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Amblyaudia: Review of Pathophysiology, Clinical Presentation, and Treatment of a New Diagnosis

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Abstract

Objective. Similar to amblyopia in the visual system, "amblyaudia" is a term used to describe persistent hearing difficulty experienced by individuals with a history of asymmetric hearing loss (AHL) during a critical window of brain development. Few clinical reports have described this phenomenon and its consequent effects on central auditory processing. We aim to (1) define the concept of amblyaudia and (2) review contemporary research on its pathophysiology and emerging clinical relevance.

Data Sources. PubMed, Embase, and Cochrane databases.

Review Methods: A systematic literature search was performed with combinations of search terms: "amblyaudia," "conductive hearing loss," "sensorineural hearing loss," "asymmetric," "pediatric," "auditory deprivation," and "auditory development." Relevant articles were considered for inclusion, including basic and clinical studies, case series, and major reviews.

Conclusions. During critical periods of infant brain development, imbalanced auditory input associated with AHL may lead to abnormalities in binaural processing. Patients with amblyaudia can demonstrate long-term deficits in auditory perception even with correction or resolution of AHL. The greatest impact is in sound localization and hearing in noisy environments, both of which rely on bilateral auditory cues. Diagnosis and quantification of amblyaudia remain controversial and poorly defined. Prevention of amblyaudia may be possible through early identification and timely management of reversible causes of AHL.

Implications for Practice. Otolaryngologists, audiologists, and pediatricians should be aware of emerging data supporting amblyaudia as a diagnostic entity and be cognizant of the potential for lasting consequences of AHL. Prevention of long-term auditory deficits may be possible through rapid identification and correction.

Keywords

amblyaudia, conductive hearing loss, amblyopia, congenital hearing loss

Hearing loss is a common diagnosis in the pediatric population, estimated at 1 to 3 of every 1000 newborns and, due to diagnostic delay, at 4 to 10 of every 1000 school-aged children.[1-4] Despite advances in diagnosis and treatment of hearing loss over the past several decades, unilateral or asymmetric hearing loss (AHL) presents a particular problem, as cases are often unidentified, lost to follow-up, or undertreated.[5-8] Lack of treatment stems, in part, from the common belief that the contralateral ear with normal or near-normal hearing is able to compensate for a unilateral hearing loss.[7] Indeed, many cases of AHL, particularly in children with acquired or transient etiologies, go unnoticed by guardians or even children themselves.[8]

Several studies have shown, however, that AHL is not benign. Children with AHL have been observed to have higher rates of academic, social, and behavioral difficulties, with estimated rates of grade repetition as high as 30% to 50%.[9-14] As a result, a growing number of otolaryngologists and audiologists now advocate for correction of AHL by either amplification or surgical intervention. AHL management is largely completed on an individualized basis, and definitive treatment guidelines for AHL do not currently exist.[15]

Recent studies have shown another alarming phenomenon: Long-term hearing deficits may remain after even AHL has been treated if the correction was not completed

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within a critical time window.[16,17] This concept has been defined in the basic science literature as ''amblyaudia,'' a term with a literal translation of *dullness of hearing*.[18] The origin of the word ''amblyaudia'' stems from parallels to the visual system and the diagnosis of amblyopia. In amblyopia, a disparity of visual input at a young age results in the permanent loss of visual acuity in the nondominant, amblyopic eye, if undertreated. Amblyopia, an ophthalmologic diagnosis, is well defined, extensively studied, and often treatable. As with amblyopia, any etiology that causes an asymmetric loss of hearing (afferent signal) during critical windows of brain development may result in lasting difficulties in challenging listening environments, particularly with regard to sound localization and the utilization of binaural cues to process speech signals embedded in high levels of background noise.[19-22]

Herein, we aim to define the clinical concept of amblyaudia, illustrating contemporary research on its pathophysiology, prevention, and treatment. We seek to draw analogies to amblyopia, a well-studied diagnostic analogue. Finally, we aim to provide a discussion of amblyaudia to assist with clinical decision making and suggest areas for future research.

Methods

A review of the literature was conducted to identify articles related to the phenomenon of amblyaudia. Articles were identified by searching the MeSH terms ''hearing loss, conductive,'' ''hearing loss, sensorineural,'' ''hearing loss, congenital,'' and ''cochlear implantation'' with combinations of ''unilateral,'' ''asymmetric,'' ''pediatric,'' ''auditory deprivation,'' and ''auditory development.'' A wide array of articles was identified, including basic and clinical studies, case series, and reviews. Titles and abstracts were reviewed for potentially relevant articles. The reference lists of each study were also examined for additional relevant papers. As the etiology and clinical standards for assessing amblyopia are already well established, a literature search was performed to identify high-impact articles and recent reviews. The Preferred Practice Pattern guidelines published by the American Academy of Ophthalmology were used as a resource for additional references. Finally, auditory neuroscientists and experts in hearing loss were contacted to ensure inclusion of the most contemporary data and interpretations.

Discussion

Part 1: Definitions of Amblyopia and Amblyaudia

The visual and auditory systems both depend on the integration of bilateral afferent sensory input. In the visual system, each eye receives information from both left and right visual fields; nasal visual field information is projected ipsilaterally, while temporal visual field information is projected contralaterally, crossing at the optic chiasm.[23] These projections are integrated at the level of the primary visual cortex so that each brain hemisphere receives bilateral input from the corresponding visual fields of each eye.[23] The visual cortex is able to fuse input from the 2 eyes in its interpretation of a single image—a concept known as ''binocular vision.''[24] By utilizing the disparity between the 2 images, binocular vision affords many advantages, including contrast differentiation, depth perception, and target localization in space.[25-29]

Any disruption of visual afferent input in a single eye during a critical period of childhood development may result in abnormal and persistent deficits of central visual processing pathway, termed ''amblyopia.''[24] There are 3 primary types of amblyopia: strabismic, refractive, and deprivational.[30,31] Each type of amblyopia has a slightly different pathophysiologic basis; however, all 3 result in an asymmetric mismatch in sensory information gathered by each eye. Classic experiments by Hubel and Wiesel in the early 1960s first demonstrated the lasting effects of asymmetric visual input on the developing visual system in a cat model: after 1 eyelid was reversibly sutured shut from birth for a period of 2 to 3 months, the anatomic and neurophysiologic organization of the primary visual cortex revealed a persistent influence of monocular deprivation that greatly exaggerated the representation of the nondeprived eye at the expense of a diminished representation of the developmentally deprived eye.[32,33] The perceptual outcome is the creation of a ''dominant'' eye with normal or near-normal visual acuity and an ''amblyopic'' eye with decreased visual acuity.

Decades of research have shown that amblyopia is a relatively common disorder affecting up to 3% of the population.[34] This persistent imbalanced central representation leads to disrupted binocular functioning, often resulting in inaccurate tracking, decreased contrast sensitivity, unsteady fixation, prolonged reaction times, and loss of depth perception.[35] The impact of resulting visual difficulties on patient quality of life is significant; thus, management strategies today emphasize optimal visual correction with early detection and treatment.[30,36-38]

Analogous to the visual system, the auditory system depends on the integration of afferent signals from both ears.[39] Sound input from the periphery is transformed into neural signals in the inner ear and is transmitted by the auditory nerve to the cochlear nucleus, the first station of sound processing in the brain. The cochlear nucleus contains excitatory and inhibitory projections that innervate second-order auditory brainstem nuclei in both hemispheres of the brain.[39] The integration of these bilateral excitatory and inhibitory signals is essential for complex auditory processing. Bilateral, or binaural, hearing affords 2 major advantages. First, the redundancy of auditory input leads to a summation effect, lowering an individual's overall threshold of sound detection. Second, the auditory brain regions use bilateral cues, such as the interaural time difference and interaural-level difference to isolate target signals (eg, speech information) in complex, reverberant environments and to transform 1-dimensional neural signals into a 3-dimensional representation of space.[40,41]

A mismatch in bilateral auditory input during development can disrupt the integration of binaural cues at the level of the auditory midbrain and cortex, termed ''amblyaudia.''[16] Amblyaudia represents the spectrum of auditory processing

deficits that are felt to be associated with AHL and may have detrimental effects on hearing and language development.[16,17] The actual mechanisms behind amblyaudia and amblyopia are by no means identical; however, we draw comparisons as a means of illustrating the concept that altered peripheral afferent input may cause potentially permanent changes in central auditory processing.

Part 2: Pathophysiology of Amblyaudia

During brain maturation, higher cortical sensory centers rely heavily on afferent input to form organized neural circuits.[42] Studies have shown that the influence of sensory input is particularly instructive during critical windows of cortical development, when highly stable frameworks of connectivity are being formed.[43] In the auditory system, it is well known that early exposure to sound promotes the proper development and maturation of the auditory processing centers.[40,44] The plasticity of the developing auditory system can be thought of as an adaptive mechanism that can, for example, account for variations in head size; during periods of head growth, the tuning of interaural relationships must continuously adapt as the distance between the external ears changes.[45]

The problem with allowing experience to guide the patterns of brain connectivity is made plain when auditory input is not normal, as in cases of AHL. Imbalanced signaling between the 2 ears during critical periods may result in altered or maladaptive patterns of neural connections that persist even after the peripheral pathology has resolved. Several animal studies have examined the physiologic effects of AHL on central auditory pathways by inducing temporary unilateral hearing loss in either neonatal or adult rodents. The key to understanding the pathophysiologic basis for amblyaudia is to examine those studies in which induced unilateral hearing loss during the critical period is later reversed, returning the examined ear to audiometric normality. Testing is then performed to quantify changes in central auditory responses (in the inferior colliculus and auditory cortex) after monaural deprivation. In one such study, Clopton et al examined the effect of surgically plugging the external auditory canal of young rats for a 3- to 5-month period, after which the plug was reversed. Results showed 2 major findings: (1) monaural deprivation starting at days 10 and 30 postnatally led to later loss of ipsilateral suppression at the level of the inferior colliculus, and (2) surgically plugging the external auditory canal at 60 days of life (after the critical period) did not result in loss of ipsilateral suppression at the level of the inferior colliculus.[46] Similar experiments have also shown disruption of binaural interaction at the level of the auditory cortex following monaural deprivation during critical periods of brain development.[17,18,47,48]

Disrupted signaling following periods of sensory deprivation can be partially explained at the cellular level. Studies in a variety of animal models have shown detrimental effects in the morphology of auditory brainstem nuclei following external ear blockage, including reduced cell body diameter,[49,50] disrupted maturation of dendritic morphology,[51,52] and disrupted cell metabolism.[53,54] As a result of this pathology, neural transmission from the affected side may be significantly weakened as compared with the unaffected side. The net effect of this asymmetric signaling is the creation of a "dominant" ear at higher stages of the central auditory pathway, much like the emergence of a dominant eye at the level of the primary visual cortex, as described by the amblyopia literature. During critical periods of neural plasticity, this imbalanced weighting of interaural cues may disrupt the representation of binaural stimuli in a manner that persists for an unknown length of time after the hearing loss is reversed in later life.[17,18]

The maladaptive neural plasticity associated with asymmetric hearing has demonstrable effects on behavioral assays that emphasize spatial hearing. Knudsen et al examined barn owls that were monaurally occluded for multiple months starting at various ages. Owls occluded <8 weeks of age were able to adjust their sound localization during this period; however, they showed large localization errors once the plugs were removed. In contrast, owls occluded >8 weeks of age were unable to adjust their sound localization during the occlusion period, but they fully recovered their localization accuracy once the plugs were removed. These data suggest a sensitive period between 0 to 8 weeks of life in which the stable connections within the auditory system are formed.[45] Similar disruptions in sound localization accuracy following periods of monaural deprivation have been shown in guinea pigs.[55] Thus, from animal studies, we have seen that during critical periods of development, the central auditory pathways are extremely sensitive to peripheral deprivation, resulting in lasting abnormalities of binaural processing. These data form the basis for the phenomenon of amblyaudia.

Part 3: Clinical Presentation and Significance of Amblyaudia

As a newly defined phenomenon, the clinical presentation and long-term impact of amblyaudia are not well characterized. To provide a framework for future investigation, individuals at risk for amblyaudia must present with 3 key aspects of hearing loss: (1) The defect must be asymmetric. Asymmetry is crucial to the pathophysiology of this disorder. If both sides are equally affected, the mismatch in binaural processing and neural maturation will not exist. (2) There must be a measurable hearing loss, commonly defined by thresholds ≥30 dB. Most animal studies utilize methods that introduce >30-dBHL loss; however, the minimum threshold necessary to result in amblyaudia in humans is not currently known. Furthermore, it is not yet understood how the severity or duration of hearing loss influences central auditory processing, and specific treatments may vary accordingly. (3) The hearing loss must occur during a critical period of early childhood development with subsequent correction or reversal[16,17] (**Table 1**). If these 3 aspects of hearing loss are met, the patient could be at risk for amblyaudia and potentially developing lasting abnormalities in auditory processing.

Table 1. Working Definition of Amblyaudia.

1. Unilateral or asymmetric auditory dysfunction
2. Hearing loss resulting in decreased afferent signal to auditory cortex[a]
3. Occurs during critical period of development with subsequent correction or reversal[b]

[a]Any peripheral etiology of hearing loss may put an individual at risk for amblyaudia; the effect of different types and severity of hearing loss is currently unknown.
[b]The critical period is not yet well defined, and duration of asymmetric hearing loss may also be an important factor.

The clinical presentation of amblyaudia may be subtle and not detectable on standard audiometric tests. At the time of testing, most will have normal or near-normal pure tone thresholds.[16] Individuals with amblyaudia, however, are predicted to have difficulty with auditory processing that relies on bilateral cues—namely, sound localization and signal-to-noise suppression.[7,16,19,20] These tasks contribute greatly to human communication by providing cues as to the source of sounds and by enabling the separation of specific sounds in the setting of background noise.[56] With altered binaural hearing, individuals with amblyaudia are likely to have difficulty comprehending speech, particularly in noisy environments.[19,20,22,57] This can lead to problems in social and educational settings, as individuals must use extra effort to comprehend normal conversation and instruction. For children in particular, such deficits may have far-reaching consequences on language and behavioral development. Taken together, it is possible that individuals with amblyaudia may not present with complaints of hearing difficulties at all but rather with psychological symptoms and fatigue.[58,59]

The best audiometric test for understanding the long-term consequences of amblyaudia is currently unknown.[16] By definition, sound thresholds in individuals with amblyaudia are normal after the hearing loss has been corrected, so testing of ''preferential listening'' or ''hearing acuity'' differences would not be revealing. One method of measuring binaural processing deficits is examining the masking-level differences (MLDs) between the 2 ears. MLD is a measurement of signal to noise and is tested by asking an individual to distinguish a signal presented in one ear while noise is presented in the opposite ear. Individuals with amblyaudia would be expected to perform poorly on this task. Many studies have shown decreased MLD in children with histories of otitis media (OM).[22,57,60] Few studies have also shown abnormal MLDs in patients with corrected congenital unilateral hearing loss 1 month to 1 year following correction.[19,61,62] Unfortunately, MLD is not routinely measured in clinical settings, so the true extent of these difficulties in the population is unknown. Other tests that may identify amblyaudia include auditory brainstem responses, sound localization tasks, and general language measures.[16,63] Future studies looking specifically at binaural processing differences (eg, speech in noise and sound localization testing) following correction of congenital hearing anomalies are warranted.

Part 4: Populations at Risk for Amblyaudia

Amblyaudia may theoretically result from any form of asymmetric auditory deprivation, including conductive and sensorineural causes, occurring during a critical period of development. Investigations on amblyaudia have thus far predominately investigated conductive hearing losses.[16,64] The reason for the focus on conductive hearing loss likely relates to the fact that, by definition, a diagnosis of amblyaudia necessitates complete reversal of hearing loss, which is most likely to occur in the setting of conductive hearing loss through surgical correction. Conductive hearing loss is also easily studied in animal models by surgical manipulation of the ear canal or middle ear.[16,18,54]

Congenital abnormalities leading to one-sided or asymmetric conductive hearing most closely parallel the conditions presented in animal studies revealing the development of amblyaudia. Limited studies examining hearing outcomes following correction of congenital hearing loss confirm lasting audiometric abnormalities. Wilmington et al examined 19 patients with unilateral congenital hearing loss secondary to either aural atresia or middle ear malformations following surgical correction. Despite near-normal postoperative audiograms, all patients were found to have some lasting deficits in binaural hearing, particularly in complex processing tasks such as speech comprehension and sound localization, as long as 6 months after surgery.[19] Breier et al also examined hearing outcomes following correction of aural atresia and delineated the results based on age at time of surgery. In this cohort, patients corrected prior to puberty were found to have less lasting asymmetric ear advantage than that of patients corrected postpuberty, illustrating the concept of a critical period in which the auditory system is still amenable to changes, albeit not well defined.[65]

Amblyaudia may also result from temporary or acquired causes of AHL, such as OM. Several studies have linked recurrent OM to deficits in binaural processing and also language and learning disabilities.[22,57,66-70] These data are controversial, and several studies also show no connection between OM and long-term hearing deficits. Studies on OM may not serve as reliable indicators of long-term effects of monaural deprivation given that conductive hearing loss occurs in only an estimated 15% of cases of OM.[16,71] A recent meta-analysis concluded that only individuals with a consequent conductive hearing loss from OM would be at risk for amblyaudia.[16] It should also be noted that audiometric tests are not always performed in pediatric cases of OM, so physicians and caregivers should maintain a high index of suspicion for abnormal hearing in any child with a history of OM or other temporary causes of hearing loss at a young age.

The evidence linking sensorineural hearing loss and amblyaudia is largely absent in the literature. Investigations on auditory prostheses, such as hearing aids or cochlear implants, provide some insight. Data from sensorineural hearing loss should be approached carefully, however, as

the afferent signal in the cases of sensorineural hearing loss is altered in the presence of an auditory prosthesis. Indeed, amblyaudia has been described as resulting from a hearing ''loss,'' which generally refers to hearing thresholds. However, hearing loss also refers to a decrement in the quality or clarity of the afferent signal. Stated differently, rich and meaningful auditory perception requires more than just detecting the presence of a sound. While the amplified sound level (eg, decibel hearing level) of an auditory prosthesis may reach that of normal hearing, the quality of afferent signals is altered by signal filtering and processing. Conventional cochlear implants may not preserve binaural information related to timing or frequency matching. Consequently, while evaluation of data from auditory prostheses is helpful, as they provide an improvement in hearing thresholds, results should be approached cautiously.

In terms of hearing aids, amplification for unilateral sensorineural hearing loss is gaining popularity given the literature linking unilateral hearing loss to behavioral and academic delays.[15] Results in children with unilateral hearing loss who have received auditory amplification in the poorer-hearing ear have shown marked benefits in terms of speech comprehension and sound localization.[72-75] Similar to trends seen in correction of conductive hearing loss, studies have suggested that binaural benefit following amplification for unilateral sensorineural hearing loss is more profound when amplification is begun at younger ages.[75,76] These outcomes again point to auditory benefit when AHL is minimized before the resolution of a critical period.

Bilateral CI amplification for profound sensorineural deafness also provides interesting outcomes that shed light on aspects of amblyaudia. Bilateral cochlear implantation may be completed either sequentially or simultaneously. When implants are completed at different periods, the time in between is, essentially, an induced period of asymmetric hearing (one side with amplification, one side with profound deafness). Not surprisingly performance outcomes in children have shown significant benefits with simultaneous implantation and with lesser amount of time between subsequent implantation.[75,77,78] In such cases, the period of auditory asymmetry is minimized; thus, there is less risk of the formation of imbalanced neural connections. Interestingly, one study showed no difference in sequential versus subsequent implantation outcomes when both were completed before 3.5 years of age, which is likely still within the critical window of auditory development.[79]

The precise timing of the critical period for binaural processing in humans remains largely unknown. Data from the cochlear implant literature may be used to highlight this critical period of auditory development. As described, repeated studies have shown significantly better speech perception and performance outcomes in children implanted at younger ages, suggesting that there remains a period of auditory plasticity in which neural structures may still be altered.[80-83] Precise age cutoffs for improved performance vary between studies. Current guidelines suggest better implant outcomes prior to 3 years of age, with several studies showing optimal results when implanted at <2 years of age.[80,81,83] Similarly, studies showing a correlation of OM-induced conductive hearing loss with symptoms of amblyaudia have age ranges between 1 and 9 years,[16] and one study looking specifically at correction of congenital hearing loss suggests that the critical period may be complete by age 5.[65] Future studies are needed to determine the precise timing and duration of the critical period for binaural processing, as this has direct implications for the timing of treatment options.

Part 5: Prevention and Treatment of Amblyaudia

Studies have unequivocally shown that early correction of visual abnormalities results in decreased severity of amblyopia.[36,37,84] As such, clinical practice guidelines emphasize the importance of early visual screening and rapid treatment. Currently, the American Academy of Ophthalmology urges testing of visual acuity before 5 years of age.[85] Similarly, it is likely that the prevalence and severity of amblyaudia in the population can be minimized by early identification and correction of AHL, ideally within the critical window of auditory development.

In the United States, there is the opportunity for early identification of hearing loss as the result of a robust universal newborn hearing screening program. In 1993, the National Institutes of Health formally endorsed the screening of all newborns for hearing loss before leaving the hospital, including testing of otoacoustic emissions and/or auditory brainstem responses within each ear.[86] Today, it is estimated that approximately 95% of newborns undergo such screening.[86] As a result, the mean age of diagnosis of hearing loss—particularly unilateral hearing loss—has decreased significantly.[87] Unfortunately, despite improvements in screening, patients with unilateral hearing loss still appear to be underdiagnosed and undertreated. Spivak et al retrospectively studied screening and pediatric audiologist follow-up records for >100,000 infants over a 6-year period and found that unilateral hearing loss was the strongest predictor for late hearing aid fitting and loss to follow-up.[6]

As amblyaudia is a relatively newly identified phenomenon, there is no standard practice for management. The treatment of amblyopia provides a potential analogue of treatment for amblyaudia. The main treatment of amblyopia involves decreasing input to the dominant eye, which can be achieved through either patching or pharmacologic therapy with medication, such as atropine eye drops.[30] In doing so, the net input from the nondominant eye is increased, as a result of both a relative increase in ipsilateral signaling from the nondominant eye (as this is the only eye viewing the entire visual field) and decreased contralateral signaling (from the occluded dominant eye).[88] Over time, this self-imposed visual rebalancing leads to correction of the amblyopia. Such methods of occlusion have proven to be very effective in restoring appropriate visual acuity.[89] In the auditory system, perhaps a similar method of reweighing binaural signaling may improve hearing perception outcomes in individuals with amblyaudia.

Other methods that have been investigated to treat amblyopia include active vision therapy. Repetitive training of positional acuity tasks, known as perceptual learning, has been shown to improve visual performance.[90,91] This occurs as the result of an experience-induced retuning of the visual information, leading to a reduction of internal neural noise and more efficient use of the incoming stimulus.[90,91] Recent development of particular types of action video games utilizing these concepts has shown promise as a treatment option for adults with amblyopia.[92,93]

Similar to active vision therapy, in the auditory system of monaurally deprived ferrets, frequent training of sound localization was found to have an effect on recalibrating spatial information.[94] Likewise, training regimens that compensate for the loss of signal transmission through the deprived ear may support the recovery of binaural processing.[95] In a recent study, adult subjects with normal hearing engaged in an immersive audiomotor training task that required them to discriminate changes in the level of a faint signal in noise.[96] Improved performance in the game was correlated with a generalized improvement in speech comprehension in noise based on Quick SIN (Speech in Noise), one widely utilized test for speech comprehension in noise.[96] Thus, based on the success of analogous software therapies for older individuals with amblyopia,[97,98] the design of interactive auditory training software that has been inspired by auditory neuroscience may provide the means to minimize the long-term effects of amblyaudia in older children and adolescents who are outside the classically defined critical period. It should be emphasized, however, that maximally effective remediation for older subjects would not be expected to take the place of prevention or early-life intervention.

Part 6: Implications for Practice and Controversies

Knowledge of the basic tenants of amblyaudia may lead to a shift in treatment paradigms of AHL in children or, at a minimum, guide future research on the subject. It is commonly accepted that bilateral hearing loss should be quantified and corrected, as there are time-sensitive decisions regarding language acquisition. Decisions have broad implications and include spoken versus signed language and school environment. Clinical management of AHL has been more ambiguous and generally thought of as less critical when compared with bilateral hearing loss, as the child is still able to hear and communicate.[99] Currently, there are no established guidelines for treatment of pediatric AHL, and rates of correction for unilateral abnormalities are variable. Preliminary aforementioned research demonstrates that patients with delayed treatment of AHL are at risk for amblyaudia, and these lasting auditory deficits may have even further effects on language acquisition and social behavior.[66,70]

On an individual patient level, health care providers should be mindful when young children present with congenital acquired ear disease that have potential for AHL. Steps toward correction of these abnormalities are not without risk, including radiation exposure for imaging, as well as risks of anesthesia and surgery. Nevertheless, these risks should be weighed against the potential long-term consequences of amblyaudia. Although controversial, it is important to educate patients and families and to emphasize the importance of correction as early as possible, since the ''critical window'' remains unknown.

Finally, there are still many unknown questions about the phenomenon of amblyaudia. Although we know that the pathophysiology is the result of disrupted afferent signaling to the central auditory pathway, it is unclear what threshold of hearing imbalance is necessary to cause lasting defects. Furthermore, it is unknown if different etiologies of deprivation (ie, sensorineural vs conductive hearing loss) change the presentation and sequelae of this diagnosis. The relationship between amblyaudia and sensorineural hearing loss is currently not well studied or understood, although it is clear from animal studies that sensorineural loss in early life can lead to transneuronal degeneration.[100] Last, it is difficult to assess the prevalence of amblyaudia, as audiometric tests that would give insight into this disease (MLD, spatial localization, etc) are not commonly performed or reported.

Conclusion

Amblyaudia describes lasting hearing difficulties in individuals with AHL during critical periods of auditory development. Otolaryngologists, audiologists, pediatricians, and associated health care providers should be aware of emerging data supporting amblyaudia as a diagnostic entity and be cognizant of the potential for lasting consequences of AHL. Further research is needed to better understand the clinical implications of this newly described phenomenon and to inform treatment decisions regarding early management of AHL.

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Author Contributions

Alyson B. Kaplan, conception, drafting, review, final approval; **Elliott D. Kozin,** conception, drafting, review, final approval; **Aaron Remenschneider,** conception, drafting, review, final approval; **Kian Eftekhari,** conception, drafting, review, final approval; **David H. Jung,** conception, drafting, review, final approval; **Daniel B. Polley,** conception, drafting, review, final approval; **Daniel J. Lee,** conception, drafting, review, final approval.

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