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ARTICLES

Remote microphone systems as assistive technology for children with autism spectrum disorder: what does the evidence say?

Sistemas de microfone remoto como tecnologia assistiva para crianças com transtorno do espectro autista: o que dizem as evidências?

Sistemas de micrófono remoto como tecnología asistiva para niños con trastorno del espectro autista: ¿qué dice la evidencia?

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Abstract

Introduction: The Remote Microphone System (RMS) is an assistive technology designed to facilitate speech perception. Hearing children diagnosed with Autism Spectrum Disorder (ASD) may present auditory deficits, auditory hyper-responsiveness, or both, and may also benefit from RMS. **Objective:** To assess the benefits of using RMS in hearing children diagnosed with ASD. **Methods:** This study is an integrative literature review. A search was conducted in different databases, including studies that evaluated the use of RMS in hearing children diagnosed with ASD. **Results:** Six studies were included. Four of them also assessed teachers and/or parents. The studies demonstrated an improvement in speech perception in noisy environments with the use of RMS, as well as a reduction in auditory-related stress. Teachers reported improvements in auditory comprehension, classroom behavior, and attention. Parents

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ACJM, TFA: contributed to the methodology, data collection, data analysis, and manuscript writing.
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observed better performance in different environments and at a distance. **Discussion:** RMS can enhance communication and social interaction in children with ASD. However, some children may reject the use of personal receivers due to tactile hyper-responsiveness. **Conclusion:** The use of RMS in hearing children diagnosed with ASD may offer multiple benefits, such as improved speech perception in noisy environments, reduced stress in complex listening situations, enhanced perception of emotional prosody, increased attention and auditory memory, and a decrease in disruptive behaviors. However, the benefits vary among children, and it is not possible to guarantee them for the entire ASD population.

Keywords: Child; Autism spectrum disorder; Speech perception; Self-help devices.

Resumo

Introdução: O Sistema de Microfone Remoto (SMR) é uma tecnologia assistiva que visa facilitar a percepção auditiva da fala. Crianças ouvintes diagnosticadas com transtorno do espectro autista (TEA) podem apresentar déficits auditivos, hiper responsividade auditiva ou ambos, e também podem se beneficiar do SMR. **Objetivo:** avaliar os benefícios do uso do SMR em crianças ouvintes diagnosticadas com TEA. **Métodos:** trata-se de revisão integrativa da literatura. A busca foi realizada em diferentes bases de dados e foram incluídos estudos que avaliaram o uso do SMR em crianças ouvintes diagnosticadas com TEA. **Resultados:** seis estudos foram incluídos. Quatro estudos incluíram também a avaliação com professores e/ou pais. Os estudos demonstraram uma melhora na percepção auditiva da fala em ambientes ruidosos com o uso do SMR, além de uma redução do estresse relacionado à audição. Professores relataram melhorias na compreensão auditiva, no comportamento em sala de aula e na atenção. Pais perceberam melhor desempenho em diferentes ambientes e à distância. **Discussão:** O SMR pode favorecer a comunicação e interação social de crianças com TEA. Pode haver rejeição ao uso dos receptores pessoais por hiper responsividade tátil. **Conclusão:** O uso do SMR em crianças ouvintes diagnosticadas com TEA pode oferecer múltiplos benefícios, como uma melhor percepção da fala em ambientes ruidosos, redução do estresse em situações complexas de escuta, aprimoramento na percepção da prosódia emocional, aumento da atenção e da memória auditiva, além da diminuição de comportamentos disruptivos. No entanto, os benefícios variam entre as crianças, não sendo possível garanti-los em toda a população com TEA.

Palavras-chave: Criança; Transtorno do espectro autista; Percepção da fala; Tecnologia assistiva.

Resúmen

Introducción: El Sistema de Micrófono Remoto (SMR) es una tecnología asistiva diseñada para facilitar la percepción del habla. Los niños oyentes diagnosticados con Trastorno del Espectro Autista (TEA) pueden presentar déficits auditivos, hiperresponsividad auditiva o ambos, y también pueden beneficiarse del SMR. **Objetivo:** Evaluar los beneficios del uso del SMR en niños oyentes diagnosticados con TEA. **Métodos:** Se trata de una revisión integrativa de la literatura. Se realizó una búsqueda en diferentes bases de datos y se incluyeron estudios que evaluaron el uso del SMR en niños oyentes diagnosticados con TEA. **Resultados:** Se incluyeron seis estudios. Cuatro de ellos también evaluaron a profesores y/o padres. Los estudios demostraron una mejora en la percepción del habla en entornos ruidosos con el uso del SMR, además de una reducción del estrés relacionado con la audición. Los profesores informaron mejoras en la comprensión auditiva, el comportamiento en el aula y la atención. Los padres percibieron un mejor desempeño en diferentes entornos y a distancia. **Discusión:** El SMR puede favorecer la comunicación y la interacción social de los niños con TEA. Sin embargo, algunos niños pueden rechazar el uso de los receptores personales debido a la hiperresponsividad táctil. **Conclusión:** El uso del SMR en niños oyentes diagnosticados con TEA puede ofrecer múltiples beneficios, como una mejor percepción del habla en entornos ruidosos, reducción del estrés en situaciones auditivas complejas, mejora en la percepción de la prosodia emocional, aumento de la atención y la memoria auditiva, así como una disminución de los comportamientos disruptivos. No obstante, los beneficios varían entre los niños y no se pueden garantizar en toda la población con TEA.

Palabras clave: Niño; Transtorno del espectro autista; Percepción del habla; Dispositivos de autoayuda.

Introduction

The Remote Microphone System (RMS) is an assistive technology that aims to facilitate speech perception in noisy, reverberating settings and/or over distance between the listener and the sound source. The RMS encompasses different devices, and includes an earlier technology, the Frequency Modulation System (FM)[1]. It basically consists of two components: the transmitter and the receiver. The transmitter has a microphone that captures the speaker's voice and sends a signal via digital modulation (DM) or via frequency modulation (FM) to the receiver, improving signal/noise ratio (SNR)[2], thus contributing to the listening effort in adverse situations[3].

RMS is widely used by hearing-impaired children in classrooms[4]. In this situation, the use of the device may significantly improve the SNR, simulating a situation where the teacher seems to be at only 30 cm distance from the student, disregarding his/her position in the classroom[5]. In the individual RMS, the receiver is connected with the child's hearing aid, whether an electronic device for sound amplification, cochlear implant (CI) or bone-anchored hearing aids (BAHA). As for the RMS in free field, the receiver is a strategically located acoustic box.

Currently, recommendation for the use of RMS has not been restricted to school settings. Studies have shown the benefits of using such technology by hearing-impaired children in household settings as well[6,7]. Moreover, there is the benefit for different populations. Shiels, Tomlin and Rance[8] assessed 28 children with normal hearing thresholds who had hearing disorders and verified significantly improved speech perception and attention in the participants who made use of the RMS. Benítez-Barrera et al.[9] verified changes in the plasticity of the neural encoding of sound in schoolchildren after training with the use of RMS due to the optimized transmitted signal. Evidence also points to RMS as the most efficient technology to improve speech intelligibility in cases of Central Auditory Processing Disorders with probable changes in the neuroplasticity[10] in the long run.

There is a specific RMS device for individuals with normal hearing thresholds. It is the Roger Inspiro transmitter (Phonak®), which sends the sound to Roger Focus receivers, specifically designed to that population to provide safe, comfortable sound volume to its users. Individual receivers feature a thin tube and are open fit. It is fundamental to carry out the verification measures in their adjustment[11]. Formerly to the Roger model, Phonak® used to trade the Phonak® Inspiro transmitter with iSense receivers.

Once it can be recommended to children without changes in their hearing thresholds, another population may benefit from the use of the RMS, which is children with Autism Spectrum Disorder (ASD)[11]. Children with ASD may present hyper or hypo responsiveness to sensory stimuli[12]. Regarding hyperresponsiveness to hearing stimuli, literature presents different terminologies, as follows: hearing hypersensitivity, hyperacusis and hearing hyperresponsiveness. Authors claim that the term hearing hypersensitivity is inappropriate once it refers to a condition in a better hearing threshold than the one considered within normality, which is impossible to measure[13]. That is why, in the current study, the term hyperresponsiveness will be used.

James et al.[14] assessed 71 children between 6 and 14 years old, with normal hearing thresholds, diagnosed with ASD, and observed that 86% of them evidenced deficits in one or more applied tests. The authors verified typical failures in tests of speech recognition in the presence of noise, binaural integration and attention. Parents of children with ASD reported that the presence of noise resulted in difficulties in focusing on tasks, inattention, distraction and anguish in their children[11].

In a study[11] conducted with 12 children with normal hearing thresholds, diagnosed with Autism Spectrum Disorder (ASD), the authors observed significant improvement in attention and auditory memory in several situations in school settings as well as in household and social settings by means of the RMS. In addition, the use of the device by the participants significantly improved speech perception, noise tolerance in the presence of speech, and understanding of listening instructions. In face of the results, the authors suggested that the use of the RMS can be considered in the treatment and school and household management of the frequent auditory deficits in children with ASD.

Therefore, the current study aims to assess what scientific evidence states about the use of the RMS in children with normal hearing thresholds diagnosed with ASD.

Methods

Type of study

It is an integrative literature review which followed these steps: identification of the problem, search in the literature, assessment, data presentation and discussion.

The following guiding question was adopted: *"What are the benefits from the use of the RMS as an assistive technology for children with normal hearing thresholds diagnosed with ASD?"*

Search strategy

Search in Pubmed, LILACS and Scielo databases as well as in Scholar Google, Brazilian Digital Library of Theses and Dissertations (Biblioteca Digital Brasileira de Teses e Dissertações - BDTD) and CAPES Catalogue of Theses and Dissertations (Catálogo de Teses e Dissertações CAPES) was carried out on July 1st, 2024. The descriptors in Portuguese and English were selected from the Descriptors in Health Sciences (Descritores em Ciências da Saúde - DeCS) and Medical Subject Headings (MeSH). These descriptors were combined, according to what is presented in Chart 1. Search in the Scholar Google was limited to the first ten pages of results, considered the most relevant ones.

Chart 1. Descriptor combinations used in the search.

Databases	Search combination
Pubmed	("Child"[All Fields] OR "Child"[MeSH] OR "Children"[All Fields] OR "Child, Preschool"[MesH] OR "Child, Preschool"[All Fields] OR "Preschool Child"[All Fields] OR "Preschool Children"[All Fields]) AND ("Autistic Disorder"[MeSH] OR "Autistic Disorder"[All Fields] OR "Autism Spectrum Disorder"[MeSH] OR "Autism Spectrum Disorder"[All Fields] OR "Kanner Syndrome"[All Fields] OR "Infantile Autism"[All Fields] OR "Autism"[All Fields] OR "Early Infantile Autism"[All Fields] OR "Autistic Spectrum Disorders"[All Fields] OR "Autistic Spectrum Disorders") AND ("Self-help devices"[MeSH] OR "Self-help devices"[All Fields] OR "Assistive technology"[All Fields]) AND "Auditory Perception"[Mesh]
LILACS	("Child" OR "Children" OR "Criança" OR "Niño" OR "Enfant") AND ("Autistic Disorder" OR "Autism Spectrum Disorder" OR "Infantile Autism" OR "Autism" OR "Transtorno Autístico" OR "Autismo" OR "Autismo Infantil" OR "Trouble autistique") AND ("Self-help devices" OR "Tecnologia assistiva" OR "Dispositivos de Autoayuda" OR "Dispositifs d'assistance au mouvement") (db:("LILACS"))
Scielo	(criança) AND (transtorno do espectro autista) AND (tecnologia assistiva) AND in:("scl") #1 (((TS=(child)) OR TS=(children)) OR TS=(criança)) OR TS=(crianças)) OR TS=(niño) AND #2 ((((TS=(autistic spectrum disorder)) OR TS=(autism spectrum disorder)) OR TS=(autism)) OR TS=(transtorno autístico)) OR TS=(autismo infantil) AND #3 ((((TS=(self-help devices)) OR TS=(tecnologia assistiva)) OR TS=(dispositivos de autoayuda))
Biblioteca Digital Brasileira de Dissertações e Teses (Brazilian Digital Library of Dissertations and Theses)	"criança" AND "transtorno do espectro autista" AND "tecnologia assistiva"
Catálogo de Teses e Dissertações (Catalogue of Theses and Dissertations) - CAPES	criança AND transtorno do espectro autista AND tecnologia assistiva
Scholar Google	criança AND transtorno do espectro autista AND sistemas de microfone remoto child AND autistic spectrum disorder AND remote-microphone technology

Source: the authors

Selection criteria

Inclusion criteria were adopted as follows: studies available in full, with free access and/or by means of the Virtual Private Network (VPN), which assessed the use of the RMS in participants under 18 years old diagnosed with ASD. Excluded studies were studies of literature review, studies whose population presented hearing loss, studies which did not show results of participants under 18 years old separately, studies only carried out with adults (from 18 years old onward)[15], studies which did not display the results of participants with ASD separately, book chapters, informative articles on sites and event annals.

Selection process

The search was inserted in the *Rayyan* software, and duplicate studies were removed. Two independent reviewers blindly conducted the article selection, separately and simultaneously, using the blind spot mechanism of the software. In this process, retrieved studies were divided in three groups: included, excluded or maybe (which generated doubts). Initially, the studies were selected by title and abstract. A third reviewer solved the conflicts. Subsequently, full reading of the selected articles was carried out. With the application of the selection criteria, the inclusion or exclusion of the studies read in full was defined.

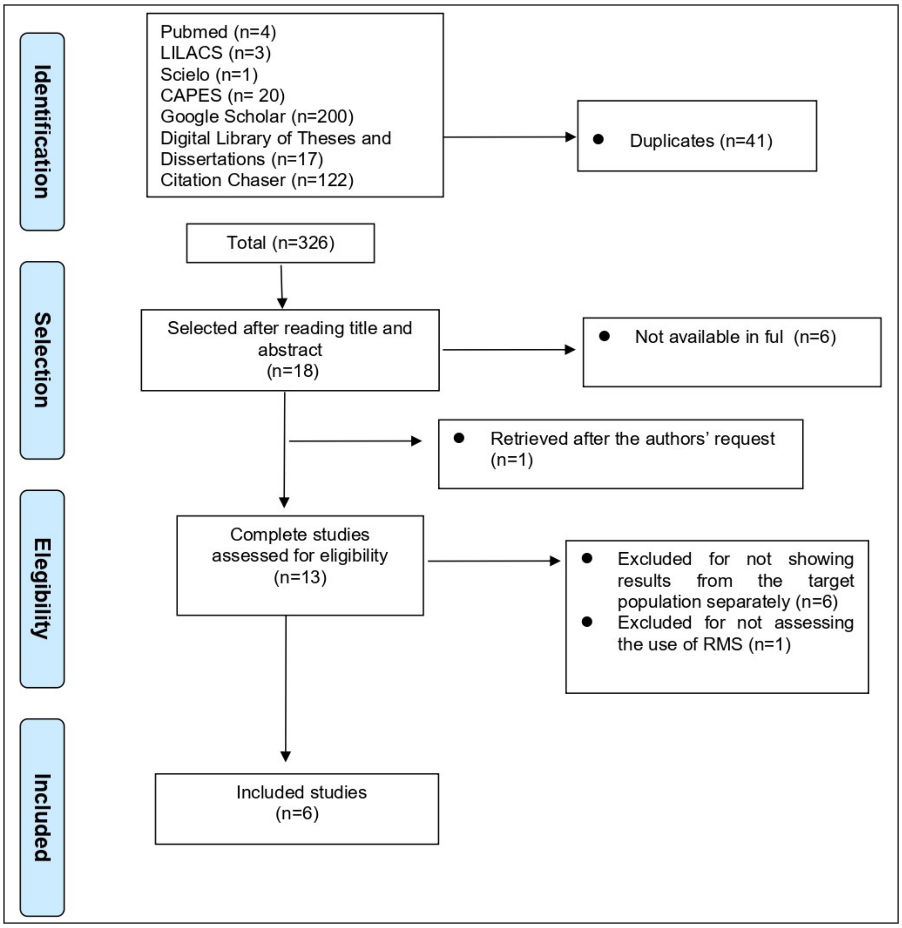
In the second step, the selected studies by title and abstract were inserted in the Citation Chaser platform. The retrieved studies by means of the platform were also reviewed by title and abstract, and the selected ones were fully read.

Data extraction

A table was elaborated for the data extraction by two independent reviewers. The following information was collected from the included studies after full reading: year of publication, authorship, sample size, participants' age, assessment method, assessment instruments, device used, main results and conclusion.

Results

A total of 367 studies were retrieved. After the exclusion of the duplicate articles, 326 studies remained; from those, 18 were selected by title and abstract. Six articles were not freely available in full or by means of the VPN and, after contacting the authors, only one of them was obtained. Thus, 13 articles were fully read. After their full reading, six studies[5,11,16-19] were included in this review (Figure 1).



Source: the authors

Figure 1. Descriptive flowchart of the search process

Three articles out of six included in this review were conducted in the United States of America (USA)[11,16,19], two in Australia[5,18], and one in New Zealand[17].

A total of 114 children were assessed, with 85 being diagnosed with ASD. Participants' age ranged between 3 and 17 years. Four studies[5,11,16,18] included not only the assessment of the child with ASD, but also the analysis under their teachers and/or parents' perspective. The main data of the studies included in the review are shown in Table 1.

Table 1. Main data of included studies in the review (n=6)

Year	Author	n	Age (years)	Assessment Method	Assessment Instruments	Device used	Main results	Conclusion
2020	Keller et al.	7	3 to 5	Assessment held in three classrooms with background noise of 65dB, during free play, interval between 1 and 7 days in a maximum period of 2.5 months. Sessions were audiovisually recorded and assessed blindly later, without reviewer's knowledge on the listening situation (RMS on or off)).	Observational measure of functional auditory performance by means of three instructional tasks held by the examiner during each assessment session: (a) response to the name, (b) identification of the object and (c) execution of an instruction from a step. Each task was assessed regarding: (a) level of independence of the stimulus, and (b) latency of the correct response (seconds between the end of the command by the examiner and moment in which the child provided the proper response). Numbered score was attributed based on the level (or amount) of necessary stimulus for the child to respond it successfully. The highest probable latency score for a child was10.	Phonak® Inspiro Transmitter. Receiver: Phonak® Roger DigiMaster 5000 sound field loudspeaker, fixed on the wall at a distance of about 1.2 to 3 meters	3 participants presented score indicating greater independence to perform the task with the RMS on. 4 participants showed lower latency to respond the situation with RMS on	There is evidence of modest short-term effects in the use of RMS on the functional auditory performance of pre-school children with ASD.
2017	Rance et al.	26	7 to 15	2 groups Group A (n=16): use of personal RMS Group B (n=10): use of RMS in free field Use of RMS for 1 to 2 weeks at school and at household environment for 4-6 hours a day.	Parents: CBCL; Teachers: TRF Children: APHAB; CNC; CELF-4; Cortisol Analysis	Transmitter: Phonak® Roger-Inspiro Receiver: Phonak® Roger Focus	Significantly better performance with RMS on the test of speech perception in noise. By using RMs, children with lower performance for their age in the CNC, were rated with normal hearing thresholds. .The rates of perceived difficulties were reduced with the use of the RMS. Two out of 6 parents who filled out the CBCL, after the use of the RMS, reported reduction in the level of their child's social anxiety. There was significant difference in the cortisol rate in noise by using the RMS.	The use of RMS may enhance speech perception and reduce listening-related stress in children with ASD.

Year	Author	n	Age (years)	Assessment Method	Assessment Instruments	Device used	Main results	Conclusion
2016	Schafer et al.	12	6 to 17	Assessment before and after 6 weeks from the test with RMS	Parents: CHILD Teachers: LIFE-R; CHAPS; Children: LIFE-R Student Version; BKB-SIN; RIPA-P; Acceptable Noise Level Test	Transmitter: Phonak® Roger-Inspiro Receivers: Phonak® Roger Focus	Enhanced speech perception in noise with RMS ranged from 0.25 to 9.25dB. In general, the participants showed noise tolerance level up to 10dB higher with RMS. Teachers observed significant benefits from the use of RMS in educational situations.	The use of RMS significantly improved speech perception, noise tolerance in presence of speech and understanding of listening instructions in children with ASD.
2014	Rance et al.	20	8 to15	2 groups: GE:with ASD. Use of the RMS for 4-6 hours/ day (n=10) GC: neurotypical; tests with and without RMS (n=10)	Teachers: LIFE Children: APHAB; Listening in Spatialized Noise test; CNC;	Transmitter: Phonak® Inspiro Receivers: Phonak ® iSense	Teachers considered RMS highly beneficial to the participating children. Significant improvement in speech perception with RMS in both groups. In the GE, average score in the CNC for the condition without RMS was 68.9%, and for the condition with RMS was 85.6%.	The use of RMS improved CAP skills, resulting in enhanced auditory recognition, attention and social interaction, being a feasible option to some children with ASD.
2013	Schafer et al.	22	9 to11	3 groups: SAD (n=7) ADHD (n=4) Neurotypical (n=11) Test 1: Use of RMS in classroom for 8 days during 45 min/day Test 2: Use of the RMS in classroom for 13 days	Parents: Teachers: SIFTER; CHAPS; Informal questionnaire of social validation Participants: BKB-SIN; Behavioral observation in classroom; Informal questionnaire of social validation	Transmitter: Phonak® Inspiro Receivers: Phonak ® iSense	Most children could tolerate and use the RMS receivers in a consistent way for 280 minutes in test 1, and 455 minutes in test 2. All children evidenced improvement in speech recognition in noise of a minimum 3dB in one of the two sessions of test. Maximum improvement with RMS was 11dB. In Test 1, there was advantage of 6.1dB for the group with ASD using RMS . In Test 2, the advantage was 7.8dB. Medians in teachers' assessments evidenced significantly lower listening difficulties for children who made use of RMS.	The use of RMS significantly improved speech recognition in noise and reduced inattention behaviors in children with ASD. Teachers reported positively on the benefit of the RMS in classroom.

Caption: ACS= Wechsler Advanced Clinical Solutions; ADHD=Attention Deficit/Hyperactivity Disorder; APHAB=Abbreviated Profile of Hearing Aid Benefit; ASD=Autism Spectrum Disorder; AT= Auditory Training; BKB-SIN=Bamford-Kowal-Bench Speech-in-Noise; CAEP= Cortical Auditory Evoked Potentials; CBCL=Child Behavior Checklist; CELF-4=Clinical Evaluation of Language Fundamentals; CHAPS=Children's Auditory Performance Scale; CHILD=Children's Home Inventory for Listening Difficulties; CNC=Consonant-Nucleus-Consonant Word Test; IVA-QS CPT=Integrated Visual and Auditory Quick Screen Continuous Performance Task; LIFE-R=Listening Inventory for Education-Revised; LBAS=Listening Behaviors in Autism Scale; LiSN-S=Listening in Spatialized Noise – Sentence; n= number of participants; MMN=Mismatch Negativity; RIPA-P=Ross Information Processing Assessment – Primary; SIFTER=Screening Instrument for Targeting Educational Risk; RMS=Remote Microphone System; SSP=Short Sensory Profile 2; TRF=Teacher Report Form

ARTICLES

References of the studies excluded after the full reading as well as the reasons for the exclusion are listed in Chart 2.

Chart 2. Excluded studies after full reading.

Reference of the excluded study	Reason
Dunn A, James P, Pelosi A, Sorensen E, Oleson J. Managing listening difficulties in patients with ASD and normal hearing sensitivity. Hear Rev. 2021; 28(10):12-16.	Did not assess the benefits fom the use of RMS.
Feldman JI, Thompson E, Davis H, Keceli-Kaysili B, Dunham K, Woynaroski T et al. Remote microfone systems can improve listening-in-noise accuracy and listening effort for youth with autism. Ear Hear. 2022; 43(2):436-447. Doi: https://doi.org/10.1097/AUD.0000000000001058	Population from 7 to 21 years old. Did not report the results of the population up to 18 years old separately
Gopal KV, Schafer EC, Mathews L, Nandy R, Beaudoin D, Schadt L et al. Effects of auditory training on electrophysiological measures in individuals with autism spectrum disorder. J Am Acad Audiol. 2020; 31:96-104. Doi: https://doi.org/10.3766/jaaa.18063	Combined use of auditory training
Leung JH, Purdy SC, Corballis PM. Improving emotion perception in children with autism spectrum disorder with computer-based training and hearing amplification. Brain Sci. 2021; 11(4):469. Doi: https://doi.org /10.3390/brainsci11040469	Combined use of auditory training
Schafer EC, Gopal KV, Mathews L, Kaiser K, Canale E, Creech A. Verification and validation of remote-microphone technology on children and college-age adults who have autism spectrum disorder. J Educ Ped Rehab Audiol. 2019; 24:1-7.	Population from 7 to 21 years old. Did not report results from population up to 18 years old or the population with ASD separately
Schafer EC, Gopal KV, Mathews L, Thompson S, Kaiser K, McCullough S et al. Effects of auditory training and remote microphone technology on the behavioral performance of children and young adults who have autism spectrum disorder. J Am Acad Audiol. 2019; 30:431-443.Doi: https://doi.org /10.3766/jaaa.18062	Combined use of auditory training
Schafer EC, Traber J, Layden P, Amin A, Sanders K, Bryant D et al. Use of wireless technology for children with auditory processing disorders, attention-deficit hyperactivity disorder, and language disorders. Semin Hear. 2014; 35(3):193-205. Doi: https://doi.org 10.1055/s-0034-1383504	Did not report results of children with ASD separately
Thompson E, Feldman JI, Valle A, Davis H, Keceli-Kaysili B, Dunham K et al. A comparison of listening skills of autistic and non-autistic youth while using and not using remote microphone systems. J Speech Lang Hear Res. 2023; 66(11):4618-4634. Doi: https://doi.org/10.1044/2023_JSLHR-22-00720	Population from 7 to 22 years old. Did not report results from population up to 18 years old separately

Source : the authors
Caption: ASD= Autism Spectrum Disorder; RMS= Remote Microphone Systems.

Discussion

The earliest study included in this review dates back 2013[16] and was conducted by a team of researchers from the USA. In Brazil, also in 2013, RMS (at the time making use of FM technology) was included in the Table of Procedures, Medications, Orthesis, Prosthesis and Special Materials of the Unified Health System (Sistema Único de Saúde – SUS) as an assistive technology for hearing-impaired children[20].

In the USA, it seems that scientific investigations on the theme have advanced as two studies included in this review were conducted in this country, and six fully read studies, but not included, which also assessed the benefit from the use of the RMS in individuals with ASD (Chart 2). Other studies related to this theme will also be presented in the form of subtopics in this discussion in order to facilitate reading.

Speech Perception

The studies[5,11,16-19] included verified that the RMS provided improvement in the speech perception in listening children diagnosed with ASD.

Schafer et al.[16] used a test of speech perception with competitive noise by presenting sentences for recognition at a fixed intensity (60 dBNA), and noise at varied ranges of intensity. The obtained result was the necessary SNR so that the child recognized speech in 50% of the presentations. Initially, that assessment was held within the last two days from a period of 8 days making use of the RMS. At a second moment, the assessment was repeated after a new period of 13 days of use. In both moments, two situations were assessed: without the use of RMS and with the use of RMS. The authors found the highly beneficial effect of the RMS in the studied sample. However, the analysis of the effect magnitude was conducted with combined data of groups of children with ASD and ADHD due to the sample size. When comparing the groups (children with ASD, children with ADHD and neurotypical children), the authors did not find significant differences, evidencing that children with ASD and ADHD may have the same benefit from the use of the RMS for speech perception in classrooms as their neurotypical peers.

In the study by Schafer et al.[11], all the eight assessed children evidenced a better threshold of speech recognition in the presence of noise during the use of the RMS. Improvement ranged between 0.25 and 1 dB for two participants, while for the other six participants, it ranged between 3.75 and 9.25 dB. In addition, five children could complete an assessment task at reasonable levels of noise, which demanded them indicate the level of competitive noise that they could tolerate while they would hear a speech signal. In general, the assessed children tolerated noise levels up to 10 dB louder with the use of the RMS, and one of the participants evidenced toleration to noise intensity up to 14 dB louder when making use of the device.

By assessing a mixed group of children and adults with SAD, Schafer et al.[21] reported an average improvement of 29% in speech perception in noise. In the study, 14 out of 19 participants experienced improvements ranging from 10% to 80%, with the other participants showing little or no improvement. Thompson et al.[22] assessed groups of young individuals with and without ASD and verified that the young with ASD evidenced better results regarding their speech perception with the use of the RMS. Rance et al.[18] assessed 20 children with ASD and reported that these children considered their hearing ability impaired in a wide range of circumstances. The authors observed that the RMS provided them with improved speech perception even without any previous training or experience with the device in ten participants who made use of it. All of them reported improvement in the SNR and greater facility in their social interaction by using the RMS.

Children with ASD may present dysfunctional or immature central auditory nervous system, resulting in deficits at the cortical and brain stem level, commonly occurring hearing disorders[23]. In the study by Rance et al.[18], 12 out of 20 children assessed (60%) evidenced CAPD. Among the population of children with ASD, speech perception is related to the non-verbal reasoning[24], occurring a bidirectional association between brain and behavior. Auditory perception influences language learning, while language use and experience facilitate efficient auditory processing[25]. Thus, considering that the RMS may enhance speech perception in children with ASD, the use of the device may contribute to better communication.

Rance et al.[5] assessed 26 children, dividing them into two groups: 16 participants, ages between 6 and 12 years, used the personal RMS, and 10 participants, ages 13 to 16 years, used RMS in free field in the classroom environment. The authors mentioned that the use of the personal RMS receiver is more tolerable for younger children than for adolescents, thus justifying the division between the groups. Results showed benefits for both types of RMS. However, the authors pointed out that RMS in free field is a feasible option to enhance auditory skills in the classroom for children with ASD, dismissing the use of the personal device. A randomized clinical study[26] concluded that free-field amplification systems can be used as a strategy in an inclusive classroom, supporting elementary-school students with ASD, who evidenced enhanced speech processing after the use of that technology. It is worth pointing out that the mentioned study[26] did not encompass the use of RMS.

Keller, Tharpe and Bodfish[19] assessed the efficacy in the use of RMS in free field in classrooms of preschoolers with ASD. Although the effects were modest, the results showed preliminary evidence that the device can be efficient to improve functional auditory performance among that population. During instructional procedures, the use of the RMS evidenced its strength to reduce response latency in some preschoolers with ASD, which, in turn, may increase the amount of active learning held at a certain timespan. Small improvements in the functional auditory performance, which favor the development of receptive language, fundamental in the first school years, may have significant impact on the development of communication and social interaction[19].

Children with ASD may also present difficulties in using emotional prosodic speech information, which may hinder their social communication[27]. In this context, Leung et al[17] aimed to investigate how the perception of emotional prosody differs between children with ASD and neurotypical children. Therefore, they conducted a longitudinal study which assessed the results of an intervention with children with ASD in four steps: twice before the intervention and twice after a period of three weeks from the intervention. During that period, all children with ASD participated in nine sessions of computerized auditory training, 20 to 30 minutes each session, three times a week, using their RMS. With the children's consent and their parents and teachers' support, the group with ASD also used the RMS in school and household environments during the intervention. All children presented normal hearing thresholds and were submitted to the Cortical Auditory Evoked Potentials (CAEPs) test, featuring recorded speech samples of /ba/ monosyllables by a male speaker, with irritating, happy, sad and neutral emotional tones of voice. In the post-intervention assessment, the authors observed that the main effect of the intervention (auditory training combined with the use of the RMS) was in the CAEP latencies. Before the intervention, the group of children with ASD produced significant slower responses when compared with the group of neurotypical children. After the intervention, there was significant improvement in the response speed of the children with ASD, eliminating the significant differences in latency between the groups. Moreover, after the intervention, the children with ASD began to react differently to different emotional tones of voice.

Evidence[28] shows that individuals with ASD present differences in their cortical auditory processing when compared with their neurotypical peers, being commonly observed a reduction in the amplitude, and increase in the CAEP latencies in this population[29]. Gopal et al.[30] assessed 15 children and adolescents with ASD, submitting them to computerized auditory training program combined with the use of the RMS in household and school settings for 12 weeks. Post-intervention results showed lower latencies and larger amplitudes of the brainstem auditory evoked potentials (BAEP). Schafer et al.[31] also assessed children and young adults with ASD and observed that the combination of a computerized auditory training program, oriented by a speech therapist, using RMS in household and school environments, significantly improved the skills of the central auditory processing and the working memory in this population. However, authors highlight that such evidence cannot be generalized to the whole population with ASD, as the studied sample was homogeneous regarding ethnicity and race, and had enough receptive language to understand task instructions In a study[32] conducted with adults with ASD, results uncovered functional disorders in the lateral temporal cortex for the information processing of the emotional prosody, and the reduction of the cortical response was associated with the ASD severity, closely correlated with social and communicative difficulties among that population. In that sense, considering that the use of the RMS may contribute to enhance the cortical responses as well as the processing of the emotional prosody, one may think about the benefit from the use of the device for the social and communicative difficulties of individuals with ASD.

Tactile hyperresponsiveness

Evidence points to dysfunctional somatosensory nerve cells in several models with ASD, in addition to disorders in brain circuitry, especially in the somatosensory cortex, closely associated with characteristic behaviors among that population[33].

In the study conducted by Schafer et al.[16], seven participants removed the RMS receiver during the use while reporting annoyance or discomfort. The time span that those children remained without the receiver, after its removal, ranged from 10 to 41.5 minutes, median of 18 minutes. Additionally, there were occasional reports of complaints related to the receiver retention in the ear. However, after adjustments performed by the professional, the participants remained with the device. Despite the reported difficulties by some participants, results suggest highly positive responses regarding the facility of its use and comfort.

Rance et al.[18] verified that two out of ten children who tested the RMS, did not adapt to the device. One of these children could not tolerate the use of the receiver in the ear for over some minutes due to their tactile hyperresponsiveness. The latency in the processing of tactile stimuli can be lower in children with ASD when compared with their neurotypical peers, even more acute in younger children. That evidence faster tactile processing and, consequently, higher tactile responsiveness in this population[34]. Thus, the use of the personal RMS receiver, located at the child's ear level, may not be a feasible option to all children with ADS[5]. In this context, the use of the RMS in free field (Dynamic Soundfield) seems to be a feasible alternative to enhance SNR in classrooms, especially to children with ADS who present tactile hyperresponsiveness.

Behavior

Among other signs, children with ADS may present disruptive behaviors, such as irritability and hyperactivity, which affect their social interactions negatively in household and school settings[35,36].

In the study by Schafer et al.[16], four evaluators (two primary evaluators and two for the analysis of reliability) observed the behavior of children with ASD in classroom. Assessments were held in 77 intervals of 30 seconds each, and behaviors were rated in seven main categories, including disruptive, inappropriate and inattentive behaviors. The size of the effect was calculated for conditions with and without the use of the RMS, with results pointing to significant effect, rated as large. These findings corroborate RMS efficacy to reduce disruptive behaviors in the classroom among children with ADS.

Rance et al.[5] also observed significant benefits related to the use of the RMS. In the study, the device reduced auditory stress in children, with results pointing out significantly lower levels of cortisol during challenging listening situations. Although it is not possible to determine what aspects of interaction improved with the intervention in a precise way, it is acceptable that the enhanced auditory sign provided by the RMS has contributed to their higher ability of focusing, thus reducing distraction, resulting in better joint attention.

Children with ASD may consistently be prone to enhancing their disruptive behaviors along the time, especially those who demonstrate better school adaptation and less need of support[36]. In this sense, it is essential to assess each case individually. Auditory interventions, which reduce stress, such as the use of the RMS, have shown relevant to that population and must be considered mainly in the school environment[5]. In addition, interventions that also address behavior issues may strengthen the benefit in other areas, improving social interaction between children and their peers and teachers, and promoting greater engagement in the proposed activities[37].

Teachers and parents' perspectives

During childhood and adolescence, household and school settings are the main interactional environments, both strongly influenced by behaviors of children with ASD[38]. In addition, the successful use of RMS requires partnership among speech therapist, family and school[1]. It is essential that all the involved individuals perceive the benefits of the device to the child. It is important to point out that not all children with ASD can understand instructions and answer questionnaires or tests of speech perception[11,16-18]. Therefore, parents and teachers' reports play a fundamental role in the assessment of the device by hearing health professionals.

In the studies included in this review, parents and teachers' perception was assessed by means of validated questionnaires, applied in the form of interview or independently filled out (Table 1). Teachers reported that the RMS was greatly beneficial for children with ASD, suggesting perceived improvement in the auditory understanding, in the classroom behavior and attention[11,18]. The teachers also observed positive changes in students' ability to follow verbal instructions in group situations, in noisy environments and during teachers' movements around the classroom[11]. In one of the studies[16], teachers' answers indicated moderate effects on the use of the RMS in quiet and noisy situations, as well as on the auditory memory, although its impact on the auditory attention was rated as low. In the whole, teachers reported more facility in attracting children's attention with the use of the RMS. However, they pointed out that some children presented more difficulty in adapting to it, and the device could be more useful in classrooms where students have academic levels.

Parents of children with normal hearing thresholds and ASD reported that their children presented fewer difficulties in quiet and noisy environments when they interacted with distant sound sources, and in social situations by making use of the RMS. They also observed a reduction in auditory hyperresponsiveness, with lower occurrence of negative responses to loud noise[11]. However, Rance et al.[5] verified that the use of the RMS did not change their aversion to sounds significantly; among parents who finished completing a questionnaire on their children's level of anxiety, two of them reported improvement over 15 points with the use of the device, while the others had similar answers in the conditions of use situations and not use of the RMS.

Despite the reported benefits, barriers for the use of the RMS may rise not only in household settings, but also in school settings. In a study[16], parents of a participant requested discontinuing the use of the RMS without justification, even after repeated requests from the school and from the researchers. The authors suggested that resistance could be associated with one of the parents' refusal in accepting the use of hearing aids by the child. Difficulties in the adherence to the use of the RMS have been reported even by hearing-impaired children who already make use of hearing aid[1]. Among the challenges mentioned which stand out, the shame of wearing the device and difficulty in handling it. Despite that, most parents of hearing-impaired children who do not adhere to the use of RMS, do not make any suggestions to improve the adjustment process[39].

That resistance can be even higher in children with normal hearing thresholds, considering that, initially, they do not present any evident need for auditory devices, and the use of the RMS may expose a condition that would not be visible, thus, bringing about potential stigmatization. In a study[11], two teachers refused to answer the questionnaires and implement the use of the RMS in the classroom by justifying that they did not know about the benefits of the device, how to handle it, and how it works[40]. That stresses the importance of guiding and training strategies, not only aiming at teachers of hearing-impaired children, but also those who work with children with ASD.

Other considerations

For the proper adaptation of the RMS in children with normal hearing thresholds diagnosed with ASD, Schafer et al.[21] provided evidence that supports a three-step approach: (1) to document the educational need for the use of the RMS; (2) to carry out the adjustment and electroacoustic verification of the device; (3) to validate the obtained benefits. The authors point out that the assessment of speech perception, combined with qualitative measures, may document the child's difficulties and justify the use of the device in school settings. This information can be collected by an educational speech therapist. However, the assessment of the use of the RMS in children with ASD feature significant challenges.

In the study by Schafer et al.[41], no children with ASD could complete the test of speech perception in noise. Rance et al.[18] reported that all participants in their study could communicate verbally and understand the instructions to carry out the proposed assessment. Fourteen out of 20 participants successfully completed the assessment task of auditory processing. In another study[11], children with ASD also present difficulties in understanding and carrying out tests of speech perception in noise, as well as answering the instruments, such as questionnaires. Eight out of 12 assessed children could participate in the test of speech perception with competitive noise.

Leung et al.[17] offered children with ASD, participants in their study, the possibility to conduct the behavioral evaluations and auditory training sessions in two settings: in the teaching clinic at the University or in a quiet environment, at the children's own homes. The authors pointed out the importance of making sure that those children were in an environment where they would feel comfortable and less anxious at the moment of the evaluation. To register for the BAEP, an acoustic booth was used, located at the University.

For further investigations on the benefits of RMS use in children with ASD, especially those which include tests on speech perception with competitive noise, and/or assessment of the auditory processing, it is essential to ensure the performance of the procedures at proper environments. Ensuring conditions that reduce probable interferences of disruptive behaviors favors more dependable and reliable responses.

Practical implications of the study

ASD is one of the most frequent causes of vulnerability in child development. The identification and management of the hearing impairment in that population are essential, considering that hearing loss, as well as auditory processing disorders are frequently observed and may worsen social difficulties and communication, central characteristics of this disorder. Listening difficulties in situations with competitive noise are common among children with ASD. Thus, the use of wireless technologies, particularly RMS, feature feasible strategies to cope with such difficulties in part of that population[42].

However, Keller, Tharpe and Bodfish[19] point that the use of the RMS should not be considered an isolated treatment, but it should be combined with evidence-based behavioral interventions, and with other devices of assistive technology, such as those from augmented and alternative communication.

Communication among researchers, professionals, managers in charge of formulating public policies and the community of individuals with ASD is essential to ensure that devices of assistive technology are available and accessible to that population[42].

Evidence[1,3-4] highlights the benefits from the use of the RMS for hearing-impaired children in Brazil. However, scientific articles have not been found on the use of the device by children with normal hearing thresholds, diagnosed with ASD until the completion of this review. The theme addressed in this study is recent and scarcely investigated. By discussing the benefits and prospective challenges related to the use of the RMS in children with normal hearing thresholds, diagnosed with ASD, the current study may serve as a starting point to trigger discussions on that possibility, particularly in Brazil where this recommendation has not been a reality yet.

Thus, speech therapists, who work with the adjustment of hearing aids, and those who work in intervention with children with ASD, may consider assessments among that population to recommend the use of the RMS as an assistive technology. Such initiatives may foster new studies which, in the long run, may contribute to the formulation of public policies oriented to the inclusion and well-being of those children.

Limitations

One of the limitations in this study is the fact that being an integrative review, not all the available databases were included. Only six studies presented the results on the RMS in children with ASD separately. In addition, the reduced number of participants was highlighted by the authors. Further research is suggested in order to investigate, in a broader way, the positive and negative effects of the use of the RMS in that population.

Conclusion

The use of RMS in listening children diagnosed with ASD may offer multiple benefits, such as better speech perception in noisy environments, reduction of stress in complex listening situations, improvement in the perception of emotional prosody, enhancement in attention and auditory memory, in addition to the reduction of disruptive behaviors. However, evidence points out that such benefits are not uniform to all the population with ASD. Children who rely on lower levels of support show greater benefit from the use of RMS, while those with tactile hyperresponsiveness may not tolerate the use of a personal receiver in the ear level. Thus, the importance of accurate, individualized assessment is deemed necessary before recommending its use for that population. Additionally, measurement of the device benefits can be challenging, demanding specific adjustments to meet each child's needs.

References

1. Esturaro GT, Youssef BC, Ficker LB, Deperon TM, Mendes BCA, Novaes BCAC. Adherence to Remote Microphone System at school in children and adolescents with hearing loss. CoDAS. 2022; 34(3): e20200326. Doi: https://doi.org/10.1590/2317-1782/20212020326

2. Walker EA, Curran M, Spratford M, Roush P. Remote Microphone Systems for preschool-age children who are hard of hearing: access and utilization. Int J Audiol. 2019; 58(4): 200-7. Doi: https://doi.org/10.1080/14992027.2018.1537523

3. Cruz AD, Gagné J, Cruz WM, Isotani S, Gauthier-Cossette L, Jacob RTS. The effects of using hearing aids and a frequency modulated system on listening effort among adolescents with hearing loss. Int J Audiol. 2020; 59(2): 117-23. Doi: https://doi.org/10.1080/14992027.2019.1671992

4. Carvalho DS, Pedruzzi CM. Uso do sistema de frequência modulada por escolares com perda auditiva. Dist Comum. 2019; 31(1): 12-21. Doi: https://doi.org/10.23925/2176-2724.2019v31i1p12-21

5. Rance G, Chisari D, Saunders K, Rault J. Reducing listening-related stress in school-aged children with autism spectrum disorder. J Autism Dev Disord. 2017; 47: 2010-22. Doi: https://doi.org/10.1007/s10803-017-3114-4

6. Benítez-Barrera CR, Angley GP, Tharpe AM. Remote microphone system use at home: impact on caregiver talk. J Speech Lang and Hear Res. 2018; 61(2): 399-409. Doi: https://doi.org/10.1044/2017_JSLHR-H-17-0168

7. Thompson EC, Benítez-Bezerra, CR, Angley GP, Woynaroski T, Tharpe AM. Remote microphone system use in the homes of children with hearing loss: impact on caregiver communication and child vocalizations. J Speech Lang Hear Res. 2020; 63(2): 633-42. Doi: https://doi.org/10.1044/2019_JSLHR-19-00197

8. Shiels L, Tomlin D, Rance G The assistive benefits of remote microphone technology for normal hearing children with listening difficulties. Ear Hear. 2023; 44(5): 1049-60. Doi: https://doi.org/10.1097/AUD.0000000000001351

9. Benítez-Barrera CR, Key AP, Murray MM, Retsa C, Ricketts TA, Tharpe AM. Plasticity changes in central auditory systems of school-age children following a brief training with a remote microphone system. Ear Hear. 2023; 44(4): 803-15. Doi: https://doi.org/10.1097/AUD.0000000000001329

10. Crum R, Chowsilpa S, Kaski D, Giunti P, Bamiou D, Koohi N. Hearing rehabilitation of adults with auditory processing disorder: a systematic review and meta-analysis of current evidence-based interventions. Front Hum Neurosci. 2024; 18: 1406916. Doi: https://doi.org/10.3389/fnhum.2024.1406916

11. Schafer EC, Wright S, Anderson C, Jones J, Pitts K, Bryant D et al. Assistive technology evaluations: remote-microphone technology for children with autism spectrum disorder. J Commun Disord. 2016; 64:1-17. Doi: https://doi.org/10.1016/j.jcomdis.2016.08.003

12. American Psychiatric Association. Manual Diagnóstico e Estatístico de Transtornos Mentais, 5ª Ed – DSM-5 [Internet]. Disponível em: https://www.institutopebioetica.com.br/documentos/manual-diagnostico-e-estatistico-de-transtornos-mentais-dsm-5.pdf [acesso 2024 Set 16].

13. Stefanelli ACGF, Zanchetta S, Furtado EF. Hiper-responsividade auditiva no transtorno do espectro autista, terminologias e mecanismos fisiológicos envolvidos: revisão sistemática. CoDAS. 2020; 32(3): 20180287. Doi: https://doi.org/10.1590/2317-1782/20192018287

14. James P, Schafer E, Wolfe J, Matthews L, Browning S, Oleson J et al. Increased rate of listening difficulties in autistic children. J Commun Dis. 2022; 99:106252. Doi: https://doi.org/10.1016/j.jcomdis.2022.106252

15. BRASIL. Lei nº 8069, de 13 de julho de 1990. Dispõe sobre o Estatuto da Criança e do Adolescente e dá outras providências [Internet]. 1990. Disponível em: https://www.planalto.gov.br/ccivil_03/leis/l8069.htm [acesso 2024 Set 17]

16. Schafer EC, Mathews L, Mehta S, Hill M, Munoz A, Bishop R et al. Personal FM systems for children with autism spectrum disorders (ASD) and/or attention-deficit hyperactivity disorder (ADHD). J Commun Disord. 2013; 46:30-52. Doi: https://doi.org/10.1016/j.jcomdis.2012.09.002

17. Leung JH, Purdy SC, Corballis PM. Improving emotion perception in children with autism spectrum disorder with computer-based training and hearing amplification. 2021; 11(4): 469. Doi: https://doi.org/10.3390/brainsci11040469

18. Rance G, Saunders K, Carew P, Johansson M, Tan J. The use of listening devices to ameliorate auditory deficit in children with autism. J Pediatr. 2014; 164(2): 352-57. Doi: https://doi.org/10.1016/j.jpeds.2013.09.041.

19. Keller MA, Tharpe AM, Bodfish J. Remote microphone system use in preschool children with autism spectrum disorder and language disorder in the classroom: a pilot efficacy study. Am J Speech Lang Pathol. 2021; 30(1): 226-78. Doi: https://doi.org/10.1044/2020_AJSLP-20-00056

20. BRASIL. Portaria nº 1.274, de 25 de junho de 2013. Inclui o Procedimento de Sistma de Frequência Modulada Pessoal (FM) na Tabela de Procedimentos, Medicamentos, Órteses, Próteses e Materiais Especiais (OPM) do Sistema Único de Saúde [internet]. 2013. Disponível em: https://bvsms.saude.gov.br/bvs/saudelegis/gm/2013/prt1274_25_06_2013.html [acesso 2024 Nov 06]

21. Schafer EC, Gopal KV, Mathews L, Kaiser K, Canale E, Creech A. Verification and validation of remote microphone technology on children and college-age adults who have autism spectrum disorder. J Commun Disord. 2016; 64: 1-17. Doi: https://doi.org/10.1016/j.jcomdis.2016.08.003

22. Thompson E, Feldman JI, Valle A, Davis H, Keceli-Kaysili B, Dunham K et al. A comparison of listening skills of autistic and non-autistic youth while using and not using remote microphone systems. J Speech Lang Hear Res. 2023; 66: 4618-34. Doi: https://doi.org/10.1044/2023_JSLHR-22-00720

23. Gonçalves LF, Paiva KM, Patatt FSA, Stolz JV, Haas P. Association between autism spectrum disorder and changes in the central auditory processing in children. Rev Assoc Med Bras. 2021; 67(1): 156-162. Doi: https://doi.org/10.1590/1806-9282.67.01.20200588

24. Chowdhury R, Sharda M, Foster NEV, Germain E, Tryfon A, Doyle-Thomas K. et al. Auditory pitch perception in autism spectrum disorder is associated with nonverbal abilities. Perception. 2017; 46(11): 1298-1320. Doi: https://doi.org/10.1177/0301006617718715

25. Arnett AB, Hudac CM, Deschamps TD, Cairney BE, Gerdts J, Wallace AS et al. Auditory perception is associated with implicit language learning and receptive language ability in autism spectrum disorder. Brain Lang. 2018; 187: 1-8. Doi: https://doi.org/10.1016/j.bandl.2018.09.007

26. Wilson WJ, Harper-Hill K, Armstrong R, Downing C, Perrykkad K, Rafter M et al. A preliminary investigation of sound-field amplification as an inclusive classroom adjustment for children with and without Autism Spectrum Disorder. J Commun Disord. 2021; 93:106142. Doi: https://doi.org/10.1016/j.jcomdis.2021.106142

27. Scheerer NE, Shafai F, Stevenson RA, Iarocci G. Affective prosody perception and the relation to social competence in autistic and typically developing children. J Abnorm Child Psychol. 2020; 48(7): 965-75. Doi: https://doi.org/10.1007/s10802-020-00644-5

28. Williams ZJ, Abdelmessih PG, Key AP, Woynaroski TG. Cortical auditory processing of simple stimuli is altered in autism: a meta-analysis of auditory evoked responses. Biol Psychiatry Cogn Neurosci Neuroimaging. 2021; 6(8): 767-81. Doi: https://doi.org/10.1016/j.bpsc.2020.09.011

29. Kamita MK, Silva LAF, Matas CG. Cortical auditory evoked potentials in autism spectrum disorder: a systematic review. CoDAS. 2021; 33(2): e20190207. Doi: https://doi.org/10.1590/2317-1782/20202019207

30. Gopal KV, Schafer EC, Mathews L, Nandy R, Beaudoin D, Schadt L et al. Effects of auditory training on eletrophysiological measures in individuals with autism spectrum disorder. J Am Acad Audiol. 2020; 31: 96-104. Doi: https://doi.org/10.3766/jaaa.18063.

31. Schafer EC, Gopal KV, Mathews L, Thompson S, Kaiser K, McCullough S et al. Effects of auditory training and remote microphone technology on the behavioral performance of children and young adults who have autism spectrum disorder. J Am Acad Audiol. 2019; 30: 431-43. Doi: https://doi.org/10.3766/jaaa.18062

32. Hashimoto R, Okada R, Aoki R, Nakamura M, Ohta H, Itahashi T. Functional alterations of lateral temporal cortex for processing voice prosody in adults with autism spectrum disorder. Cereb Cortex. 2024; 34(9): bhae363. Doi: https://doi.org/10.1093/cercor/bhae363

33. Schaffler MD, Middleton LJ, Abdus-Saboor I. Mechanisms of tactile sensory phenotypes in autism: current understanding and future directions for research. Curr Psychiatry Rep. 2019; 21(12): 134. Doi: https://doi.org/10.1007/s11920-019-1122-0

34. Espenhahn S, Godfrey KJ, Kaur S, Ross M, Nath N, Dmitrieva O et al. Tactile cortical responses and association with tactile reactivity in young children on the autism spectrum. Mol Autism. 2021; 12:26. Doi: https://doi.org/10.1186/s13229-021-00435-9

35. Hirota T, King BH. Autism spectrum disorder: a review. JAMA. 2023; 392(2):157-168. Doi: https://doi.org/10.1001/jama.2022.23661

36. Rosen NE, Schiltz HK, Lord C. Teacher-and parent-reported trajectories of maladaptive behaviors among individuals with autism and non-spectrum delays. Autism Res. 2023; 16(1): 174-89. Doi: https://doi.org/10.1002/aur.2854

37. Martins JS, Camargo SPH. A adaptação de crianças com autismo na pré-escola: estratégias fundamentadas na Análise do Comportamento Aplicada. Rev Bras Estud Pedagog. 2023; 104: e5014. Doi: https://doi.org/10.24109/2176-6681.rbep.104.5014

38. Bone ME, Leppert MLO. Autism spectrum disorder at home and in school. Pediatr Clin N Am. 2024; 71: 223-39. Doi: https://doi.org/10.1016/j.pcl.2024.01.008

39. Saltiél DR von, Teixeira AR, Costa SS da. The use of system of Frequency Modulation by children and adolescents from a hearing health care service. Audiol Commun Res. 2021; 26: e2459. Doi: https://doi.org/10.1590/2317-6431-2020-2459

40. Fidêncio VLD, Costa CA, Sousa IS, Romão JMFE. Investigation of the knowledge of teachers of regular schools of a region of the Federal District about the frequency modulation system. Audiol Commun Res. 2020; 25: e2278. Doi: https://doi.org/10.1590/2317-6431-2019-2278

41. Schafer EC, Traber J, Layden P, Amin A, Sanders K, Bryant D et al. Use of wireless technology for children with auditory processing disorders, attention-deficit hyperactivity disorder, and language disorders. Semin Hear. 2014; 35(3): 193-205. Doi: https://doi.org/10.1055/s-0034-1383504

42. Rance G. Wireless technology for children with autism spectrum disorder. Semin Hear. 2014; 35(3): 217-26. Doi: https://doi.org/10.1055/s-0034-1383506