



Review

Autism and central and peripheral hearing loss: A systematic review

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ABSTRACT

Background and objective: Individuals with autism spectrum disorder (ASD) may have an increased risk of developing both peripheral and central hearing loss. This study conducts a systematic review of the literature to determine their relationship.

Material and method: A systematic search of the PubMed and Web of Science databases was conducted for studies evaluating the potential association between autism and hearing loss. The initial search identified 840 studies. After applying the inclusion criteria, 21 studies were analysed.

Results: Seventeen studies found a predisposition to developing either central or peripheral hearing loss. Autistic children were also found to have an increased incidence of ear infections. In children with both autism and hearing loss, delays in diagnosis of either condition were observed due to overlapping clinical presentations.

Conclusion: Children with autism may have a higher risk for hearing impairment. Hearing tests are recommended to avoid delays in diagnosis and to provide the best therapeutic options.

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Autismo e hipoacusia central y periférica: revisión sistemática

RESUMEN

Fundamento y objetivo: Los individuos con Trastorno del Espectro Autista (TEA) pueden tener un mayor riesgo de desarrollar pérdida de audición tanto periférica como central. Este estudio realiza una revisión sistemática de la literatura para determinar su relación.

Material y método: Se realizó una búsqueda sistemática en las bases de datos PubMed y Web of Science de estudios que evaluaran la posible asociación entre autismo y pérdida de audición. La búsqueda inicial identificó 840 estudios. Tras aplicar los criterios de inclusión, se analizaron 21 estudios.

Resultados: Diecisiete estudios hallaron una predisposición a desarrollar pérdida de audición central o periférica. También se observó que los niños autistas tenían una mayor incidencia de infecciones de oído. En los niños con autismo y pérdida de audición, se observaron retrasos en el diagnóstico de ambas afecciones debido a la superposición de las presentaciones clínicas.

Conclusiones: Los niños con autismo pueden tener un mayor riesgo de padecer una discapacidad auditiva. Se recomienda realizar pruebas de audición para evitar retrasos en el diagnóstico y ofrecer las mejores opciones terapéuticas.

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Palabras clave:

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Introduction

Autism spectrum disorder

Autism spectrum disorder (ASD) is a group of neurodevelopmental disorders that includes autism, Asperger syndrome (AS), and pervasive developmental disorder-not otherwise specified (PDD-NOS).¹

ASD is characterized by difficulties in social communication and the presence of restricted, repetitive, and stereotyped behaviors. Clinical manifestations are heterogeneous, ranging from intellectual disability and limited language skills to above average intellectual and linguistic ability but with difficulties in social communication. These difficulties include problems in understanding social norms, rigid behaviors, and the need to maintain specific routines.²

A diagnosis of autism is reached after obtaining a patient's developmental history, often referred by parents, and observing the individual interacting with other people, according to the latest version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5).³

Autism comorbidities

Symptoms of ASD typically begin in childhood, usually from the age of 18 months. However, diagnosis is challenging because it often coexists with other clinical presentations such as attention deficit hyperactivity disorder (ADHD), anxiety, depression, or sleep disturbances. Additionally, individuals with ASD are at higher risk of presenting somatic comorbidities, such as epilepsy, gastrointestinal disorders, or visual and hearing impairments. Hyperstimulation is also common in these patients. They show disproportionate responses to sensory stimuli, including hyperacusis, sensory defensiveness, and aversion, and lack of habituation to stimuli.^{4,5}

Autism and hearing loss

There is growing evidence that people with ASD are at increased risk of developing hearing loss. This hearing loss may be conductive (CHL), due to alterations at the level of the outer or middle ear. These patients have been found to have an increased prevalence of middle ear impedance defects and an increased incidence of ear infections such as acute otitis media and suppurative otitis media.⁶⁻⁸

Hearing loss may also be neurosensory (SNHL), as alterations have been observed in the transmission of auditory stimuli at different levels of the inner ear, the auditory nerve, or the central nervous system, including the brainstem, which contains the cochlear nuclei, the superior olivary complex, the lateral lemniscus, and the inferior colliculus, the auditory thalamus, consisting of the medial geniculate nucleus and the thalamic reticular nucleus, and the auditory cortex at the level of the temporal and prefrontal lobes.⁹ In addition, these patients have a high prevalence of auditory processing disorders (APD), resulting in difficulties with sound and speech perception, especially in noisy environments, as well as problems with learning and responding verbally to others.⁶

Autistic individuals have been found to have altered lateralization in the auditory cortex, with either increased activity in the right hemisphere or decreased activity in the left hemisphere, which has been linked to language processing disorders in this population.¹⁰

There is also evidence that children with severe hearing loss are more likely to be diagnosed with ASD than those with milder hearing loss. The relationship between autism and hearing loss is

thought to be better explained by the presence of neurological alterations that lead to the development of these two conditions rather than the idea that hearing loss causes the development of ASD.^{11,12}

Peripheral hearing loss can be measured by pure-tone audiometry, and tympanic or ossicular alterations by tympanometry. Central auditory processing disorders can be detected by the auditory brainstem response (ABR), which measures the subcortical component, and by electroencephalography (N1 wave response), which measures the cortical component. The mismatch negativity (MMN) paradigm is used to demonstrate automatic orientation reflexes following the detection of disturbances in the individual's immediate environment by electroencephalography (EEG). The positive deflection, called P3a amplitude, can also be studied.¹³

Delayed diagnosis

Because reduced receptive and expressive language skills are a hallmark of ASD, ear disorders may remain undiagnosed and untreated for longer in this population than in neurotypical individuals. Diagnosis of one condition (hearing loss or autism) often leads to a delayed diagnosis of the other. Delayed diagnosis of ASD is due to misattribution of behaviors to hearing loss. Delayed diagnosis leads to poorer educational outcomes.^{6,14}

Objective

The aim of this study is to determine the association between autism spectrum disorder and hearing loss.

Material and method

Study design

This study conducted a systematic review of published studies investigating the association between autism and hearing loss. The study was designed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.¹⁵ A protocol for this systematic review was developed a priori and subsequently registered in the PROSPERO database before the start of the study (registration number: CRD42024540648).¹⁶

Search strategy

A systematic search of the PubMed and Web of Science databases was conducted for experimental studies published up to May 2024 that evaluated the potential association between autism and hearing loss. Search terms included: "autism" OR "autistic disorder" AND "hearing loss" OR "hearing impairment" OR "deaf" OR "deafness" OR "auditory processing" OR "peripheral hearing" OR "hearing". Details of the number of articles retrieved using these terms are shown in Fig. 1.

The search was limited to articles published in English, Spanish and French. In addition, systematic reviews and meta-analyses on the topic helped to identify additional articles missed in our initial database search.

Inclusion and exclusion criteria

Experimental studies evaluating the association between autism and peripheral and central hearing loss were included. Inclusion was restricted to controlled studies that confirmed

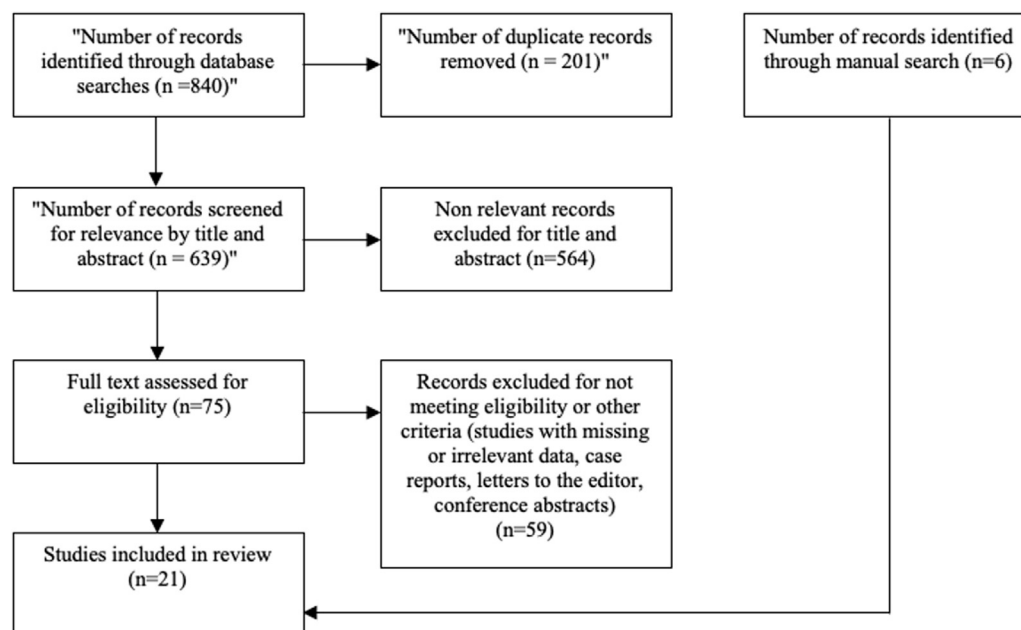


Fig. 1. Flow chart of systematic review.

the presence of autism by analyzing the patient's medical history, by clinical criteria according to the DSM, or by the Autism Diagnostic Observation Schedule (ADOS) or Autism Diagnostic Interview-Revised (ADI-R) questionnaires, and by testing for conductive and/or sensorineural hearing loss. Studies that analyzed the incidence of ear infections in people with autism and delays in diagnosis in people with both conditions were also included. Studies that examined other comorbidities in ASD without considering hearing ability and those that measured hearing ability in patients with neurodevelopmental disorders other than autism were excluded.

Data extraction and quality assessment

For each study, data extracted included study design, sample size, participant characteristics (age and gender), tests used to diagnose autism, tests used to measure hearing ability, and outcomes. The literature review was conducted by two reviewers independently of each other. Any discrepancies between the reviewers were resolved by consensus with the third co-author. The overall quality of the studies was assessed using the Newcastle-Ottawa Scale.¹⁷

Results

A meticulous review of the available literature that was published up to May 2024 was carried out. A total of 840 articles were obtained from the initial search. Two hundred and one duplicate records were removed. After reviewing of the titles and abstracts, 564 articles were not relevant and were removed. The identified studies were assessed for eligibility, and only those that investigated the association between autism and hearing loss, peripheral auditory defects in ASD, and auditory brainstem response abnormalities in autistic patients, as well as the diagnosis of hearing loss in people with autism, were included. Case studies, animal studies, letters to the editor, conference abstracts, reviews, and studies with missing or irrelevant data were excluded. Articles were retrieved and independently assessed for inclusion by two authors for inclusion. Fifty-nine records were excluded because they did not meet the eligibility criteria. Five studies were identified by manual

search. Twenty-one records were included in the review (Fig. 1). The following data from the included studies (study design, sample size, characteristics of the participants such as age and gender, tests used to diagnose autism, tests used to measure hearing ability, outcomes, and the score on the Newcastle-Ottawa Scale) are presented in Table 1.

Of the 21 articles included, 18 assessed the presence of peripheral or central hearing loss in children with a previously diagnosis of autism, 1 assessed the presence of autism in children with a previous diagnosis of hearing loss, 1 assessed the incidence of auditory infections in autistic patients, and 1 assessed the differences in clinical manifestations between autistic children with hearing loss and autistic children with preserved hearing. Of the 18 studies that assessed the presence of hearing loss in patients with autism, 16 found significant hearing deficits in these patients. Two of these studies also investigated the age of diagnosis of ASD in children with hearing loss.

Discussion

The association between autism and hearing loss is a topic of growing interest in the scientific community. Although current knowledge is limited, both disorders share several clinical and etiological characteristics that suggest a possible relationship.

Behavioral audiometry can be challenging in autistic children due to their lack of cooperation. Jure et al.,¹⁴ were able to carry out these tests on 46 autistic children with known hearing loss and found that severe or total deafness was present in 50% of cases. The cause of this hearing loss was unknown in half of the patients, while in the other half multiple etiologies were identified, including congenital infection, low birth weight and others. Similarly, Demopoulos et al.,¹⁸ found audiometric abnormalities in 13% of children with ASD, which correlated with those who had greater language difficulties. Altered audiometric results were also found in the study by Tharpe et al.,¹⁹ in which the hearing thresholds of autistic children were higher than in the control group. These findings are consistent with those of Rosenhall et al.,²⁰ who found that 7.9% of autistic individuals had mild hearing loss and 3.5% were deaf. In contrast, Gravel et al.,⁸ found no statistical differences in

Table 1
Characteristics of the included studies.

| Author and date | Study design | Sample (<i>n</i> children) ^a | Range of age ^b | Sex ^c | Development measures ^d | Audiological measures ^e | Audiological results in autistic patients | Audiological results in control group | Quality score (NOS) |
|---------------------------------------|----------------------------|---|----------------------------------|------------------------------------|-----------------------------------|---|---|---|---------------------|
| Skoff et al. (1980) ²² | Case-control | ASD: 19 Control: 20 healthy | 5–13 y Control: 5–16 y | 12 M, 7 F Control: 10 M, 10 F | N/A | ABR | Increased brainstem transmission time (interpeak I–IV latency) in 9 autistic children (56%) Abnormal impedance: 83% | Normal latencies | 6 |
| Smith et al. (1988) ²¹ | Case-control | ASD: 11 Control: 19 healthy | 45–217 m Control: 84–148 m | 8 M, 3 F Control: 9 M, 10 F | N/A | Tympanometry | | Abnormal impedance: 34% | 6 |
| Jure et al. (1991) ¹⁴ | Observational (no control) | ASD + HL: 46 | 10 m–17 y | 30 M, 16 F | DSM-3R | Behavioral audiometry PTA ABR | <ul style="list-style-type: none"> • HL: 1 (2.2%) mild, 8 (17.4%) moderate, 14 (30.4%) severe, 23 (50%) almost deaf • Age of diagnosis: HL: 2 years; ASD: 4 years • HL etiology: 23 unknown, 23 known (congenital infections, structural encephalopathy, hypoxia, encephalic malformation) | N/A | N/A |
| Rosenthal et al. (1999) ²⁰ | Case-control | +teenagers: ASD: 126 Control: 58 | 1.2–21.3 y Control: 4–20 y | 153 M, 46 F Control: 31 M, 27 F | DSM-3R | PTA ABR Tympanometry | <ul style="list-style-type: none"> • PTA/ABR (HL): 10 (7.9%) mild (all SNHL) (4 unilateral, 6 bilateral); 2 (1.6%) unilateral pronounced HL; 7 (3.5%) bilateral pronounced hearing loss/deafness; 18% hyperacusis • Tympanometry: 23.5% had serous otitis media | Normal results | 7 |
| Boddaert et al. (2004) ²³ | Case-control | ASD: 11 Control: 6 children with idiopathic mental retardation | 4–10 y Control: 3–9 y | 10 M, 1 F Control: 4 M, 2 F | DSM-4 ADI-R | rCBF (with PET) during passive listening to complex speech-like sounds while sleeping | <ul style="list-style-type: none"> • Activation of the auditory cortex in the bilateral superior temporal gyrus (Brodmann's area 22). No left dominance • Left middle temporal gyrus (Brodmann's areas 21 and 39) and the left precentral gyrus (Brodmann's area 43/6) were less activated | <ul style="list-style-type: none"> • Activation of the auditory cortex in the bilateral superior temporal gyrus (Brodmann's area 22). No left dominance • Brodmann's areas 21 and 39 normally activated | 8 |
| Gravel et al. (2006) ⁸ | Case-control | ASD: 37 Control: 37 healthy | 1.8–9.5 y Control: 6.2–12.6 y | N/A | ADI (parents) ADOS (children) | Behavioral audiometry Tympanometry OAE ABR | Non-significant differences (normal peripheral hearing) | N/A | 8 |

Table 1
(Continued)

| Author and date | Study design | Sample (<i>n</i> children) ^a | Range of age ^b | Sex ^c | Development measures ^d | Audiological measures ^e | Audiological results in autistic patients | Audiological results in control group | Quality score (NOS) |
|---|----------------------------|--|---|--|-----------------------------------|---|--|---|---------------------|
| Tharpe et al. (2006) ¹⁹ | Case-control | ASD: 22 Control: 22 healthy | 3–10 y Control: 3–10 y | 18 M, 3 F | DSM-4 | Behavioral audiometry Tympanometry OAE | Non-significant differences (normal peripheral hearing) | N/A | 7 |
| Tas et al. (2007) ²⁴ | Case-control | ASD: 30 Control: 15 healthy | 2–7 y. 21 M, 9 F Control: 2–6 y. 12 M, 3 F | 21 M, 9 F Control: 13 M, 3 F | DSM-4 | OAE ABR | <ul style="list-style-type: none"> • OAE absence: unilaterally in 2 (6.6%); bilaterally in 3 (10%) • ABR: <ul style="list-style-type: none"> - No wave V (80 dB) in ears of 3 children with bilateral negative OAE - Elevation of hearing level to 59 dB HL in the 2 children with unilateral negative OAE - Longer bilateral III–IV IPLs mean in ASD - No difference at mean latencies of waves I–V and I–III IPLs • 17 (2.2%) diagnosed with ASD + HL • Age of diagnosis: HL 16.4 m; ASD 51.5 m • OAE uni- or bilateral absence: 0.7-kHz, 66; 1-kHz, 58; 2-kHz, 39; 4-kHz, 40 • Tympanometry abnormal uni- or bilateral: 25 | <ul style="list-style-type: none"> • OAE: Present in both ears of all children • ABR: <ul style="list-style-type: none"> - Wave V was obtained in both ears of all children - Normal latencies on waves III–IV | 8 |
| Fitzpatrick et al. (2014) ²⁵ | Observational (no control) | HL: 785 | 0–18 y | N/A | DSM-4 | PTA ABR | <ul style="list-style-type: none"> • 17 (2.2%) diagnosed with ASD + HL • Age of diagnosis: HL 16.4 m; ASD 51.5 m | N/A | N/A |
| Rafal et al. (2013) ²⁶ | Case-control | ASD: 100 Control: 100 healthy | 3–18 y Control: 3–18 y | 81 M, 19 F Control: 51 M, 49 F | N/A | OAE Tympanometry | <ul style="list-style-type: none"> • OAE uni- or bilateral absence: 0.7-kHz, 66; 1-kHz, 58; 2-kHz, 39; 4-kHz, 40 • Tympanometry abnormal uni- or bilateral: 25 | <ul style="list-style-type: none"> • OAE uni- or bilateral absence: 0.7-kHz, 55; 1-kHz, 4; 2-kHz: none; 4-kHz, 36 • Tympanometry abnormal: 8 | 8 |
| Ludlow et al. (2014) ²⁷ | Case-control | ASD: 11 Control: 11 healthy | 11–16 y Control: 11–15 y | 11 M Control: 11 M | DSM-4 ADOS | MMN (with EEG) | <ul style="list-style-type: none"> • Reduced amplitudes for speech-like stimuli (words and pseudowords) • Reduced activation in frontal and central parietal regions with standard speech but not with non-speech stimuli • Detail-focused cognitive style (weak central coherence) • Prolonged latency (lower amplitude) • Right hemisphere is the dominant one in the processing of auditory stimuli | Normal latencies for speech-like stimuli | 8 |
| Azouz et al. (2014) ²⁸ | Case-control | ASD: 30 Control: 15 healthy | 2–7 y | 23 M, 7 F | DSM-4-TR ADI-R | ABR (subcortical auditory processing) N1 wave (cortical auditory processing) | <ul style="list-style-type: none"> • Prolonged latency (lower amplitude) • Right hemisphere is the dominant one in the processing of auditory stimuli | Normal latencies for speech-like stimuli | 7 |
| Miron et al. (2015) ²⁹ | Case-control | ASD: 30 Control: 30 healthy | 0.2 m–3.5 y Control: 2–5.5 m | 24 M, 6 F | DSM-4 | ABR | 70% prolonged latency wave V | 20% prolonged latency wave V | 8 |
| Adams et al. (2016) ⁷ | Case-control | ASD: 48,762 Control: 243,810 | 2–18 y | 38,373 M, 10,389 F Control: 205,355 M, 38,455 F | ICD-9-CM | Records of AOM, OME, otorrhea, and pressure equalizer (PE) tube placement | Incidence density per 100 person-years: <ul style="list-style-type: none"> • Acute otitis media: 4.78 • Otitis media with effusion: 2.17 • Otorrhea: 0.48 • Tube placement: 0.79 | Incidence density per 100 person-years: <ul style="list-style-type: none"> • Acute otitis media: 4.20 • Otitis media with effusion: 1.60 • Otorrhea: 0.27 • Tube placement: 0.36 | 8 |

Table 1
(Continued)

| Author and date | Study design | Sample (<i>n</i> children) ^a | Range of age ^b | Sex ^c | Development measures ^d | Audiological measures ^e | Audiological results in autistic patients | Audiological results in control group | Quality score (NOS) |
|--|----------------------------|--|-----------------------------|-----------------------------------|-----------------------------------|------------------------------------|---|---|---------------------|
| Demopoulos et al. (2016) ¹⁸ | Case-control | +teenagers ASD: 59 Control: 14 | 5–18 y | N/A | DSM-IV-TR ADOS ADI-R | PTA Tympanometry OAE ABR | PTA: 13% abnormal Tympanometry: 9% abnormal OAE: 18% abnormal ABR: 7% abnormal Deficient audition in 55% | PTA: 0% abnormal Tympanometry: 0% abnormal OAE: 0% abnormal ABR: 0% abnormal Deficient audition in 6% | 7 |
| Foss-Feig et al. (2017) ³⁰ | Case-control | ASD: 24 Control: 27 healthy | 10–13 y | N/A | ADOS, ADI-R | CELF-4 CTOPP | <ul style="list-style-type: none"> Higher auditory gap detection thresholds Impairment in rapid auditory temporal processing and poorer phonological processing and receptive language (impairment in communication) | Normal detection of auditory gap | 7 |
| Vlaskamp et al. (2017) ³¹ | Case-control | ASD: 35 Control: 38 healthy | 7 y 11 y | 28 M, 7 F Control: 27 M, 11 F | DSM-4-TR ADOS ADI-R | MMN P3a wave (with EEG) | Prolonged latencies | Normal latencies | 8 |
| Mamashli et al. (2017) ³² | Case-control | ASD: 19 Control: 17 healthy | 10–16 y Control: 10–14 y | 19 M -17 M | ADOS | MMF | Difficulties: <ul style="list-style-type: none"> Extract language from noise Processing auditory stimuli in noisy conditions Processing information | | 8 |
| Chen et al. (2019) ³³ | Case-control | ASD: 15 Control: 20 | 3–6 y | 12 M, 3 F Control: 14 M, 6 F | CARS ADOS | ABR | Prolonged latencies | Normal latencies | 7 |
| Ting et al., 2023 ³⁴ | Observational (no control) | ASD: 129 | 24.3–53.1 m | 103 M, 26 F | ADOS-2 ADI-R DSM-5 | PTA ABR | 13 (10%) mild HL (26–40dB) 2 (1.6%) moderate-severe HL (56–70 dB) 7 conductive HL/7 sensorineural HL/1 mixed 11 bilateral/4 unilateral | N/A | N/A |
| Hodkinson et al. (2023) ³⁵ | Case-control | ASD + HL: 65 Control (ASD-HL): 41 | 2–18 y | 55 M, 10 F Control: 28 M, 13 F | DSM-5 ADI-R | N/A | ADI-R: <ul style="list-style-type: none"> Mannerisms, rituals, facial expressions for communication and language: no differences ASD + HL: Responding to approaches from other children or engaging in imaginative play were reduced. | | 9 |

^a ASD: autism spectrum disorder; HL: hearing loss.^b y: years; m: months.^c M: male; F: female.^d DSM: Diagnostic and Statistical Manual of Mental Disorders; ADI: Autism Diagnostic Interview; ADOS: Autism Diagnostic Observation Schedule; ICD-9-CM: International Classification of Diseases, Ninth Revision, Clinical Modification; CARS: Childhood Autism Rating Scale.^e ABR: auditory brainstem response; PTA: pure-tone audiometry; rCBF: regional cerebral blood flow; PET: positron emission tomography; OAE: otoacoustic emissions; MMN: mismatch negativity; EEG: electroencephalography; CELF-4: clinical evaluation of language fundamentals; CTOPP: comprehensive test of phonological processing; AOM: acute otitis media; OME: otitis media with effusion.

hearing thresholds between the autistic and control groups during behavioral audiometry.

The studies reviewed have shown that hearing loss in autistic patients may be due to otic or neurological pathology. These two entities should be considered separately as they differ in clinical presentation and aetiology.

To investigate the occurrence of peripheral hearing loss in these patients, several studies have been conducted using tympanometry or impedance testing in children with ASD. The objective of these tests was to determine whether there were any changes in the middle ear. Smith et al.²¹ found that 83% of individuals with autism had abnormal tympanometric results, whereas only 34% of controls had alterations. Similarly, Rosenhall et al.²⁰ identified patterns of serous otitis media in 23% of autistic individuals using tympanometry and otomicroscopy.

Tas et al.²⁴ also found curves corresponding similar to those observed in chronic otitis media with effusion more frequently in autistic children than in controls. In contrast, no abnormalities were found in the studies by Tharpe et al.¹⁹ and Gravel et al.⁸

It is possible that these middle ear alterations are a consequence of the predisposition that autistic children have to develop otitis. Adams et al.⁷ reviewed the history of acute otitis media, otitis media with effusion, otorrhea, and tube placement in autistic and non-autistic children. They found a significantly higher incidence of these conditions in autistic children, especially those under the age of 10. This may be because autistic children have more risk factors for developing ear infections, such as reduced vaccination against pneumococcal or influenza due to the unfounded belief that vaccines may cause ASD.³⁶ It is also possible that the communication difficulties experienced by autistic children in expressing their otitis symptoms, and the difficulty of otoscopic examination due to lack of cooperation, may lead to delayed diagnosis and treatment.

Auditory brainstem response (ABR) has been the most used test to determine the prevalence of potential central hearing loss in the autistic population. Skoff et al.²² observed a prolongation of interpeak latencies I–IV in 56% of autistic children compared to the established normal limits in the control group. These areas correspond to the pontine area and the mesencephalon, specifically to the subcortical auditory system, the mesencephalic reticular formation, and the vestibular system, which are involved in the perception and modulation of sensory input.³⁷ Wave I, corresponding to cranial nerve VIII, was not altered, suggesting that this nerve is intact in these patients.²² In the study by Tas et al.,²⁴ interpeak latencies III–IV were significantly prolonged compared to controls. Azouz et al.²⁸ found significantly prolonged waves V latencies, interpeak latencies I–V, and interpeak latencies III–IV in the ASD group compared to the control group. Similar results were obtained by Miron et al.²⁹ and Chen et al.³³ It is possible that there is an alteration in the myelination of the auditory system in autism, resulting in a delay in the development of the neural network, which could explain the language impairment observed in these children.

Another possible explanation for central hearing loss is an alteration at the level of the cerebral cortex. There are several methods to measure brain activity in response to auditory stimuli. Boddaert et al.²³ analyzed cerebral blood flow (rCBF) in a group of autistic and neurotypical children while listening to speech-like stimuli using PET. They observed a reduction in cortical activation in areas associated with language in the left hemisphere, including Wernicke's area, in autistic people. The middle and inferior temporal gyri (Brodmann area 21) were also less activated. These areas are associative auditory areas involved in word processing.³⁸ Bilateral temporal auditory cortex was activated in both groups, but individuals with ASD showed an anomalous lateralization, with reduced activation on the left side compared to non-autistic individuals. The dysfunction of the left hemisphere cortical areas associated with language may explain the alterations in language development. In

addition, an abnormal functional network was activated with the activation of other brain areas outside the temporal lobe, including the posterior parietal lobe, brainstem, and cerebellum. The authors suggest that this may explain the exaggerated behavioral responses to sound exhibited by individuals with ASD.²³ Ludlow et al.,²⁷ analyzed the mismatch negativity (MMN) using electroencephalogram (EEG) to determine brain activity during automatic language processing. They observed a significant reduction in the amplitude of the MMN response to speech-like stimuli (both words and pseudowords) in frontal cortex and central parietal areas. This suggests that individuals with ASD have altered functional connectivity at the level of the cerebral cortex, particularly in circuits that connect frontal areas with other brain systems. As a result, auditory discrimination of infrequent changes in sounds is impaired in autistic children, without automatic attention to changes in auditory stimuli in the environment. They have a detail-focused cognitive style focused on details, called weak central coherence, which consists of an increased ability to focus on details rather than the whole, which has been demonstrated to be detrimental to the processing of other sounds.²⁷ In the study by Vlaskamp et al.,³¹ the maximum amplitude of MMN was observed in the frontocentral region of the brain and was smaller in autistic children than in neurotypical children. A reduction in the MMN has also been observed in patients with schizophrenia, raising the possibility that autistic children may be at an increased risk of developing schizophrenia.³⁹ A correlation has been found between symptom severity and MMN amplitude; with children with more severe ASD symptoms having higher MMN amplitudes, similar to those observed in children without ASD. This may explain their more sensitive automatic discrimination and hyper-responsiveness to deviant sounds, which may lead to greater distraction in everyday life.³¹ Mamashli et al.³² investigated the cortical response to a passive auditory mismatch paradigm with and without background noise, focusing on the neural source generators of auditory change detection (MMF). In the silence condition, the results were the same for autistic and non-autistic individuals. In the background noise condition, reduced MMF responses were found in the ASD group in the right inferior frontal gyrus (IFG), which plays a role in regulating the sensory system according to processing demands. In speech perception, the extent to which the IFG is involved determines the ability to extract speech in noisy environments. Azouz et al.²⁸ analyzed the latency of the N1c and found that it was also significantly prolonged in the ASD group. This suggests a slower transmission of information through neural pathways in these patients due to bitemporal hypoactivity in response to auditory stimuli. In addition, a right hemisphere dominance was observed in the processing of auditory stimuli, whereas in non-autistic subjects, they are predominantly processed in the left hemisphere. This suggests a reorganization of the right and left hemispheres during early neurodevelopment for auditory information processing, resulting in increased right hemisphere activation during tasks involving secondary auditory areas such as the lateral surface of the superior temporal gyrus, where the N1c wave is generated. In other words, right hemisphere compensation is secondary to early left hemisphere dysfunction.²⁸

Regarding the age of diagnosis of children with autism and ASD, Jure et al.¹⁴ found that the age of diagnosis of hearing loss was approximately 2 years old. In 5 of the 46 children with autism, the symptoms were attributed to autism, rather than hearing loss, which was overlooked. Similarly, in half of the participants, autism was not diagnosed until the age of four because the symptoms were attributed to hearing loss. This may be explained by the findings of Hodkinson et al.,³⁵ who used the ADI-R to assess similarities and differences in the symptoms of autistic children with and without hearing loss. Most of the items analyzed showed no significant differences between the two groups. These included preoccupation with intensity, mannerisms or stereotypes, routines, compulsions

or rituals, sensory interests or interest in the non-functional aspect of objects, and the use of facial expressions to communicate. It was observed that deaf autistic children were less likely to respond to other children's approaches or to engage in imaginative play. There were also no significant differences in the use of language. This allows us to understand the diagnostic delays in children with autism and hearing loss, as the symptoms overlap, and it is easy to attribute the same clinical entity.

These findings may suggest that there are prenatal or perinatal mechanisms that may lead to lesions at the level of the nervous system involved in hearing, or alterations in the middle ear that may predispose to complications of ear infections. Further research is needed to fully understand the relationship between autism and hearing loss and to identify potential early interventions that may improve the quality of life of affected children. It is also important to raise awareness among healthcare professionals of the importance of assessing both hearing and speech development in autistic children to avoid late diagnosis and ensure comprehensive care.

Our review of clinical studies seems to suggest that there is an association between hearing loss and autism at the central level. However, it is difficult to establish whether hearing loss leads to autism or whether autism is associated with central alterations in auditory perception at the cortical level. In the clarification of this relationship, studies in animal models both in peripheral⁴⁰ neuropathology and at central nervous system⁴¹ level are important.

Study limitations

The main limitation of this review was the limited number of studies conducted to date that investigate the relationship between autism and hearing loss. Another limitation was the difficulty in conducting tests, such as behavioral audiometry, to children with autism due to a lack of cooperation from some of them. This meant that some studies were unable to assess all participants with certain tests or had to assess hearing function with different tests for some participants. This made the data more heterogeneous and the analysis more difficult.

Conclusion

Although the relationship between ASD and hearing loss remains controversial, numerous studies have shown an increased prevalence of both central hearing loss, due to changes at the level of the brainstem and auditory cortex, and peripheral hearing loss, due to an increase in complicated ear infections in autistic children. This can lead to disruptions in language and communication development. Therefore, it is recommended that all children with suspected ASD have their hearing monitored on an ongoing basis to provide them with the best therapeutic option at an early stage.

CRediT authorship contribution statement

Acquisition of data: MC and AV.

Analysis: MS.

Ethics approval and consent to participate

This revision study did not need the approval by the Ethics Committee of our institution.

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Conflict of interest

The authors have no conflicts of interest to declare.

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