishes ASD from other psychiatric disorders.

Sensory information processing in individuals with autism often manifests as an explosive reaction to sensory stimuli, leading to an inability to differentiate between foreground and background information (Bogdashina, 2003).

SDDs are characterized by deficits in perceiving and interpreting the quality of stimuli, whether they are visual, tactile, auditory, vestibular, proprioceptive, gustatory, or olfactory in nature (Caminha, 2008; Lambertucci, 2013). SDDs affect individuals' ability to identify differences and similarities between stimuli, influencing their ability to differentiate temporal and spatial qualities (Lane et al., 2000; Caminha, 2008; Magalhães, 2008).

In this study, the following characteristics related to the auditory sensory system of individuals with autism are highlighted:

Research conducted by Tomchek and Dunn (2007) among individuals with autism revealed that:

[a] 73% seem not to hear what is said to them;

[b] 51.2% do not respond when their names are called despite having no hearing impairment that would prevent them from hearing;

[c] 50.9% react negatively to unexpected loud noises;

[d] 52% enjoy strange noises and seek to make noise due to the sound;

[e] 58% become distracted or have difficulty functioning when there is too much noise around them;

[f] 79% have trouble paying attention; and

[g] 45.6% cover their ears to protect themselves from sound.

According to Tomchek, Little, and Dunn (2015), individuals with autism struggle to function in environments with background noise.

Research by Kern et al. (2001) and Rosenhall et al. (1999) indicates that individuals with autism often experience auditory defensiveness or hyperacusis, which can manifest as discomfort or even painful responses to certain sounds, such as vacuum cleaners or school bus engines. Kern et al. (2001) note that this sensitivity is more pronounced when noise levels are high or when there are multiple noise sources, such as in restaurants.

Therefore, designing the acoustics of educational environments based on the unique auditory perceptions of individuals with autism will contribute to their acoustic comfort, academic progress, and personal and behavioral development.

Application of the Map of Applied Behavior Analysis (MABA)

This work is part of a research project submitted for ethical review through the Plataforma Brasil. It is registered under the CAAE no. 46597821.8.0000.5257 and received the consubstantiated opinion of the research ethics committee (CEP) on August 16, 2021, with the status: "Opinion Status: Approved."

Sensory mapping was conducted by using the digital platform Google Forms and involved the participation of parents of students with autism as well as education and healthcare workers who deal directly with students with ASD.

Figures 1, 2, and 3 are part of the sensory mapping conducted with the teachers of a student with ASD and education and healthcare workers who deal directly with individuals with autism.

Figure 1 shows the responses to the following question: "What sensory stimuli (sight, hearing, touch, smell, and taste) affect the development of your students — children/adolescents with autism — during their activities in the school environment?"

Figure 2 represents the response to the following question: "Please identify which school environments negatively influence your students—children/adolescents with autism—due to auditory stimuli, triggering stereotyped behaviors and negatively impacting their development."

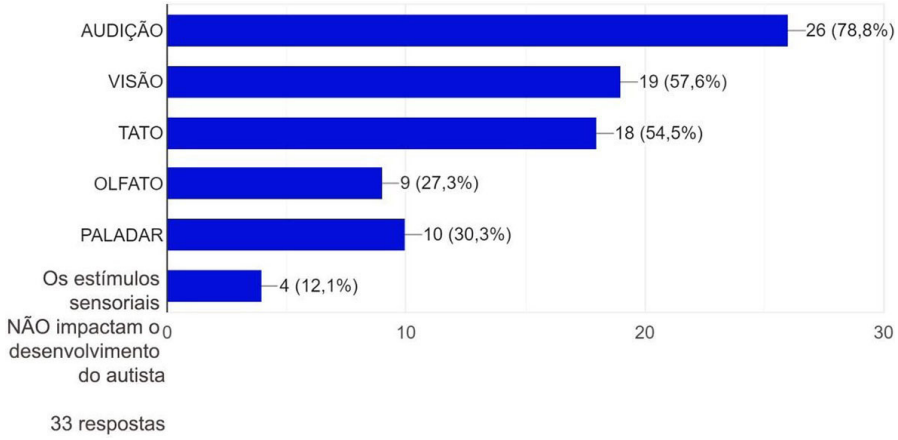

Figure 1: Sensory stimuli that most impact the development of students, children/adolescents with autism, according to workers' responses. Source: Silva (2022). Available from: https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.xhtml?popup=true&id_trabalho=11895742

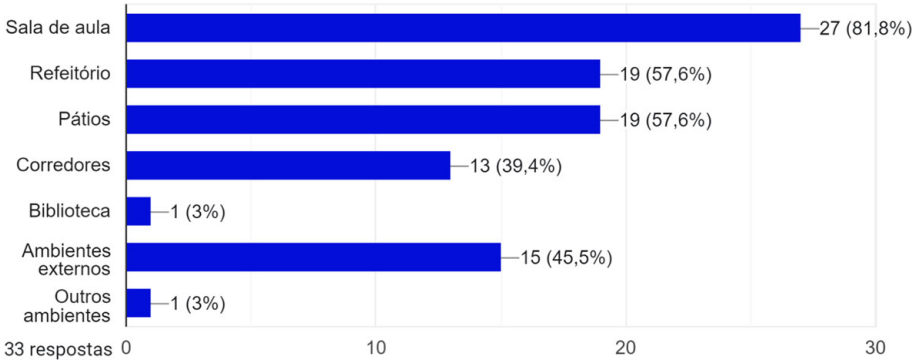

Figure 2: School environments where students, children/adolescents with autism, are most negatively affected by auditory stimuli, according to workers' responses. Source: Silva (2022). Available from: https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.xhtml?popup=true&id_trabalho=11895742

Figure 3 represents the response to the following question: "Which AUDITORY stimuli present in the environment(s) selected in Figure 2 negatively impact the behavior of your students—children/adolescents with autism? Please select one or more options."

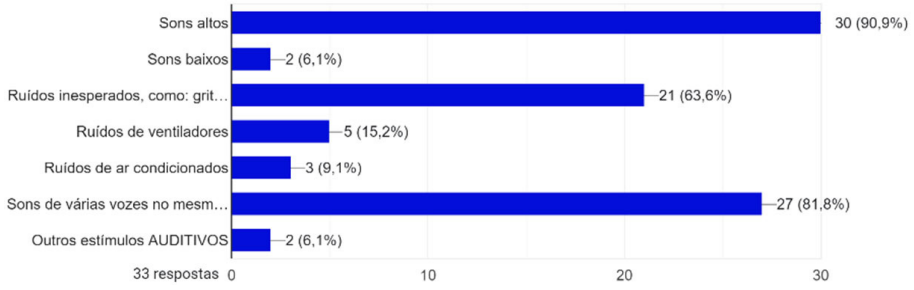

Figure 3: Auditory stimuli present in school environments (Figure 2) that most negatively impact the behavior of your students—children/adolescents with autism—according to workers' responses. Source: Silva (2022). Available from: https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.xhtml?popup=true&id_trabalho=11895742

Figures 4, 5, and 6 are part of the sensory mapping conducted with parents or guardians of a child/adolescent who is on the ASD.

Figure 4 represents the response to the following question: "Which sensory stimuli (vision, hearing, touch, smell, and taste) impact the development of the child/adolescent with autism, for whom you are responsible, during their activities in school and home environments?"

Figures 1 and 4 show that hearing is the sensory stimulus that most significantly affects individuals with autism during their activities in school environments.

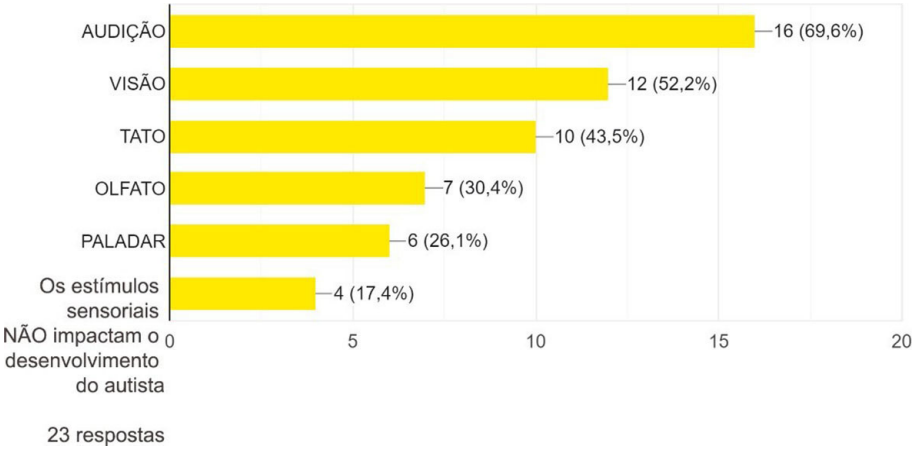

Figure 4: Sensory stimuli that most impact the development of students, children/adolescents with autism, according to responses from guardians. Source: Silva (2022). Available from: https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.xhtml?popup=true&id_trabalho=11895742

Figure 5 represents the response to the following question: "Please identify which SCHOOL environments negatively affect the child/adolescent with autism, for whom you are responsible, due to AUDITORY stimuli that trigger stereotyped behaviors and negatively impact their development."

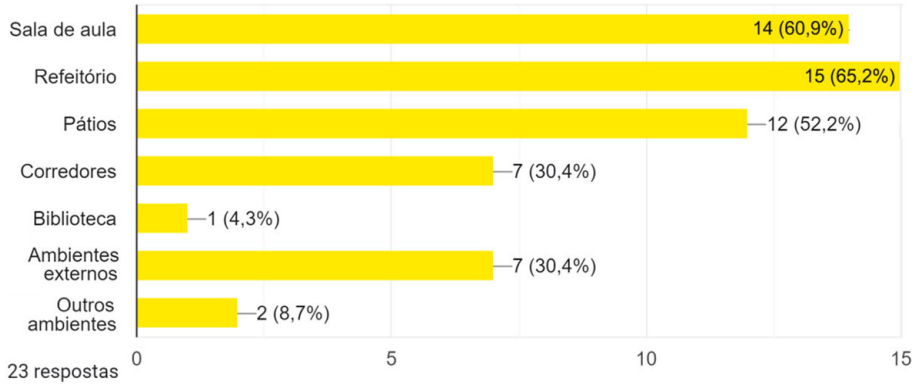

Figure 5: School environments where students, children/adolescents with autism, are most negatively affected by auditory stimuli, according to responses from guardians. Source: Silva (2022). Available from: https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.xhtml?popup=true&id_trabalho=11895742

As observed in Figures 2 and 5, the school environments that most negatively impact students with autism due to auditory stimuli are the classroom and the cafeteria.

Figure 6 represents the response to the following question: "Which AUDITORY stimuli present in the environment(s) selected in Figure 5 negatively impact the behavior of the child/adolescent with autism for whom you are responsible? Please select one or more options."

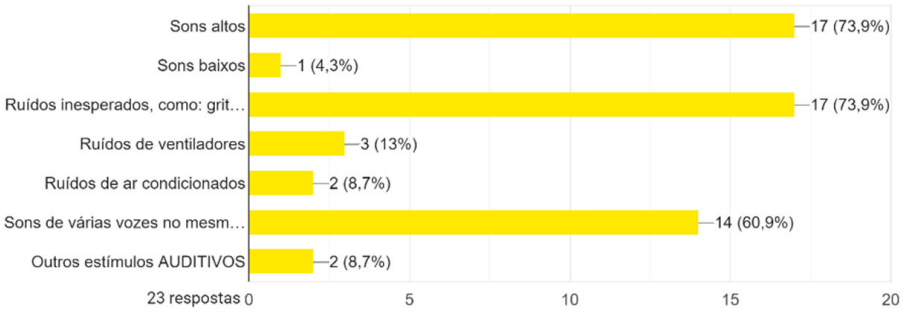

Figure 6: Auditory stimuli present in school environments (Figure 5) that most negatively impact the behavior of students, children/adolescents with autism, according to responses from guardians. Source: Silva (2022). Available from: https://sucupira.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.xhtml?popup=true&id_trabalho=11895742

As indicated in Figures 3 and 6, loud noises, unexpected sounds, and the sound of multiple voices in the exact location are the auditory stimuli that most negatively impact the behavior of students, children/adolescents with autism.

In light of the highlighted information, it is clear that auditory stimuli are the most significant negative influence on students with ASD during their academic activities. The classroom and cafeteria are the school environments with the most significant negative impact from noise. This underscores the need to establish architectural design guidelines that consider the auditory sensory characteristics of individuals with autism to promote balance in their auditory sensory system and achieve acoustic comfort.

Design recommendations for acoustically sensitive environments for autistic students: the inclusive regular classroom and cafeteria

Based on the analyses conducted in this research, there is a clear need to propose educational environments that appropriately stimulate individuals with autism. This study provides design recommendations for the inclusive regular classroom and the cafeteria, identified through sensory mapping as the environments that most negatively impact autistic students due to auditory stimuli.

To ensure that a regular classroom is inclusive and sensitive to the needs of students with ASD, the architectural design must manage sensory information effectively. This allows autistic students to remain in the environment for extended periods and engage in activities that require attention and concentration. Additionally, the

GENERAL PARAMETERS FOR ENVIRONMENTS	GENERAL DESIGN RECOMMENDATIONS	ENVIRONMENTS	SPECIFIC RECOMMENDATIONS BY ENVIRONMENT
➢ Locate external and internal sound sources. ➢ Select appropriate construction materials. ➢ Mitigate/control the transmission of external noise into the interior environments. ➢ Position openings, doors, and windows with consideration of external and internal noise sources. ➢ Mitigate/control the transmission of noise between internal environments. ➢ Enhance the acoustic intelligibility of speech. ➢ Reduce multiple sound reflections and increase sound absorption. ➢ Decrease sound reverberation time. ➢ Provide necessary reverberation to ensure speech intelligibility for listeners further from the sound source. ➢ Mitigate/control airborne noise (voices, horns, etc.). ➢ Mitigate/control impact noise (object falls, footsteps, etc.). ➢ Mitigate/control background noise (noise generated within the	**1) Geometry of the space that contributed to the reverberation of sound:** 1.1) Design spaces to enhance acoustic comfort. **2) Floor that is easy to maintain and contributes to noise attenuation/control:** 2.1) Noise control between floors: • Acoustic blanket under the subfloor; • Acoustic blanket under the cladding; • Floating slabs; and 2.2) Control of noise between floors and noise coming from the use of the rooms, such as dragging chairs, tables, other furniture, falling objects: • Internal flooring to control noise and impact. **3) Easy-to-maintain wall that contributes to noise attenuation/control:** 3.1) Double external walls with acoustic insulation: masonry + internal filling of PET wool + masonry; 3.2) Double wall with insulation partially filling the air gap (thermal and acoustic insulation of double external walls with expanded cork agglomerate, partially filling the air gap); 3.3) Double drywall partitions with internal filling of PET wool to divide the teaching rooms; 3.4) Use of cork in the walls to control noise and display teaching materials; and 3.5) To eliminate the throbbing echo between two parallel, rigid walls, cover one or both with fiberglass panels covered with fabric, or similar sound-absorbing material. (This works well if the panels are interspersed along the opposite walls, so that a panel on one wall faces the untreated surface of the opposite wall). **4) Easy-to-maintain roof:** 4.1) Use of PET wool panels developed for acoustic treatment; 4.2) Use of coverings that have perforations and grooves that absorb sound due to their perforation, providing acoustic comfort and noise reduction; and 4.3) Use of wooden ceilings with perforations and grooves that absorb	**Inclusive regular classroom**	The inclusive mainstream classroom needs to be acoustically controlled so that the autistic person can stay in this environment for as long as possible and can carry out activities that require attention and concentration. 1) Inclined reflective ceiling in the front area (speaker/teacher area). 3) Use of panels made of absorbent material on the back wall of the rooms to prevent the teacher's voice from reflecting from the back to the front of the classroom, causing multiple reflections. 4) Acoustically reflective panels made of MDF for the central area of the ceilings to provide the reverberation of sound necessary for speech intelligibility. 5) Fix acoustic foam under the seat cushions to absorb noise. 5) Use anti-noise protectors on the bases (feet) of each chair and on the table. 2, 3, 4, and 5) Create micro-environments with greater acoustic control within the classroom, so that students with ASD are in the same teaching environment as neurotypical students and, at the same time, have their individuality and auditory sensitivity respected. This microenvironment would function as a kind of cocoon, and by means of absorbent

environment itself).	sound due to their perforation, providing acoustic comfort and noise reduction. **5) Flexible furniture - desks/tables/chairs that contribute to noise attenuation/control:** 5.1) Use of individual pieces of furniture with soft, sound-absorbing acoustic foam upholstery. **6) Safe, efficient soundproofed openings to isolate internal environments from external noise and internal environments from other internal environments:** 6.1) Double-glazed acoustic windows: with 6 mm glass + 20 mm air chamber + 6 mm glass; and 6.2) Wooden acoustic doors. **7) Safe, efficient air conditioning that attenuates noise:** 7.1) Use of ultra-quiet air conditioning units. **8) Sizing the environment and the number of users:** 8.1) A minimum area of 2.00m^2 per student is recommended. However, it is necessary to check this minimum area against the different types of spatial arrangements of the environments and not just considering the square area. **9) Safe, efficient hydro-sanitary system that attenuates noise:** 9.1) Blankets for the acoustic insulation of hydro-sanitary pipes, with the aim of attenuating vibrations and airborne noises coming from the passage of water through the hydraulic system. **10) School buzzer:** 10.1) Use time markers to announce the end of one lesson and the start of another without generating auditory sensory overload, not using the conventional signal. Use clocks in classrooms.		materials around the "walls," on the "ceiling" and on the "floor" this more controlled microenvironment would be created to control the noise that reaches the user.
		Cafeteria	The cafeteria needs to control the acoustic information so that the autistic child can eat with the other students and practice socialization. 5) Fix acoustic foam under the seat frame to absorb noise. 5) Use anti-noise protectors on the bases (feet) of each chair and table. 5) Use individual and collective furniture with upholstery made of noise-absorbing materials. 2, 3, 4, and 5) Create micro-environments with greater acoustic control within the cafeteria that allow students with ASD to be in the same environment and have their meals with neurotypicals, but at the same time allow autistic students to have their individuality and hearing sensitivity respected. This environment would function as a kind of cocoon, whereby absorbent materials around the "walls," on the "ceiling" and on the "floor" would create a more controlled micro-environment to control the noise that reaches the user.

Table 1: Matrix of recommendations for inclusive regular classrooms and cafeterias in schools sensitive to autistic students - acoustic comfort. Source: Adapted from Silva (2022).

classroom should include spaces for both collective and individual use, respecting the individuality and personal space of students with autism. Similarly, cafeterias must also manage sensory information so autistic students can comfortably eat and socialize. The cafeteria must offer communal and individual spaces to honor the personal space and individuality of students with autism (Silva, 2022).

Thus, based on a systematic literature review and responses gathered through the MABA Sensory Mapping, design recommendations have been developed (as shown in Table 1) for the inclusive regular classroom and cafeteria in schools sensitive to students with ASD.

Thus, it is evident that designing the inclusive regular education classroom and cafeteria around the sensory specificities of individuals with autism can significantly enhance their sensory perception by minimizing sensory overload and appropriately stimulating their senses. This approach benefits students with ASD and contributes to their academic and social development.

Final Considerations

From this study, it is crucial to consider the characteristics of autistic students when designing school architecture. This approach allows the development of spatial solutions and proposals that consider the sensory particularities of individuals with autism, thereby improving the quality of education and learning for these students.

The application of sensory mapping revealed that hearing is the sense that most significantly affects the behavior of individuals with autism and, consequently, their academic and social development. Exposure to noise in environments such as the mainstream classroom and cafeteria — identified as the most negatively impacted by auditory stimuli — can lead to sensory overload and trigger stereotypic behaviors.

The recommendation matrix created for the above environments outlines general parameters and general and specific design recommendations. The specific recommendations emphasize the importance of creating more controlled microenvironments within these key spaces, intending to protect the personal space of individuals with autism.

In this way, recognizing educational environments as places capable of adequately accommodating diverse individuals who interact with the environment in specific ways is to recognize the built environment as a facilitator of human development for the entire school community. The analysis of the particularities of individuals with autism has allowed the identification of critical characteristics inherent in the physical structure of schools and has enabled the development of recommendations for designing acoustically sensitive school environments. These recommendations aim to create spaces that meet the auditory sensory needs of autistic students, thereby promoting their sensory development, independence, and academic growth.

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